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Profile Distribution of Available Boron and Secondary Micro Nutrients in Rice-Groundnut Growing Soils of Jajpur District, Odisha, India

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Authors' contributions

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

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ABSTRACT

An investigation was conducted to examine the distribution of available Boron secondary micro nutrients and the relationships between boron with soil properties and other nutrients in the rice-groundnut growing soils of Jajpur district, Odisha. The clay content increased downward without following any definite trend. Soil pH of surface horizons was acidic and increased downward to neutral range. EC ranged between 0.02 dSm^{-1} to 0.13 dSm^{-1}. The soil organic carbon ranged from 0.17% to 0.63% with decreasing trend towards sub surface horizon. The exchangeable Ca, Mg and S content varied from 3.68 mg kg^{-1} to 6.76 mg kg^{-1}, 0.82 cmole (p^+) kg^{-1} to 6.24 cmole (p^+) kg^{-1} and 0.62 mg kg^{-1} to 14.19 mg kg^{-1} respectively. Ca and Mg increased with increasing depth, whereas S

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showed the reverse trend. The DTPA- Fe, Mn, Cu, Zn and B content of pedon soil ranged from 60.68 mg kg^{-1} to 312.08 mg kg^{-1}, 6.48 mg kg^{-1} to 36.76 mg kg^{-1}, 0.62 mg kg^{-1} to 4.15 mg kg^{-1}, 0.42 mg kg^{-1} to 1.15 mg kg^{-1} and 0.05 mg kg^{-1} to 1.01 mg kg^{-1} respectively Fe, Mn and Zn increased from surface to sub surface but Cu and B showed the reverse trend. The availability of Boron is positively correlated with organic carbon, Exch. Mg, Fe, and Cu. Negatively correlated with pH, Exch. Ca, S, Mn, and Zn. Pedon soils were deficient with B, S, Zn and rich in Ca, Mg, Fe, Mn and Cu. Fe was in toxic level in table land zone of sukinda. The available B was found to be deficient throughout the district in up and medium land except in subsurface layers of low land. The availability of B is positively correlated with organic carbon, Exch. Mg, Fe and Cu factors but negatively correlated with pH, Exch. Ca, S, Mn, and Zn. In an agricultural district like Jajpur the key element B for rice-groundnut crop sequence should be applied to soil and leaf of rice, groundnut, and other crops grown in the district.

Keywords: Boron; cropping system; micro-nutrients; profile distribution.

1. INTRODUCTION

Rice-groundnut is an important cropping system of coastal Odisha occupying an area of 120.92 (000 ha) and Jajpur district 33000 ha alone [1]. The yield is declining gradually which can be ascribed due to micronutrient deficiency particularly Boron in soil. Boron plays an important role in plant but required in small quantity [2]. B application in rice-groundnut cropping system increased dry matter production (straw) up to 15.4 % and higher Harvest index [3] and also reducing chaffiness up to 35% in rice. It increases 15-20 nodules early maturity, pod weight and use efficiency of other nutrients increases resulting in higher yield. Adsorption of micronutrient atoms results into structural destruction of the adsorbents with a high adsorption energy [4,5] and metallic nutrients become very popular because of the easy synthesis process and low cost [6]. Application of B with lime in acid soil enhances the nodular properties of legumes [7]. Soil is the principal source of Boron but Odisha soil is deficiency with B. The availability of Boron is influenced by several soil factors. The profile distribution of B in soil puts light on its status and relation with other parameters of soil tells its availability. Micronutrients are elements that are required for plant growth in minute quantity. Amelioration of problem soil like acid soil with liming materials also increase the groundnut yield [8] and rhizosperic activity [9].

“Even though B is required in smaller quantities, it holds equal functional importance as macronutrients and plays crucial roles in plant growth” [10]. “The sources of soil micronutrients are diverse, including parent materials, sewage sludge, municipal waste, farmyard manure, organic matter, and atmospheric depositions” [11]. “Trace elements, such as boron, in soil exist in various forms like water-soluble, exchangeable, complex, chelated, and within the structure of primary and secondary minerals” [12]. “Numerous studies have indicated that micronutrient availability in the rhizosphere depends on factors such as soil pH, organic matter, clay content, and other physical, chemical, and biological elements” [10]. “Interactions with other soil nutrients also influence boron availability. Regional variation in boron availability is significantly affected by the soil formation process, lithology, parent material, and pedogenesi” [13]. “Therefore, understanding the boron status in a region's soil is crucial for identifying deficiencies/toxicities and formulating agricultural strategies. This knowledge helps farmers address issues related to soil nutrients and determine the optimal amount of fertilizers for cost-effective production” [14]. The primary objective of this study was to investigate the available boron status in soil profiles and its correlation with other soil properties, aiming to enhance comprehension of boron availability in the soil environment [15].

2. MATERIALS AND METHODS

The research focused on the Sukinda, Badachana, and Dasarathpur blocks of the Jajpur district, situated in the Mid Central Tableland and North Eastern Coastal plain agro-climatic zone of Odisha, India. The study area was categorized into three main physiographic divisions based on slope and elevation: gently sloping upland (350 feet above Mean Sea Level (MSL), with a slope of 5-10%), very gently sloping medium land (310 feet above MSL, with a slope of 0-5%), and virtually level lowland (298 feet above MSL, with a slope of 0-1%).

To determine the landform of the research area, a GPS device (Garmin make, model: GPS map 76CSx) was used to collect elevation data above MSL during traverses of the region. After a comprehensive survey, three representative soil profiles were chosen from different topographic positions: upland (21°06'779"N 86°05'707"E), medium land (20°04'114"N 86°00'215"E), and low land (20°05'990"N 86°02'915"E). Pedon 1, 2, and 3 corresponded to the soil profiles of highland, medium land, and low land, respectively.

Sampling involved collecting soil samples from four layers with varying depths at different locations. The soil samples underwent testing for texture using the Bouyoucos Hydrometer [16], pH (1:2.5), electrical conductivity (EC) (1:2.5), organic carbon [17], exchangeable Ca & Mg [18], sulfur [19], DTPA extractable iron, manganese, copper, and zinc [20], and hot water extractable boron [21]. Pearson correlation analyses were performed using established methods [22].

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

"The fine earth fractions are the active part of soil. Table 1 displays the size distributions of the fine earth fraction of soil particles. The data from Pedon 1 revealed that sand (%) ranged from 57.2 to 59.2, silt (%) ranged from 4.0 to 5.0, and clay (%) ranged from 35.8 to 38.8. In Pedon 2, sand, silt, and clay exhibited ranges of 60.2% to 68.2%, 7.0% to 9.0%, and 24.8% to 30.8%, respectively. For Pedon 3, sand percentages ranged from 58.2% to 64.2%, silt from 5.0% to 9.0%, and clay from 28.8% to 35.8%. The sand content decreased with increasing pedon depth, while the clay content displayed the opposite trend. This phenomenon was attributed to percolating water and the leaching of clay and colloidal fractions from the soil surface to the subsurface layers. The statistically significant negative correlation between sand and clay suggested that clay formation occurred through the transformation of sand to silt and the neosynthesis of clay" [23].

The sand dominated this fraction. It ranged between 57.2 %to 68.2 %. The content of sand decreased towards sub surface horizons. It was more in Badachana soil (Pedon 2) and less in Sukinda soil (Pedon 1). The silt content was found increasing from surface to sub surface layers. The silt content was minimum compared to sand and clay. The clay content in 3 pedons varied from 24.8 % to 38.8 %. It increased with depth without any trend. The clay content was comparatively more in Sukinda soil (Pedon 1) than that of other pedons. Sukinda soil was relatively heavier than others. Textural classes were sandy clay loam to clay, Accordingly the texture changed from lighter on surface to heavier texture in below layers [24].

Table 1. Distribution of particle size, soilpH, EC and Organic carbon in representative pedons

Pedon Depth(cm)	Sand (%)	Silt (%)	Clay (%)	P^H (1:2.5)	EC (dS m^{-1})	OC (%)
Pedon 1 (Up land)Sukinda						
0-12	59.2	5.0	35.8	5.69	0.09	0.72
12-42	59.2	4.0	36.8	5.84	0.04	0.48
42-82	57.2	4.0	38.8	5.92	0.04	0.18
Pedon 2 (Medium land)Badachana						
0-18	68.2	7.0	24.8	5.84	0.13	0.63
18-54	62.2	7.0	30.8	7.04	0.12	0.30
54-76	59.2	6.0	34.8	7.36	0.12	0.24
76-110	60.2	9.0	30.8	7.65	0.11	0.18
Pedon 3 (low land)Dasarathapur						
0-22	62.2	9.0	28.8	6.3	0.08	0.59
22-56	64.2	5.0	30.8	6.59	0.07	0.52
56-82	58.2	6.0	35.8	6.76	0.06	0.41
82-120	63.2	5.0	31.8	7.02	0.02	0.17

3.2 Soil Reaction (pH)

Pedon 1's Surface soil exhibited a moderately acidic pH of 5.69. Pedon 2's surface soil was slightly acidic, recording a pH value of 5.84. Notably, the pH increased with soil depth in Pedon 2, reaching 7.65 at a depth of 76-110 cm. In contrast, Pedon 3's surface soil was characterized by neutral pH values of 6.3. The trend observed in Table 1 indicated a general increase in pH with depth. “This rise in soil pH with increasing depth may be attributed to the leaching of basic cations from upper to lower horizons, particularly during periods of intense rainfall” [36].

The pH of different horizons ranged from 5.69 to 7.65. The pH value increased with increasing depth and become slightly alkaline except Sukinda (Pedon 1) which was acidic [12].

3.3 Electrical Conductivity (EC)

The electrical conductivity (EC) values for all soil profiles consistently stayed below 1 dSm^{-1}, indicating a non-saline nature and suitability for cultivating various crops. The low electrical conductivity observed is likely attributed to the leaching of soluble salts and effective drainage, particularly during periods of heavy rainfall [25].

3.4 Organic Carbon (OC)

The surface layers of Pedon 1, 2, and 3 showed organic carbon percentages of 0.72%, 0.63%, and 0.59%, respectively (Table 1). A consistent decrease in organic carbon was noted as soil depth increased across all profiles. The higher organic carbon content in the surface layers of all three pedons is likely associated with the continuous accumulation of crop residues and the application of organic manures [26].

3.5 Distribution of Available Secondary and Micronutrients

3.5.1 Exchangeable calcium and magnesium

The surface layers of Pedon 1, 2, and 3 contained 3.68 (cmol (p^+) kg^{-1}), 3.68(cmol (p^+) kg^{-1}), and 4.56 (cmol (p^+) kg^{-1}) exchangeable Ca, respectively (Table 2). Distribution of Exchangeable Ca followed an increasing trend with depth in all pedons and was found to be highest in a depth of 42-82 cm ,76-110 cm, and 82-120 cm, i.e. 6.24 (cmol (p^+) kg^{-1}), 6.4 (cmol (p^+) kg^{-1}), and 6.76(cmol (p^+) kg^{-1})) in pedons 1, 2, and 3 respectively. In three pedons Ca ranged between 3.68 to 6.76 cmol (p+)/kg soil. The lowest Ca was in Sukinda (pedon 1) and Badachana blocks (pedon 2) surface horizon and highest in Dasarathapur (pedon 3). “The surface layers of Pedon 1, 2, and 3 contained 0.8, 1.92, and 2.68 (cmol (p^+)/kg) exchangeable Mg, respectively (Table 1). The distribution of Exchangeable Mg followed a similar trend as that of exchangeable Ca. Calcium and Magnesium deficiency is not so high because of the substantial quantity of Ca and Mg in the parent rock and minerals. Conscious farmers of the Jajpur district apply agricultural liming materials, which also act as a source of nutrients.The surface soils contained a lower amount of exchangeable Ca and Mg than the sub-surface layers of a profile. This may be due to the removal of exch. Ca and Mg by the crop/vegetation from the surface horizons” [27]. Both Ca and Mg content of pedon soils increased with increasing depth of soil. Maximum quantity of Ca and Mg were observed in Dasarathpur (pedon 3) soils which might be due to washout deposit of these nutrients in low land from adjacent up and medium land. The value of Ca was more than Mg due to the fact that present rocks and minerals on earth crust contains more Ca than Mg [28].

3.5.2 Available sulphur

“In pedon 1, the upper layer (0-12 cm) contained the most available S (2.47 mg kg^{-1}) and the lower layer contained the least (0.91 mg kg^{-1}) (42-82 cm). In pedon 2 the uppermost layer (0-18 cm) contained the maximum sulphur (14.19 mg kg^{-1}). While the lowest concentration (2.67 mg kg^{-1}) was detected in the bottom layer (76-110 cm). In pedon 3, the highest concentration of available S (3.08 mg kg^{-1}) was found in the surface layer (0-22 cm) while the lowest concentration (0.62 mg kg^{-1}) was found in the lower layer (82-120 cm) (Table 2). Surface layers included more available sulphur than subsurface layers, which could be attributed to higher organic matter content in surface layers than deeper layers, as well as variable land usage and parent material” [36].

Plant available S was decreasing towards lower horizon. Surface horizon of Badachana was showing high 14.19 mg kg^{-1} and lower horizon of Dasarathpur showing low S (0.62 mg kg^{-1}) [29].

3.5.3 Available iron

The range of available Fe in surface and subsurface soils was 60.68 to 242.16 mg kg^{-1} and 85.5 to 312.08 mg kg^{-1} respectively. In pedon 1 the surface layer (0-12 cm) contained available Fe (242.16 mg kg^{-1}) and the lower layer contained the maximum (312.08 mg kg^{-1}) (42-82 cm). In pedon 2, the upper layer (0-18 cm) contained the lowest available iron (115.84 mg kg^{-1}) and the bottom layer contained the maximum available Fe (124.2 mg kg^{-1}). In pedon 3, the surface horizon (0-22 cm) contained the minimum concentration of available Fe (60.68 mg kg^{-1}) and the lower horizons (82-120 cm) contained the minimum concentration (85.5 mg kg^{-1}) (Table-2). The increasing trend of available Fe from surface layers towards sub surface because of crop uptake, run off and leaching loses [30]. The available Iron content in Sukinda soil found to be maximum (312.08 mg kg^{-1}) and Dasarathpur soil contained low available Fe (60.68 mg kg^{-1}), but all pedon soils were rich in Fe due to Fe bearing parent material from which soil had been derived.

3.5.4 Available manganese

The availability of manganese in surface and sub-surface soils varied between 6.48 to 26.08 mg kg^{-1} and 9.3 to 36.76 mg kg^{-1} respectively (Table 2). The content of Mn is sufficient in all pedons and the quantity increased towards sub surface layers which might be due to the presence of Mn bearing parent material and crop uptake of available Mn from surface layer [31].

3.5.5 Available copper

In Pedon 1 the surface layer (0-12 cm) contained the most available Cu (3.90 mg kg^{-1}) and the bottom layer contained the maximum (4.17 mg kg^{-1}) (42-82 cm). In pedon 2, the surface (0-18 cm) and bottom layer (76-110 cm) contained maximum (2.06 mg kg^{-1}) and minimum (0.62 mg kg^{-1}) concentrations of available copper, respectively. In pedon 3, the surface (0-22 cm) contained the maximum available Cu (2.27 mg kg^{-1}) and the lowest (0.86 mg kg^{-1}) was found in the lowest horizon (82-120 cm) (Table 2).

Sufficient quantity of Cu was found in all pedons. The value of Cu decreased from surface to sub surface layers except in Sukinda profile which might be due to rich Cu bearing parent material slow leaching and pH of horizon soils [30].

3.5.6 Available zinc

The DTPA Zn content in pedon 1, 2, 3 were 0.56 to 0.75, 0.42 to 0.89 and 0.49 to 1.15. The range of available zinc in surface and sub-surface soils were 0.42 to 0.56 mg kg^{-1} and 0.75 to 1.15 mg kg^{-1}, respectively. In most of the surface horizon soil, Zn was found to be deficient. It increased downwards which might be due to presence of Zn bearing minerals in below horizons and leaching effect. Crop uptake and losses might have reduced the content in the surface layers [32].

Table 2. Depth-wise distribution of available secondary and micronutrients in pedons

Pedon Depth(cm)	Exch.Ca (cmol(p$^+$)/kg	Exch.Mg (cmol(p$^+$)/kg	Avail S (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	B (mg kg^{-1})
Pedon 1 (Up land)Sukinda								
0-12	3.68	0.8	2.47	242.16	26.08	3.90	0.56	0.12
12-42	5.44	2.4	1.62	284.56	36.36	4.15	0.68	0.43
42-82	6.24	2.80	0.91	312.08	36.76	4.17	0.75	0.25
Pedon 2 (Medium land)Badachana								
0-18	3.68	1.92	14.19	115.84	8.64	2.06	0.42	0.05
18-54	5.44	2.32	6.37	117.24	12.56	1.31	0.61	0.15
54-76	5.6	3.24	5.55	121.32	22.84	0.62	0.72	0.07
76-110	6.4	3.04	2.67	124.2	22.68	0.68	0.89	0.05
Pedon 3 (Low land)Dasarathapur								
0-22	4.56	2.68	3.08	60.68	6.48	2.27	0.49	0.27
22-56	5.64	3.06	1.03	68.68	7.4	1.99	0.64	1.01
56-82	6.68	3.12	0.88	74.20	8.2	0.98	1.02	0.96
82-120	6.76	2.84	0.62	85.50	9.3	0.86	1.15	0.43

Table 3. Correlations analysis between B vrs. All other characters

	Sand (%)	Silt (%)	Clay (%)	PH (1:2.5)	EC (dS m-1)	OC (%)	Exch.Ca (cmol(p+)/kg	Exch.Mg (cmol(p+)/kg	Avail S	Fe	Mn	Cu	Zn	B
Sand (%)	1													
Silt (%)	.431*	1												
Clay (%)	-.089	-.254	1											
PH (1:2.5)	.073	.168	.082	1										
EC (dS m-1)	.342	.627**	-.275	-.033	1									
OC (%)	.138	.030	-.559**	-.495*	.222	1								
Exch.Ca (cmol(p+)/kg	-.407	-.098	-.117	.233	-.375	-.493*	1							
Exch.Mg (cmol(p+)/kg	-.031	-.117	.169	.543**	-.425*	-.482*	.302	1						
Avail S	.421	.437*	-.627**	-.309	.700**	.499*	-.263	-.493*	1					
Fe	-.459*	-.334	.090	-.260	-.491*	.082	.259	-.086	-.325	1				
Mn	-.370	-.120	.177	-.282	.008	-.117	.215	-.403	-.028	.477*	1			
Cu	-.162	-.145	-.188	-.623**	.036	.489*	-.124	-.584**	.191	.547**	.650**	1		
Zn	-.109	-.167	.056	.472*	-.604**	-.422	.670**	.453*	-.398	.134	.021	-.325	1	
B	-.157	-.235	-.344	-.296	-.195	.453*	-.026	.105	-.009	.240	-.291	.101	-.002	1

***. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed)*

3.5.7 Available boron

The hot water extractable boron content in pedon 1, 2 and 3 were 0.12 to 0.43, 0.05 to 0.15 and 0.27 to 1.01. Boron availability in surface and sub surface soils were between 0.05 to 0.27 mg kg^{-1} and 0.05 to 1.01 mg kg^{-1} respectively. In Pedon 1, the sub surface layer (12-42 cm) contained the maximum concentration of available B (0.43 mg kg^{-1}), while the lowest concentration (0.12 mg kg^{-1}) was found in the surface horizon (0-12 cm). In pedon 2 the sub surface layer (18-54 cm) contained the maximum quantity of available boron (0.15 mg kg^{-1}) and the lowest (0.05 mg kg^{-1}) was observed in the surface layer (0-18 cm). In pedon 3, the sub surface (22-56 cm) contained the maximum concentration of available B (1.01 mg kg^{-1}), while the lowest concentration (0.27 mg kg^{-1}) was observed in the surface layer (0-22 cm). Boron's greater buildup in the subsurface was aided by the leaching of boron in soluble form, which ocuurred in soils with a light texture and an acidic pH (10). The available B content of pedon soil increased up to second horizon then decreased downwards. B is highly soluble and leached from light texture surface soil and get deposited in second layer [33]. In soils of Badachana and Sukinda available B was in deficient status. Where as in Dasarathpur soils sufficient level of B was found in sub surface horizons. It might be due to deposition of B in these layers.

3.6 Correlation of B with Other Parameter of Soil

Profile distribution of B was correlated with pH and other soil parameter presented in Table -3. It was found that B was positively correlated with organic carbon, Exch. Mg, Fe, Cu, and negatively correlated with other parameters. Positive correlation indicated the availability of B will be increased by increasing the organic carbon. Negative correlation with clay and pH indicated that further increasing in clay and pH will decrease the availability B to the crop. The chelating effect of clay with B will decrease the availability of B to the crop plant. However multiple regression analysis showed the overall contribution of 13 parameters taken have 68.2 % contribution for availability of B. The highest correlation with EC followed by Zn, Fe, Exch. Mg, and organic carbon, all other parameters show negative regression. By increasing soil organic carbon,exch. Mg, available Fe, and Zn will positively helped in availability of B in soil for rice-groundnut cropping system [34].

3.7 Regression Equation

$$Y=3.264-0.006X_1-0.054X_2-0.025X_3-0.348X_4+7.644X_5+0.180X_6-0.069X_7+0.104X_8-0.042X_9+0.002X_{10}-0.012X_{11}-0.029X_{12}+0.830X_{13}$$

(X_1-(sand %), X_2-(silt %), X_3-(clay %), X_4- pH (1:2.5), X_5-EC (dS m^{-1}), X_6-OC (%), X_7-Exch.Ca (cmol(p+)/kg^-, X_8- Exch.Mg (cmol(p+)/kg^-, X_9-Avail S, X_{10}-Fe, X_{11}-Mn, X_{12}-Cu, X_{13}-Zn.)

4. CONCLUSION

In the research area, the distribution of plant nutrients varied with topography, although the differences between upland, medium land, and low land were not statistically significant. The decrease in sand and increase in clay with pedon depth were attributed to the translocation of clay and colloidal fractions from the surface to sub-surface layers, influenced by percolating water and leaching processes. Across all pedons, soil pH increased, while electrical conductivity (EC) and organic carbon content declined with depth. Surface soils exhibited lower levels of exchangeable calcium (Ca) and magnesium (Mg) compared to subsurface layers, possibly due to the extraction of Ca and Mg by crops/vegetation from the surface strata.

In terms of micronutrient status, the order in the study region was Fe > Mn > Cu > Zn > B. Available Ca and Mg increased with soil depth, whereas sulfur (S), Fe, Cu, Zn, and B decreased. Available Fe, Mn, Cu, and Zn showed positive correlations with soil organic carbon and negative correlations with soil pH. The higher micronutrient levels observed in surface soils are likely a result of increased breakdown of soil organic matter and agricultural residues. Additionally, root distribution and rooting depth play a role in micronutrient concentrations, as nutrients taken up by deeper roots are transported above ground and redeposited on the soil surface.

The correlation statistics suggest that the application of organic manure, magnesium, and zinc could enhance the availability of boron in the rice-groundnut cropping system in the Jajpur district of Odisha [34,35].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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