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CHARACTERIZATION OF SOILS ALONG TOPOSEQUENCE UNDERLAIN BY SANDSTONE IN AJIDINKPOR, IKOM, CROSS RIVER STATE

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ABSTRACT

The knowledge of the pattern of soil distribution and the characteristics are very essential for a better understanding, use and management of soils. It is with this background that the present study aims to characterize soil properties along toposequence in soil developed on sandstone parent material. The texture observed varied considerably, ranging from silty clay, clay loam, clay, silt clay loam, clay loam to silt loam. Bulk density had a mean value of 1.58 g/cm^3, 1.61 g/cm^3, and 1.15 g/cm^3, in the crest, middle slope and valley slope soils. The soil was strongly acidic with pH in the crest, middle slope and valley bottom being 5.4, 5.35, and 5.4. The soil low in OC contents, all topographic positions had OC <1 %. The values of soil fertility indicators (organic carbon, total nitrogen, available P, exchangeable Ca, Mg, and K) were generally low. The findings further revealed that soil in the valley slope was better in quality than soils within the crest and middle slope. Cu had a mean value of 3.97 mg/kg, 2.17 mg/kg and 1.2 mg/kg in the crest, middle slope and valley slope soils, respectively. The values of Mn, Zn and Fe were above critical limit for deficiency. The values of estimated micronutrient indicated that the soils are safe for crop cultivation. Hence, to raise the productivity level of the present soil for optimum performance of crop, the management techniques such as continuous application of organic manure/crop residues to the soil, and use of low levels of chemical inputs should be put in place.

KEYWORDS: Sandstone, toposequence, micronutrient, nutrient availability, soil quality

INTRODUCTION

Decisions on land use should be made based on biophysical status of the soil. However, in developing countries, such decisions are multifaceted, influenced by a combination of economic, social, environmental and political factors. In Nigeria and Cross River state in particular, most farms and plantations are established primarily to forestall land encroachment by land speculators and landlords' communities, and no feasibility studies are carried out to determine the suitability or otherwise of such soils for cultivation (Amalu and Isong, 2015. This led to fundamental knowledge gaps; hindering the ability of the farm managers to manage and improve land and soil quality.

The knowledge of the pattern of soil distribution and the characteristics are very essential for a better understanding, use and management of soils.

For profitable cultivation of any specified agricultural crop, information on soil properties and soil quality are pre-requisite, as this information will identify important capabilities and constraints which will need to improve upon and /or addressed respectively for overall increase in efficiency of production and yield of crops (Amalu and Isong, 2015).

Understanding soil characteristics along a toposequence, particularly in areas underlain by sandstone, is crucial for effective land management and agricultural planning. Toposequences represent a sequence of soils formed on a landscape with variations in elevation, slope, and drainage, providing valuable insights into soil development processes and properties (Da Silva et al., 2019; Filho et al., 2020). Sandstone is a common geological substrate in various regions globally, characterized by its porous and permeable nature.

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Soils developed on sandstone parent material often exhibit distinctive properties influenced by factors such as drainage, mineral composition, and weathering processes. Consequently, studying soils along toposequences underlain by sandstone offers a unique opportunity to explore the relationship between landscape position, soil development, and agricultural potential.

Research by Fonseca et al. (2021), Lima *et al*. (2021) and Filho *et al.* (2022) emphasizes the importance of understanding soil variability along toposequences, particularly in landscapes dominated by sandstone. The study conducted in a sandstone-dominated region (Lima *et al.,* 2021) demonstrated significant variations in soil properties such as texture, organic matter content, and nutrient availability across different landscape positions. These findings underscored the influence of topographic factors on soil formation processes and highlighted the need for comprehensive soil characterization along toposequences for informed land management decisions.

Furthermore, investigations by Osujieke (2017) focused on the impact of sandstone-based parent material on soil fertility and agricultural productivity. The study revealed that soils developed on sandstone-derived parent material often exhibit low nutrient retention capacity and may require targeted management practices to enhance fertility and mitigate soil degradation risks. Understanding the distribution of soil properties along a toposequence underlain by sandstone is thus essential for optimizing agricultural practices and maximizing land productivity. This study aims to characterize soil properties along toposequence in soil developed on sandstone parent material.

MATERIALS AND METHODS

Location of the study area

The study was conducted in Ajidinkpor, Ikom Local Government Area, Cross River State. The area is located at latitude 6 ° 0' N and longitude 8 ° 40' E. Ikom Local Government Area is bounded on the North by Ogoja Local Government Area, on the North east by Boki Local Government Area, and the east by Etung Local Government, and South by Obubra Local Government Area, Cross River State, Fig 1. The study area is characterized by a humid tropical climate with distinct wet and dry seasons. This area receives average annual rainfall exceeding 2500 mm per annum; and the average minimum and maximum temperatures of this area are about 22° C and 30° C, respectively with a mean relative humidity of 83 % (Nitmet, 2021). The principal crops grown in the area include maize, sugar cane, cassava, groundnut, Cocoa, oil palm and vegetable crops (i.e. okra, *Telfairia occidentalis*, pepper, waterleaf, *Amaranthus cruentus,* etc.). The soils of the study area are developed on sandstone parent material.

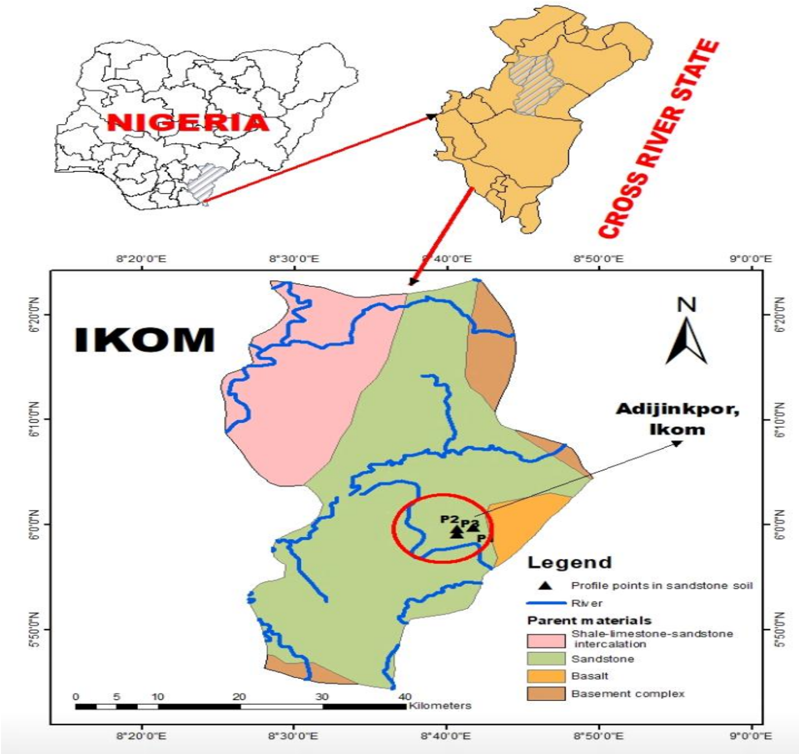

Fig 1: Map of the study areas showing sampling points

Field studies

A Modal profile pit was dug in three (3) identified toposequence (Crest, middle slope and valley bottom). Each profile pit was described according to FAO guidelines for soil description (FAO, 2006). Site characteristics such as topography and wetness among other physiography features were either estimated or measured in-situ in the field. Also, soil samples were collected from identified genetic horizons, bagged, labeled and transported to the laboratory for analysis. The exact location of each profile pit was recorded with the aid of a hand-held global positioning system (GPS) (Garmin eTrex 10).

Laboratory Analysis

The samples were air-dried, ground, and passed through a 2mm mesh sieve. The fine earth fraction (< 2 mm) was subjected to routine soil analysis: Particle size fraction analysis was determined following Gee and Bauder (1986) method. Bulk density was determined using the core method of Blake and Hartage (1986), particle density was determined using the pycnometer method as outlined by Blake (1965), while total porosity was calculated from the bulk and particle density values. Soil pH was measured potentiometrically in a soil: water suspension (mixed at a ratio of 1:2.5 soil: water) using glass electrode pH meter following procedure described by Udo *et al*. (2009). Organic carbon was determined by the dichromate wet oxidation method of Walkley and Black as outline in Nelson and Sommers (1996). Total nitrogen content of the soil was determined by wet-digestion, distillation and titration procedures of the Kjeldahl method as described by Bremner (1996). Available phosphorus (P) was extracted by Bray-1 method and the colour was developed in soil extract using ascorbic acid blue method (Udo *et al.,* 2009). Exchangeable bases (Ca^+, Mg^+, Na^+, and K^+) were extracted by saturating soil with neutral 1*M* NH_4OAc (Thomas, 1982) and Ca and Mg in the extract was determined using atomic absorption spectrophotometer (AAS) while K and Na were determined by flame photometry. Exchangeable acidity was determined by extracting the soil with 0.1*N* KCl solution and titrating the aliquot of the extract with 1*N* NaOH following the procedure outline by Udo *et al.* (2009). Effective cation exchange capacity (ECEC) was calculated by the summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) and exchangeable acidity (H^+ and Al^{3+}). Base saturation was calculated as the sum of total exchangeable bases divided by ECEC and expressed as a percentage.

Statistical analysis

The data obtained from laboratory analysis were subjected to descriptive statistics, and the results were compared with the critical limits for interpreting levels of soil fertility status (Landon, 1991).

RESULT AND DISCUSSION

Physical properties of soil along topposequence underlain by sandstone

Along the studied toposequence, sand contents in the crest, middle slope and valley slope varied from 29.2 % to 57.2 %, 49.2 % to 63.2 % and 53.2 % to 61.2 % with a mean value of 41.7 %, 55.2 % and 57.2 % respectively (Table 1). Silt contents in the crest, middle slope and valley bottom varied from 20 % to 22 %, 18% to 24 % and 20 % to 28 % with a mean value of 21 %, 20.5 and 24 % respectively. Clay contents in the crest and middle slope varied from 20.8 % to 50.8 %, and 16.8 % to 32.8 % with a mean value of 20.5 % and 24.3 %, respectively. However, for valley bottom, the mean clay content of 18.8 % was obtained. The texture observed varied considerably, ranging from silty clay, clay loam, clay, silt clay loam, clay loam to silt loam. The results indicated that soil within the valley slope had higher sand and silt contents compared with soils on the crest and middle slope whereas for clay content, valley slope had the least content. In most cases, the clay fraction of the studied soils increased with depth. Chikezie *et al.* (2009) and Esu *et al.* (2008) reported that increased in clay content of soil with depth may be the consequence of eluviation-illuviation processes as well as contributions of the underlying geology through weathering.

Further results indicated that silt/clay ratio in the crest, middle slope and valley bottom had a mean value of 0.61, 0.95, and 1.27, respectively. Soils on the valley slope had higher silt/clay ratio compared with those on the crest and middle slope. Bulk density had a mean value of 1.58 g/cm^3, 1.61 g/cm^3, and 1.15 g/cm^3, in the crest, middle slope and valley bottom soils, respectively. From the result it was found that valley slope soils had the least bulk density, whereas soil located on the crest had the highest bulk density. However, values of bulk densities reported in this study were lower than critical limits for root restriction (1.75- 1.8) g/cm3 (Soil Survey Staff, 2006).

Particle density had a mean value of 2.45 g/cm^3, 2.39 g/cm^3, and 2.32 g/cm^3, in the crest, middle slope and valley bottom soils, respectively. Soil with the highest particle density was found on the crest while valley slope soil had the least particle density. Total porosity had a mean value of 34.5 %, 31.25 % and 50.5 % in the crest, middle slope and valley bottom soils, respectively. The soil on the valley slope was more porous than other soils.

Tale 1: Physical properties of soil along topposequence underlain by sandstone

Horizon Designation	Horizon depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Silt/clay ratio	BD (g/cm3)	PD (g/cm3)	TP (%)
Crest									
Ap	0-11	57.2	22	20.8	Sc	1.05	1.48	2.75	46
Bt1	11-29	41.2	22	36.8	Cl	0.6	1.7	2.2	22
Bt2	29-60	29.2	20	50.8	C	0.4	1.61	2.66	40
Crt	60-110	39.2	20	40.8	C	0.4	1.56	2.21	30
Mean		**41.7**	**21**	**37.3**		**0.61**	**1.58**	**2.45**	**34.5**
Middle slope									
Ap	0-16	59.2	24	16.8	Scl	1.5	1.49	2.7	44
Bt1	16-46	49.2	20	30.8	Cl	0.6	1.62	2.24	27
Bt2	46-61	49.2	18	32.8	Cl	0.5	1.73	2.36	26
Crt	61-120	63.2	20	16.8	Sl	1.2	1.62	2.27	28
Mean		**55.2**	**20.5**	**24.3**		**0.95**	**1.61**	**2.39**	**31.25**
Valley bottom									
Ap	0-25	53.2	28	18.8	Sl	1.5	1.1	2.25	51
Bt	25-45	61.2	20	18.8	Sl	1.05	1.2	2.4	50
Mean		**57.2**	**24**	**18.8**		**1.27**	**1.15**	**2.32**	**50.5**

Note: BD = bulk density, PD = particle density, TP = total porosity

Chemical properties of soil along topposequence underlain by sandstone

Further results indicated that pH in the crest, middle slope and valley bottom had a mean value of 5.4, 5.35, and 5.4, respectively (Table 2). Soil across all the toposequence were strongly acidic. The result of the pH of soils underlain by sandstone somewhat agrees with the findings of Osujieke (2017) that soil pH increases from summit to toeslope. However, high pH values down the slope suggest movement of basic cations along the slope towards the toeslope, and this may account for high base saturation. OC had a mean value of 0.51 %, 0.66 % and 0.71 % in the crest, middle slope and valley bottom soils, respectively. Similarly, all the soil across the studied toposequence were deficient in soil organic carbon. The variation in organic carbon contents can be attributed to the vegetation coverage of the studied terrain. Organic carbon increase with physiographic position can be attributed to velocity of runoff, intensity of rainfall, hydro-morphology, slope, soil texture and vegetation type. This agrees with the reports of Osujieke (2017) and Igwe (2001).

The TN had a mean value of 0.04 %, 0.03 %, and 0.055 % in the crest, middle slope and valley bottom soils, respectively. All the values of total nitrogen were low in the studied toposequence. The low value of total nitrogen observes is not surprising, as light textured soils are naturally endowed with low level of native nitrogen (Amalu and Isong, 2015) and this is particularly so with soil derived from sandstone parent materials be mostly coarse in nature (Filho et al., 2022) and soils that characterized tropical regions due to high level of leaching consequent upon high rainfall amounts and high relative humidity. The C:N ratio had a mean value of 13.25, 16.25, and 17.5 in the crest, middle slope and valley bottom soils, respectively. The valley slope soil was found to have the highest C:N ratio. These values are comparable with those (11 and 13.5) reported for "acid sand" of southern-Eastern Nigeria (Enwezor *et al.,* 1991) and, also with (C/N ratios 7 -18 for top-soil and 4-13 for sub-soil) reported for some rubber growing acid sands within Calabar agro-ecology (Amalu, 1997), as well as top and subsoil values of 20.62 and 14.83 reported by Afu *et al.* (2018). This is an indicative of substantial amount of substrate for microbial mineralization of organic nitrogen into inorganic ions for the crop uptake.

The available phosphorus had a mean value of 8.15 mg/kg, 6.59 mg/kg, and 9.87 mg/kg in the crest, middle slope and valley bottom soils, respectively. The phosphorus content across all the studied toposequence were generally low based on the rating for Nigerian soils (<15 mg kg^{-1}) (Enwezor *et al.*, 1990). From our investigation, soil P although was generally low, however, those on the middle slope was the lowest. Generally, the low phosphorus content may be due to high soil acidity (Akpan *et al.,* 2017b). The low P content could be attributed to acidic nature of the studied soil (pH < 5.5) which are not conducive for the release of P. Phosphorus content is a major constraint to crop production, thus utilizing this soil for crop production would require judicious application of P fertilizer.

Further results indicated that exchangeable Ca in the crest, middle slope and valley bottom had a mean value of 4.65 cmol/kg, 4.75 cmol/kg, and 4.8 cmol/kg, respectively. Exchangeable Mg had a mean value of 0.45 cmol/kg, 0.35 cmol/kg, and 0.5 cmol/kg in the crest, middle slope and valley bottom soils, respectively. The exchangeable K had a mean value of 0.092 cmol/kg, 0.09 cmol/kg and 0.10 cmol/kg in the crest, middle slope and valley bottom soils, respectively. The exchangeable Na had a mean value of 0.072 cmol/kg , 0.07 cmol/kg and 0.08 cmol/kg in the crest, middle slope and valley bottom soils, respectively. For all the exchangeable cations, their nutrient values are by far below the proposed critical limits for crop production (Landon, 1991). Adequate exchangeable Ca, Mg and K remain critical in crop production. Generally, soil on the valley slope had higer CA, Mg and K contents compared with those on the crest and middle slope. Also, the exchangeable Al^{3+} had a mean value of 1.78 cmol/kg, 1.93 cmol/kg and 0.54 cmol/kg in the crest, middle slope and valley bottom soils, respectively. The exchangeable H^+ had a mean value of 1.7 cmol/kg , 1.93 cmol/kg and 1.68 cmol/kg in the crest, middle slope and valley bottom soils, respectively.

The cation exchange capacity (CEC) had a mean value of 15 cmol/kg , 15.25 cmol/kg and 9.5 cmol/kg in the crest, middle slope and valley bottom soils, respectively. However, it was found that the soil in the valley slope had low CEC while the values in the crest and middle slope were moderate. It has been reported elsewhere that the soils of Southeastern Nigeria have low CEC and basic cations (Afu et al., 2018). The low CEC observed for the valley slope soil can be attributed to the fact that soils in this region are strongly weathered, have little or no content of weathered materials in sand and silt fractions and have predominantly Kaolinite in their clay fractions. This finding is in agreement with studies of Akpan *et al.* (2017a) who work on wetland soil in Calabar and observed low CEC. The BS had a mean value of 59.75 %, 63.25 % and 71.5 % in the crest, middle slope and valley bottom soils, respectively.

Table 2: Chemical properties of soil along topposequence underlain by sandstone

Horizon Designation	Horizon depth	pH	OC %	TN %	CN ratio	AP mg/kg	Ca	Mg	K	Na	Al	H	CEC	BS %
							→			cmol/kg		←		
Crest														
Ap	0-11	5.6	0.8	0.07	11	9	4.8	0.4	0.1	0.08	1.12	0.96	10	72
Bt1	11-29	5.5	0.5	0.04	12	12.87	4.6	0.4	0.09	0.07	1.28	1.52	12	65
Bt2	29-60	5.4	0.46	0.03	15	5	5	0.6	0.1	0.08	1.88	2.44	20	52
Crt	60-110	5.1	0.3	0.02	15	5.75	4.2	0.4	0.08	0.06	2.84	1.88	18	50
Mean		**5.4**	**0.51**	**0.04**	**13.25**	**8.15**	**4.65**	**0.45**	**0.09**	**0.07**	**1.78**	**1.7**	**15**	**59.75**
Middle slope														
Ap	0-16	5.4	0.8	0.07	11	9.37	4	0.6	0.09	0.07	0.8	1.12	15	71
Bt1	16-46	5.3	0.34	0.02	17	6	5	0.4	0.07	0.06	2.2	1.32	12	61
Bt2	46-61	5.3	0.3	0.02	15	5.87	5	0.2	0.1	0.08	2.88	0.76	19	60
Crt	61-120	5.4	1.22	0.01	22	5.12	5	0.2	0.1	0.07	1.84	1.56	15	61
Mean		**5.35**	**0.66**	**0.03**	**16.25**	**6.59**	**4.75**	**0.35**	**0.09**	**0.07**	**1.93**	**1.19**	**15.25**	**63.25**
Valley bottom														
Ap	0-25	5.4	1.18	0.1	11	9.87	5.2	0.4	0.11	0.09	0.56	1.96	10	70
Bt	25-45	5.4	0.24	0.01	24	9.87	4.4	0.6	0.09	0.07	0.52	1.4	9	73
Mean		**5.4**	**0.71**	**0.05**	**17.5**	**9.87**	**4.8**	**0.5**	**0.1**	**0.08**	**0.54**	**1.68**	**9.5**	**71.5**

Soil micronutrients along topposequence underlain by sandstone

The micronutrient distribution along the toposequence is presented in Table 3. From the results, Cu had a mean value of 3.97 mg/kg, 2.17 mg/kg and 1.2 mg/kg in the crest, middle slope and valley slope soils, respectively. The result indicated Cu value to be high in the crest than other topographic positions. Considering 2 mg kg^{-1} as the critical limit for Cu deficiency (Lindsay and Norvell 1978), all the soil in the valley slope was found to be in deficient in Cu. The values of Cu obtained for this study were all below the maximum allowable limits of 100 mg kg^{-1} (Lindsay 1979) established for mineral soil environment and far below the background level of 45 mg kg^{-1} (Turekian and Wedepohl 1961). With these low contents of Cu, the soils investigated are safe for crop cultivation. The result obtained in this study conforms to the findings of Afu *et al.* (2020) in soils of Akamkpa Local Government Area of Cross River State, which had low contents of Cu.

Similarly, Mn had a mean value of 7.55 mg/kg, 1.75 mg/kg and 1.75 mg/kg in the crest, middle slope and valley slope soils, respectively. The Mn contents was also found to be the highest on the crest compared with other positions. Soil on the crest had sufficient amounts of available Mn way above 1 − 4 mg kg^{-1} critical limit for Mn deficiency (Sims and Johnson 1991), while soils in the middle slope and valley slope were within this critical limit. The Mn concentrations obtained for the study sites were far below the background level of 850 mg kg^{-1} (Turekian and Wedepohl 1961). Tena and Beyene (2011) reported that the amount of extractable Mn is generally high in the tropical soils and Mn toxicity is even more common than deficiency.

The Zn had a mean value of 5.2 mg/kg, 3.05 mg/kg and 10.25 mg/kg in the crest, middle slope and valley slope soils, respectively. The Fe had a mean value of 5.2 mg/kg, 3.05 mg/kg and 10.25 mg/kg in the crest, middle slope and valley slope soils, respectively. It was found from our investigation that the Zn and Fe contents were higher in the valley slope soil compared to other slope positions. It has been reported by Aki and Isong (2018) that the exchangeable Zn level in soil between 4.5 and 10 mg kg^{-1} would be detrimental to the growth of crop plants. However, the values of Zn obtained in this study fell within this limit. This implies that attention has to be taken in order to control the level because it may result in a dangerous effect in the future. Furthermore, the mean concentration of iron in valley slope was high (> 5.0 mg kg^{-1}) when compared with the critical limit set by Siva Prasad et al. (2017) for Agricultural soils. The high iron (Fe) content obtained in the studied soil may be attributed largely to parent materials from which the soil was formed.

Table 3: Soil micronutrients along topposequence underlain by sandstone

Horizon Designation	Horizon depth	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Fe (mg/kg)
Crest					
Ap	0-11	4.3	18.7	2.2	5.0
Bt1	11-29	7.2	5.7	2.6	1.4
Bt2	29-60	2.2	2.2	15.8	3.6
Crt	60-110	2.2	3.6	14.4	10.8
Mean		**3.9**	**7.5**	**8.7**	**5.2**
Middle slope					
Ap	0-16	1.4	1.0	11.5	2.9
Bt1	16-46	2.2	1.0	20.1	4.3
Bt2	46-61	2.9	2.6	3.6	1.4
Crt	61-120	2.2	2.4	4.3	3.6
Mean		**2.2**	**1.7**	**9.8**	**3.1**
Valley slope					
Ap	0-25	1.4	2.0	4.0	10.7
Bt	25-45	1.0	1.5	2.0	9.8
Mean		**1.2**	**1.75**	**3.0**	**10.3**

CONCLUSION

The result of our investigation indicated that soil derived from sandstone parent material in Ajidinkpor, Ikom has low soil quality. The soil was strongly acidic, and the values of soil fertility indicators (organic carbon, Total Nitrogen, available P, exchangeable Ca, Mg, and K) were generally low. The findings further revealed that soils in the valley slope were better in quality than soils within the crest and middle slope. Nevertherless, these soils can still be utilized for crop production with judicious application of lime, nitrogen and potassium fertilizer as well as the use of organic manures and crop residues. The values of estimated micronutrient indicated that the soils are safe for crop cultivation. Hence, to raise the productivity level of the soil for optimum performance for crop production, the management techniques such as continuous application of organic manure/crop residues to the soil, and use of low levels of chemical inputs should be put in place.

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