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Assessment of macronutrients and micronutrients under different indigenous cropping systems in Konkan Coastal region of Maharashtra

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ABSTRACT

Abstract: The availability and distribution of soil nutrients are strongly influenced by cropping systems, vegetation type and nutrient management practices. Twelve representative cropping systems, including cowpea + rabi crops/vegetables, kharif groundnut + rabi crops/vegetables, mango + grasses, bamboo + horticulture + agriculture, sandal + horticultural system, asana + agricultural crops, mango + finger millet/vegetable, coconut + turmeric/agricultural crops, cashew + agricultural crops, arecanut + agricultural crops/spices, rice + rabi crops/vegetables and finger millet + rabi crops/vegetables, were evaluated in the Konkan region of Maharashtra, India. The study of depth-wise distribution of available macronutrients (N, P₂O₅ and K₂O) and DTPA-extractable micronutrients (Fe, Mn, Zn and Cu) across different soil horizons of investigated soil profiles. Considerable variation in nutrient availability was observed among cropping systems and soil depths. Surface available N ranged from 197.51 to 389.40 kg ha⁻¹, P₂O₅ from 20.05 to 35.90 kg ha⁻¹, and K₂O from 144.46 to 390.31 kg ha⁻¹. The mango + grasses system was recorded the highest available N (389.40 kg ha⁻¹), while the coconut + turmeric/agricultural crops and cashew + agricultural crops systems recorded the highest surface P₂O₅ (35.90 kg ha⁻¹) and K₂O (390.31 kg ha⁻¹), respectively. Among micronutrients, surface DTPA-extractable Fe ranged from 80.84 to 121.20 mg kg⁻¹, Mn from 63.49 to 124.80 mg kg⁻¹, Zn from 1.67 to 2.48 mg kg⁻¹, and Cu from 1.59 to 2.48 mg kg⁻¹. The sandal + horticultural system showed particularly high Fe, Zn and Cu concentrations, whereas the rice + rabi crops/vegetables system recorded the highest Mn. Nutrient concentrations generally showed greater accumulation in surface horizons, although subsurface enrichment was observed for certain nutrients in individual soil profiles. The findings indicate that diversified and perennial cropping systems can enhance nutrient retention through continuous biomass production, root activity, residue return and nutrient recycling. The study highlights the importance of cropping-system diversification and depth-wise nutrient assessment for maintaining soil fertility and developing sustainable nutrient-management strategies in the Konkan region.

Keywords: Cropping systems, NPK, Zn, Fe, M, Cu

Introduction

Soil fertility is one of the major factors governing crop productivity, soil health and the long-term sustainability of agricultural ecosystems. The availability of essential plant nutrients in soil is influenced by several interacting factors, including cropping pattern, climate, soil properties, vegetation, land-use practices and nutrient management. Cropping systems play an important role in maintaining soil fertility because different crops vary considerably in their nutrient requirements, rooting behaviour, biomass production and quantity of organic residues returned to the soil. Diversified cropping systems involving agricultural crops, horticultural crops, grasses and perennial vegetation can improve nutrient cycling and contribute to the maintenance of soil quality (Shah *et al.*, 2019) [1]. Indigenous and prominent land use systems e.g. Agricultural, Horticultural and Agroforestry Systems has played a significant role in enhancing land productivity, carbon restoration and improving livelihood security for long time sustainable ecosystem. The long term intensive land use systems can be improved soil quality, microbial properties and carbon storage (Varsha *et al.*, 2024) [2]. Assessment of soil fertility and microbial diversity under different systems are very important to restore soil health over long time. Adoption of appropriate land use system and its carbon sequestration potential plays an important role to restore soil fertility, crop productivity and overall sustainability (Kaleselvi *et al.*, 2023) [3]. Mango, Cashew, Kokam, Coconut, Arecanut, Rice, Nagali, etc. based prominent cropping systems were adopted by the farmers in Konkan region of Maharashtra. Carbon sequestration is the long term storage of carbon dioxide or other forms of carbon in oceans, soils, vegetation (especially forests) and geologic formations to either mitigate or defer global warming. Carbon sequestration is the long term storage of carbon dioxide or other forms of carbon in oceans, soils, vegetation (especially forests) and geologic formations to either mitigate or defer global warming. It is a way to slow the accumulation of greenhouse gases, which are

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released due to human activities. Essential plant nutrients are broadly classified into macronutrients and micronutrients according to their quantities required by plants. Among the macronutrients, nitrogen (N), phosphorus (P) and potassium (K) are particularly important for plant growth, development and productivity (Dhaliwal *et al.*, 2019) [4]. Nitrogen is a major constituent of proteins, amino acids, enzymes and chlorophyll and is frequently one of the most limiting nutrients in agricultural soils (Mahmud *et al.*, 2021) [5]. Phosphorus plays an important role in energy transfer, root development, flowering and seed formation, whereas potassium regulates water relations, enzyme activation, photosynthesis and resistance to environmental stresses. Micronutrients such as iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu), although required in relatively small quantities, are essential for various enzymatic, metabolic and physiological processes in plants. The availability of these nutrients is strongly influenced by soil pH, organic matter, clay content, moisture status, mineral composition and redox conditions (Rengel, 2015) [6]. The Konkan region of Maharashtra is characterized by a diverse range of agricultural and horticultural production systems. Cropping systems involving mango, cashew, coconut, arecanut, bamboo, sandal, grasses, cereals, pulses, vegetables and spices are important components of the agricultural landscape. The presence of perennial horticultural crops together with annual agricultural crops creates considerable variation in root distribution, organic residue input, nutrient uptake and nutrient recycling. Consequently, soil fertility under these systems may differ substantially both among cropping systems and with increasing soil depth. In perennial horticultural and silvi-pastoral systems, continuous plant growth, extensive root systems and regular addition of leaf litter may contribute to the maintenance of soil organic matter and nutrient availability (Pries *et al.*, 2018) [7]. In contrast, annual cropping systems may experience greater nutrient removal through repeated harvesting. Legume-based systems may further influence soil nitrogen through biological nitrogen fixation, while crops with deeper root systems may access and recycle nutrients from subsurface soil layers. Such differences make comparative evaluation of cropping systems important for understanding nutrient dynamics and developing appropriate soil fertility management strategies. Available nitrogen, phosphorus and potassium provide important indicators of the nutrient-supplying capacity of soil, whereas DTPA-extractable Fe, Mn, Zn and Cu provide useful information about the availability of important micronutrients. Changes in these nutrients under different cropping systems can provide valuable information about the effects of vegetation, nutrient removal, residue return and soil-forming processes on soil fertility. However, conventional soil-fertility assessments are frequently concentrated on surface soil and may not adequately explain the vertical distribution of nutrients throughout the soil profile. Therefore, a depth-wise assessment of soil nutrient distribution is essential for understanding the influence of contrasting cropping systems on soil fertility (Meena *et al.*, 2019) [8]. Such information can help identify nutrient-enriched and nutrient-depleted soil layers and provide a scientific basis for site-specific nutrient management. The present investigation was therefore undertaken to evaluate the depth-wise distribution of available N, P₂O₅ and K₂O and DTPA-extractable Fe, Mn, Zn and Cu under different cropping systems of the Konkan region of Maharashtra. The study further aimed to compare nutrient availability among cropping systems and to identify the major patterns of nutrient accumulation, depletion and vertical redistribution within the soil profile. This approach provides a comprehensive understanding of cropping-system-induced changes in soil fertility beyond conventional surface-soil assessment and may contribute to the development of sustainable nutrient-management strategies for the diverse agricultural and horticultural systems of the Konkan region.

Materials and methods

Description of the study area

The study was conducted in Konkan region of Maharashtra and it located between 15° 36' to 20° 15' N latitudes and 72° 40' to 73° 45' E longitudes. It is a narrow coastal strip situated between the Western Ghats and the sea on the western part of Sahyadris with longitudinal distance of 500 km and a width varying from 45 to 90 km. Part of Konkan falls in the Western Ghats also, which is commonly known as the Sahyadris. This chain of mountains extends from south of Tapi in Gujarat to the tip of Indian Peninsula and forms a physical and cultural barrier between plateau and coastal low-lands. The western edge of the plateau ends abruptly with an escarpment of about 600 m, descending to the coastal low-land of Konkan. This region has a crest zone of 15 to 25 km width with the dissected and slopy hill ranges and narrow inter hill basins. The crest line decreases from north to south and has many plain hill-tops like the Bhimashankar (Bhattacharyya *et al.*, 2007) [9].

Soil sampling and analysis

Soil sampling

A total of twelve representative soil profiles under different cropping systems of the Konkan region were selected for the present investigation. The cropping systems included cowpea + rabi crops/vegetables, kharif groundnut + rabi crops/vegetables, mango + grasses (silvi-pastoral system), bamboo + horticulture + agriculture, sandal + horticultural system (jackfruit), asana + agricultural crops, mango + finger millet/vegetable, coconut + turmeric/agricultural crops, cashew + agricultural crops, arecanut + agricultural crops/spices, rice + rabi crops/vegetables and finger millet + rabi crops/vegetables. 29 soil samples were collected horizon-wise from the selected soil profiles to assess the distribution of available macronutrients and DTPA-extractable micronutrients. The soil samples representing different depths and morphological horizons were collected carefully from the selected profiles. The collected samples were processed for further laboratory analysis of available nitrogen (N), phosphorus (P₂O₅) and potassium (K₂O) and DTPA-extractable iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu). Available macronutrients were expressed in kg ha⁻¹, while DTPA-extractable micronutrients were expressed in mg kg⁻¹. After collection, the soil samples were prepared for laboratory analysis following standard soil-processing procedures. The samples were air-dried, gently crushed and passed through 2 mm sieve before chemical analysis. The processed samples were subsequently used for determining the available macronutrient and DTPA-extractable micronutrient status of the soils. The horizon-wise sampling approach was adopted to determine the vertical distribution and stratification of nutrients within the soil profile. This enabled comparison of nutrient availability between surface and subsurface horizons and assessment of the influence of contrasting cropping systems on soil fertility. Available nitrogen (N) in the soil was estimated by the alkaline permanganate method of Subbaiah *et al.* (1956) [10]. Available phosphorus (P) in the soil was estimated by the Bray's extraction method (R. H. Bray, 1945). Available potassium (K) in the soil was estimated by the ammonium acetate extraction method described by Jackson (1973) [11]. The DTPA-extractable micronutrients, namely iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu), were estimated following the method described by Lindsay and Norvell (1978). 20 g Soil sample were extracted using 40 ml DTPA extractant after shaking for two an hour. The extracts were subsequently analysed using an atomic absorption spectrophotometer (AAS) equipped with element-specific hollow cathode lamps for the determination of Fe, Mn, Zn and Cu concentrations. The values of DTPA-extractable micronutrients were expressed as mg kg⁻¹ soil. Interpretation of investigated data will be subjected to statistical analysis as given by Panse and Sukhatme (1967).

Results and discussion

Available macronutrients content in Soil: Available N varied considerably among the soil profiles and horizons, with surface-soil values ranging from 197.51 to 389.40 kg ha⁻¹. The highest concentration was recorded in Profile 3 (389.40 kg ha⁻¹), followed by Profile 5 (388.86 kg ha⁻¹) and Profile 2 (376.40 kg ha⁻¹), whereas the lowest was observed in Profile 1 (197.51 kg ha⁻¹). Relatively low surface-soil N was also recorded in Profiles 11 (206.97 kg ha⁻¹) and 12 (206.85 kg ha⁻¹). The higher N concentration in surface horizons may be attributed to greater accumulation of plant residues and organic matter, enhanced root activity, and active microbial mineralization and recycling of N. Similar enrichment of available N in surface soils has been reported by Kumar *et al.* (2012) [12]. Available N generally showed a declining trend with increasing soil depth in most profiles. The decrease was evident in Profile 3, where N declined from 389.40 kg ha⁻¹ in Ap to 367.32 kg ha⁻¹ in Bw1, and in Profile 5, where it decreased from 388.86 kg ha⁻¹ in A to 354.91 kg ha⁻¹ in Bw2. Similar depth-wise reductions were observed in several other profiles. However, Profile 1 showed an increase from 197.51 kg ha⁻¹ in Ap to 222.65 kg ha⁻¹ in Bt, indicating that the vertical distribution of N was not uniform in all profiles. The decline in N with depth may be associated with reduced organic matter inputs, root activity and microbial mineralization in subsurface horizons. Since soil organic matter constitutes an important reservoir of N, greater organic residue accumulation in surface soil generally enhances N availability. Ramana *et al.* (2015) [13] also reported a close relationship between available N and soil properties such as organic carbon, clay content and microbial activity. Available P₂O₅ varied from 15.12 to 39.75 kg ha⁻¹ across the studied soil profiles and horizons. The highest concentration was recorded in the Bw1 horizon of Profile 8 (39.75 kg ha⁻¹), whereas the lowest was observed in the Bt horizon of Profile 1 (15.12 kg ha⁻¹). Surface-soil P₂O₅ was comparatively higher in Profiles 8 (35.90 kg ha⁻¹), 12 (34.36 kg ha⁻¹), 4 (32.31 kg ha⁻¹) and 5 (29.19 kg ha⁻¹). The relatively higher P availability in surface horizons may be associated with the continuous addition and decomposition of plant residues, greater root activity, microbial mineralization of organic P and fertilizer application. Similar variations in available P under different land-use and cropping systems have been reported by Todmal *et al.* (2008) [14] and Borkar *et al.* (2017) [15]. The vertical distribution of available P₂O₅ was irregular, although a general decline with depth was observed in several profiles. For instance, P₂O₅ decreased from 23.85 to 15.12 kg ha⁻¹ in Profile 1 and from 23.59 to 17.38 kg ha⁻¹ in Profile 9. In contrast, higher subsurface values were observed in some profiles, such as Profile 5 (29.19 to 33.59 kg ha⁻¹) and Profile 8 (35.90 to 39.75 kg ha⁻¹). Such variations may reflect differences in organic matter, clay content, soil reaction, root distribution and phosphorus fixation within the soil profile. In weathered soils, P may be strongly retained by Fe³⁺ and Al-bearing minerals, thereby reducing its availability to plants (Lun *et al.*, 2018) [16]. The relatively greater P availability in surface soils can be attributed to residue-derived P inputs and fertilizer application within the cultivated layer, whereas lower concentrations in subsurface horizons may result from P fixation and reduced organic P mineralization. The observed variability among profiles therefore reflects the combined effects of land use, nutrient management, organic matter dynamics, parent material and soil mineralogy. Similar depth-wise variations in available phosphorus have been reported by Thangasamy *et al.* (2005) [17]. Available K₂O varied widely among the studied soil profiles, ranging from 144.46 to 390.31 kg ha⁻¹. The highest value was recorded in the surface horizon of Profile 9 (390.31 kg ha⁻¹) under the cashew + agricultural crops system, whereas the lowest was observed in Profile 1 (144.46 kg ha⁻¹). Comparatively higher surface-soil K₂O was also recorded in Profiles 6 (369.48 kg ha⁻¹), 7 (370.60 kg ha⁻¹) and 8 (370.33 kg ha⁻¹). The relatively high K availability in these soils may be attributed to the K-rich basaltic parent material, weathering of primary minerals, recycling of K through plant residues and leaf litter, and repeated nutrient inputs under cultivated systems. The contribution of organic residue recycling to soil K

availability has also been reported by Rakhonde *et al.* (2025). Available K₂O generally showed a declining trend with increasing soil depth, although some profiles exhibited an irregular distribution. In Profile 9, K₂O decreased from 390.31 kg ha⁻¹ in A to 361.67 kg ha⁻¹ in Bw, while Profile 8 declined from 370.33 kg ha⁻¹ in A to 321.27 kg ha⁻¹ in Bw1. Similar reductions were observed in Profiles 5, 6, 10 and 11. The higher K concentration in surface horizons may be related to greater organic residue return, active root cycling and weathering of K-bearing minerals. In contrast, variations between horizons may reflect differences in clay content, cation exchange capacity, mineralogy, parent material and the intensity of K fixation and release. Naik (2014) [18] and Mohammad *et al.* (2014) emphasized the importance of soil mineralogy, clay characteristics and parent material in regulating K dynamics. The comparatively high K₂O status of several profiles indicates the important contribution of basalt-derived minerals to the K-supplying capacity of these soils. However, the depth-wise variation suggests that available K is controlled by both pedogenic factors and land-use management, including mineral weathering, residue recycling and fertilizer application. Similar depth-wise distribution of available K has been reported by Hirekurabar *et al.* (2000) [19]. Overall, the results indicate that available K₂O was generally greater in surface horizons and tended to decrease with depth, with the magnitude of variation depending on parent material, soil mineralogy, organic residue inputs and cropping practices.

DTPA-extractable micronutrients: DTPA-extractable Fe ranged from 63.12 to 121.61 mg kg⁻¹, with the maximum concentration recorded in the Bt2 horizon of Profile 10 and the minimum in the Bw2 horizon of Profile 12. Relatively high surface Fe was observed in Profiles 5 (121.20 mg kg⁻¹), 9 (111.60 mg kg⁻¹) and 10 (101.35 mg kg⁻¹). The high Fe availability may be associated with the Fe-rich basaltic parent material and weathering of Fe-bearing minerals, while acidic soil conditions may favour Fe solubility and availability. The irregular depth-wise distribution, including subsurface enrichment in Profiles 1 and 10, may be related to clay translocation, Fe redistribution, drainage conditions and pedogenic processes. Similar variations in available Fe with depth have been reported by Shah *et al.* (2012) [20] and Pavan *et al.* (2017) [21]. DTPA-extractable Mn varied from 58.74 to 124.80 mg kg⁻¹. The highest concentration was recorded in the surface horizon of Profile 11 (124.80 mg kg⁻¹), whereas the lowest was observed in the Bw2 horizon of Profile 12 (58.74 mg kg⁻¹). Several profiles showed a decline in Mn with depth, which may be associated with decreasing organic matter and biological activity and changes in soil aeration and redox conditions. The comparatively high Mn concentration in Profile 11 may also reflect the influence of periodic wetness on Mn reduction and mobility. Similar depth-wise variations in Mn availability have been reported by Murthy *et al.* (1997) [22] and Arunachalam *et al.* (2013) [23]. DTPA-extractable Zn ranged from 1.46 to 2.48 mg kg⁻¹, with the lowest concentration recorded in the Bw1 horizon of Profile 3 (1.46 mg kg⁻¹) and the highest concentration of 2.48 mg kg⁻¹ observed in the surface horizons of Profiles 5 and 11. Surface enrichment of Zn may be associated with organic matter accumulation, root activity, residue decomposition and recycling of Zn within the cultivated layer. The generally lower Zn concentration in subsurface horizons may be related to reduced organic carbon and biological activity. Variability among profiles may further reflect differences in soil pH, clay content, parent material and cropping practices, as reported by Yadav *et al.* (2009) [24], Behera *et al.* (2014) [25], Tiecher *et al.* (2016) [26] and Khanday *et al.* (2017) [27]. DTPA-extractable Cu ranged from 1.53 to 2.48 mg kg⁻¹, with the highest concentration recorded in the surface horizon of Profile 5 (2.48 mg kg⁻¹) and the lowest in the Bw horizon of Profile 9 (1.53 mg kg⁻¹). Surface soils generally showed higher Cu concentrations, particularly in Profiles 5, 7 and 11. The higher Cu availability in surface horizons may be associated with organic matter accumulation and decomposition of crop residues, since Cu has a strong affinity for organic matter and soil colloids. Its distribution may also be influenced by soil pH, clay content and cation ex

change capacity. Similar observations have been reported by Behera *et al.* (2014) [25], Boujelben *et al.* (2009) [28], Balpande *et al.* (2007) [29] and Ali *et al.* (2016) [30]. Overall, the DTPA-extractable micronutrients showed the concentration sequence $Fe > Mn > Zn > Cu$. Their generally higher concentrations in surface horizons suggest the important role of organic matter accumulation (Meshram *et al.* 2020

and Palkar *et al.* 2022) [31], residue recycling, root activity and biological nutrient cycling, whereas variations between horizons reflect differences in parent material, soil texture, soil reaction, clay mineralogy and pedogenic redistribution. The relatively high Fe and Mn concentrations may also be related to the weathering of basaltic parent material, which provides a substantial source of these micronutrients.

Table 1. Macronutrients and micronutrients content in soil under different cropping systems of Konkan Region

Horizons/ Cropping system	Depth (cm)	Available macronutrients (kg ha ⁻¹)			DTPA-Extractable micronutrients (mg kg ⁻¹)			
		N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu
		Profile-1: Loamy, mixed, isohyperthermic Typic Rhodustalfs						
Ap	0-20	197.51	23.85	144.46	90.93	84.28	2.37	1.78
Bt	21-35	222.65	15.12	161.52	110.10	60.93	2.12	1.63
Cr	35+	-----Weather basalt-----						
		-						
		Profile-2: Loamy, mixed, isohyperthermic Typic Rhodustalfs						
Ap	0-17	376.40	28.72	310.56	86.98	87.69	1.97	1.59
Bt1	18-42	366.56	26.41	349.55	91.03	84.20	1.64	2.03
Cr	42+	-----Hard laterite-----						
		Profile-3: Loamy, mixed, isohyperthermic Typic Haplustepts						
Ap	0-16	389.40	24.88	341.75	90.01	79.98	1.67	1.99
Bw1	17-45	367.32	20.77	329.27	74.32	81.38	1.46	1.58
Cr	45+	-----Weather basalt-----						
		-						
		Profile-4: Loamy, mixed, isohyperthermic Lithic Ustorthents						
Ap	0-24	282.24	32.31	337.40	81.30	78.58	2.41	2.12
R	24+	-----Hard basalt-----						
		Profile-5: Loamy, mixed, isohyperthermic Typic Haplustepts						
A	0-13	388.86	29.19	341.26	121.20	92.81	2.48	2.48
Bw1	14-30	371.56	33.59	377.44	91.14	70.68	2.15	2.01
Bw2	31-45	354.91	20.77	343.84	105.87	64.91	1.79	1.83
Cr	45+	-----Weather basalt-----						
		-						
		Profile-6: Fine-loamy, mixed, isohyperthermic Typic Rhodustalfs						
A	0-17	354.36	20.05	369.48	80.84	89.98	1.97	1.69
Bt	18-42	331.32	20.26	267.23	74.12	76.56	1.71	1.56
Cr	42+	-----Weather basalt-----						
		-						
		Profile-7: Loamy, mixed, isohyperthermic Lithic Ustorthents						
Ap	1-20	320.10	27.95	370.60	84.09	63.49	1.99	2.41
R	21+	-----Hard basalt-----						
		Profile-8: Loamy, mixed, isohyperthermic Typic Dystrustepts						
A	0-14	348.09	35.90	370.33	96.45	76.79	2.41	2.09
Bw1	15-43	291.60	39.75	321.27	84.01	70.28	1.97	2.47
Cr	43+	-----Weather basalt-----						
		-						
		Profile-9: Loamy, mixed, isohyperthermic Lithic Haplustepts						
A	0-24	310.46	23.59	390.31	111.60	90.16	1.77	1.69
Bw	25-51	298.05	17.38	361.67	90.31	72.83	1.53	1.53
R	51+	-----Hard basalt-----						
		Profile-10: Loamy, mixed, isohyperthermic Typic Rhodustalfs						
A	0-24	344.96	22.31	298.24	101.35	79.03	2.19	2.10
Bt1	25-39	324.17	26.67	356.01	109.05	67.72	1.92	1.98
Bt2	40-65	295.53	21.90	331.20	121.61	61.98	1.78	1.86
Cr	66+	-----Weather basalt-----						
		-						
		Profile-11: Loamy, mixed, isohyperthermic Typic Haplustepts						
Ap	0-30	206.97	27.95	352.59	90.15	124.80	2.48	2.44

(continued on next page)

Horizons/ Cropping system	Depth (cm)	Available macronutrients (kg ha ⁻¹)			DTPA-Extractable micronutrients (mg kg ⁻¹)			
		N	P ₂ O ₅	K ₂ O	Fe	Mn	Zn	Cu
Bw1	31-52	189.78	31.80	255.51	76.12	116.69	2.29	2.01
Bw2	53-80	191.29	20.00	334.32	86.03	96.38	2.07	1.97
Cr	80+	-----Weather basalt-----						
-								
Profile-12: Loamy, mixed, isohyperthermic Typic Haplustepts								
Ap	0-20	206.85	34.36	321.49	90.20	67.01	1.92	2.11
Bw1	21-46	215.97	27.67	344.36	70.39	79.95	1.67	2.03
Bw2	47-66	198.05	26.67	310.63	63.12	58.74	1.54	1.94
Cr	66+	-----Weather basalt-----						
-								

Table 2. Correlation matrix (Pearson's correlation coefficients) between soil available macronutrients and DTPA-extractable micronutrients (depthwise)

	Available N	Available P ₂ O ₅	Available K ₂ O	DTPA-Fe	DTPA-Mn	DTPA-Zn	DTPA-Cu
Available N	1.000						
Available P ₂ O ₅	-0.011*	1.000					
Available K ₂ O	0.458**	0.258**	1.000				
DTPA-Fe	0.291**	-0.170**	0.035ns	1.000			
DTPA-Mn	-0.181**	0.084ns	0.028ns	-0.126**	1.000		
DTPA-Zn	-0.171**	0.390**	-0.221**	0.267**	0.439**	1.000	
DTPA-Cu	-0.086ns	0.668**	0.269**	0.080ns	0.178**	0.508**	1.000

(Data were pooled for soils under different cropping systems. Avail. = Available; DTPA = diethylenetriamine pentaacetate; N = Nitrogen; P = Phosphorus; K = Potassium; Fe = Iron; Mn = manganese; Zn = zinc; Cu = copper *Correlation is significant at $p < 0.05$ level (two-tailed), **Correlation is significant at $p < 0.01$ level (two-tailed), Negative = Non-significant)

Iron (DTPA-Fe) exhibited a significant and positive correlation with available N ($r = 0.291^{**}$) and DTPA-Zn ($r = 0.267^{**}$), indicating that the availability of Fe and Zn may have been influenced by similar soil chemical conditions. However, Fe showed significant and negative correlations with available P₂O₅ ($r = -0.170^{**}$) and DTPA-Mn ($r = -0.126^{**}$). Its correlations with available K₂O ($r = 0.035$ ns) and DTPA-Cu ($r = 0.080$ ns) were positive but non-significant. The positive relationship between Fe and Zn may indicate similar patterns of retention and release of these micronutrients in the soil. Manganese (DTPA-Mn) showed a significant and negative correlation with available N ($r = -0.181^{**}$) and DTPA-Fe ($r = -0.126^{**}$), whereas its correlations with available P₂O₅ ($r = 0.084$ ns) and available K₂O ($r = 0.028$ ns) were positive but non-significant. In contrast, Mn showed significant and positive correlations with DTPA-Zn ($r = 0.439^{**}$) and DTPA-Cu ($r = 0.178^{**}$). The relatively strong positive association between Mn and Zn suggests that these micronutrients followed relatively similar patterns of distribution and availability in the soil system. Zinc (DTPA-Zn) showed significant and negative correlations with available N ($r = -0.171^{**}$) and available K₂O ($r = -0.221^{**}$). In contrast, Zn exhibited significant and positive correlations with available P₂O₅ ($r = 0.390^{**}$), DTPA-Fe ($r = 0.267^{**}$), DTPA-Mn ($r = 0.439^{**}$) and DTPA-Cu ($r = 0.508^{**}$). Among these relationships, the strongest positive association of Zn was observed with Cu, followed by Mn and P₂O₅. This indicates that Zn availability was closely associated with the distribution of other micronutrients, particularly Cu and Mn, possibly because of their common association with organic matter, mineral surfaces and soil chemical conditions. Copper (DTPA-Cu) exhibited significant and positive correlations with available P₂O₅ ($r = 0.668^{**}$), available K₂O ($r = 0.269^{**}$), DTPA-Mn ($r = 0.178^{**}$) and DTPA-Zn ($r = 0.508^{**}$). However, its correlations with available N ($r = -0.086$ ns) and DTPA-Fe ($r = 0.080$ ns) were non-significant. The strongest positive association of Cu was observed with P₂O₅, followed by Zn, indicating a close relationship between the availability of Cu and these nutrients in the studied soils. The strong P-Cu relationship may reflect common influences of organic matter, soil reaction and mineral interactions on their availability. Overall, the

correlation matrix indicated that P₂O₅-Cu ($r = 0.668$), Zn-Cu ($r = 0.508^{**}$), Mn-Zn ($r = 0.439^{**}$) and N-K₂O ($r = 0.458^{**}$) ** were among the stronger positive relationships. Conversely, P₂O₅-Fe ($r = -0.170$), N-Zn ($r = -0.171^{**}$) and K₂O-Zn ($r = -0.221^{**}$) showed significant negative relationships. These associations indicate that the availability of macronutrients and micronutrients was interrelated and was likely governed by the combined influence of soil chemical properties, organic matter dynamics, nutrient interactions and depth-wise distribution. However, correlation represents an association rather than causation; therefore, these relationships should not be interpreted as one nutrient directly causing changes in another.

Conclusion

The present investigation demonstrated that cropping systems strongly influenced the availability and depth-wise distribution of soil nutrients in the Konkan region of Maharashtra. In general, available N, P₂O₅ and K₂O and DTPA-extractable Fe, Mn, Zn and Cu were higher in the surface horizons, reflecting the important role of organic matter accumulation, root activity, residue decomposition and nutrient recycling. Among the cropping systems, mango + grasses recorded the highest surface available N, cashew + agricultural crops recorded the highest K₂O, while coconut + turmeric/agricultural crops showed high P₂O₅ availability. The sandal + horticultural system maintained particularly high Fe, Zn and Cu, whereas rice + rabi crops/vegetables recorded the highest Mn. The micronutrients were generally adequate and followed the order $Fe > Mn > Zn > Cu$, with a predominant decline in concentration with increasing soil depth, although some sub-surface enrichment was observed. The correlation analysis further indicated significant interrelationships among nutrients, particularly the positive associations of P₂O₅ with Cu, Zn with Cu, N with K₂O and Mn with Zn. These relationships indicate the interdependent nature of nutrient availability under different cropping systems. Overall, the findings emphasize that diversified cropping systems, particularly those involving perennial crops, grasses and regular residue return, can contribute to improved nutrient retention and cycling in soil. Therefore, depth-wise assessment of soil fertility is essential for identifying nutrient-enriched and nutrient-depleted soil layers and for de

veloping sustainable and site-specific nutrient management practices in the Konkan region of Maharashtra.

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