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Evaluation of multi-nutrient extractants for determination of available phosphorus, potassium and micronutrient cations in red soils of *Alfisols*

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Abstract
The study examines multi-nutrient extractants' ability to measure available phosphorus, potassium, and micronutrient cations in *Alfisols* red soils, aiming to improve soil testing for sustainable agriculture.
Objective: The primary aim of the study is to evaluate the efficacy of various multi-nutrient extractants in determining the levels of available phosphorus, potassium, and micronutrient cations like iron, manganese, copper, and zinc in the soil samples collected.
Method: The research involved the collection and analysis of sixty soil samples from various taluks in the Bangalore Rural district. These samples were categorized based on their pH levels and tested for a range of physico-chemical characteristics. The levels of available nutrients were assessed using established procedures and various multi-nutrient extractants, specifically Ammonium bicarbonate diethylene triamine penta acetic acid (AB-DTPA), Mehlich 3, and Acid ammonium acetate-ethylene diamine tetra acetic acid (AAAc-EDTA).
Findings: The study found that the Brays, Olsen, and NH4OAc methods yielded higher mean concentrations of phosphorus and potassium than alternative methods, with NH4OAc-K_2O being particularly effective across various pH levels. Additionally, AB-DTPA and AAAc-EDTA extractants were superior in extracting soil micronutrients such as iron, manganese, copper, and zinc, especially when compared to DTPA. The correlation coefficients between DTPA and other extractants varied, indicating a potential preference for AB-DTPA and AAAc-EDTA in certain conditions.
Impact: The study suggests using multi-nutrient extractants for soil analysis to improve efficiency and promote sustainable farming, but emphasizes the need for additional validation of these results and their impact on soil testing methods.

Keywords: Multi-nutrient extractants, phosphorus, potassium, micronutrient cations

1. Introduction

Optimal plant nutrition, critical for strong crop yields, relies on soil analysis to identify necessary nutrient amendments. While traditional chemical assays are precise, they require substantial time and resources. Multi-nutrient extractants, however, offer a more efficient approach by extracting multiple nutrients simultaneously, potentially reducing time, effort, and costs [1, 2]. Yet, verifying their reliability against established soil characteristics and analytical methods is crucial. Soil fertility, especially in *Alfisols* red soils found in tropical and subtropical regions, is vital for sustainable agriculture and depends on key nutrients like phosphorus and potassium. These soils' unique weathering processes and nutrient profiles complicate the accurate measurement of available nutrients.

Unlocking the secrets of *Alfisols* red soils, traditional testing often misses the mark, either underestimating or overestimating nutrient levels due to complex soil-nutrient dynamics [3]. Typically zeroing in on a single nutrient, these tests fail to capture the soil's full fertility spectrum. Enter multi-nutrient extractants: a game-changing solution that extracts several nutrients at once for a complete fertility readout.

Phosphorus, potassium, and micronutrient cations form an integral component of the major soil testing program besides other essential nutrients. The standard methods for the determination of different nutrients in soils of Bengaluru rural district are: alkaline sodium bicarbonate extraction for neutral to alkaline soils [4] and Bray P1 method [5] for available P, 1N CH3COONH4 (pH 7.0) for available K [6], and diethylenetriaminepenta acetic acid (DTPA) (pH 7.3) extraction method for micronutrient cations [7]. However, ammonium bicarbonate-DTPA (AB-DTPA) and acid ammonium acetate-ethylene diamine tetra acetic acid (AAAc-EDTA) are the two multi-nutrient extractants that have been reported to be capable of extracting all the above-mentioned nutrients *viz*., available P, K, and micronutrient cations simultaneously in alkaline and acidic soils, respectively. Soil phosphorus (P) test selection depends on local soil pH and established practices [8, 9]. While traditional tests like the molybdate blue method gauge molybdate-reactive P, they may miss or overestimate other P forms. The Mehlich III test, gaining favor in North America, employs a chemical mix at low pH for comprehensive soil P and cation assessment, effective across different soil pH ranges [10].

The suitability of these extractants for determining the availability of nutrients has been studied extensively in different parts of the world, but only little information is available regarding the suitability in Southern India, particularly for red soils of *Alfisols*. This study assesses multi-nutrient extractants' effectiveness in measuring available nutrients in *Alfisol* red soils, aiming to enhance soil testing and support sustainable agriculture in these regions.

2. Material and Methodology

In the current study, a total of sixty soil samples were collected from various taluks in the Bangalore Rural district as shown in Figure 1. These samples were randomly selected and categorized based on their pH levels: twenty samples with a pH less than 6.5, twenty with a pH between 6.51 and 7.5, and twenty with a pH greater than 7.51. Each composite sample was made up of soil collected from 10 to 15 different locations within the farmed fields. These samples were taken from the top 15 cm of soil, which corresponds to the plow layer typically found in these regions. After collection, the soil was air-dried, pulverized with a wooden pestle and mortar, and then passed through a 2 mm mesh. To assess micronutrients, the soil was further filtered using muslin cloth. The prepared samples were then preserved in polyethylene bags at ambient temperature until analysis time.

The examined soil samples underwent testing for a range of physico-chemical characteristics using the specified methods, such as texture [11], pH and electrical conductivity [12], organic carbon [13], and cation exchange capacity [11]. The levels of available phosphorus, potassium and micronutrient cations like iron, manganese, copper, and zinc were assessed using established procedures referenced in the Introduction. The laboratory study was conducted to assess the effectiveness of various multi-nutrient extractants, specifically Ammonium bicarbonate diethylene triamine penta acetic acid (AB-DTPA) by [14], Mehlich 3 by [15] and Acid ammonium acetate-ethylene diamine tetra acetic acid (AAAc-EDTA) by [16], in comparison with current soil testing procedures for the availability of phosphorus, potassium, and micronutrient cations.

3. Statistical analysis

A descriptive analysis (range, average, median and standard deviation) was performed to described the data. Pearson correlation was used to determine variable relationships.

4. Results

4.1 Mechanical analysis

Variations in soil composition were observed across different sites, with changes in the proportions of sand, silt, and clay detailed in Table 1. The average sand content was noted to be between 34.2% and 67.3%, regardless of the soil pH levels, while silt and clay contents varied from 12.3% to 35.4%, and 17.0% to 39.0%, respectively. The textural classification ranged from sandy clay loam to clay loam.

4.2 Physico-chemical properties of soil

Soil pH and Electrical Conductivity (EC) are critical parameters in soil science, with pH values ranging from 3.96 in highly acidic soils to 8.5 in alkaline soils (Table 1). The average pH values are 5.306 for acidic, 7.02 for neutral, and 7.93 for alkaline soils. EC, indicative of soil salinity, shows variation in line with soil pH, with average values between 0.12 and 0.19 dS m^{-1}, which is within the acceptable range for most crops. Soil organic carbon content also varies with soil acidity, ranging from 2.3 g kg^{-1} in acidic to 10.9 g kg^{-1} in alkaline conditions, with mean values of 4.5, 5.6, and 4.5 g kg^{-1}, respectively.

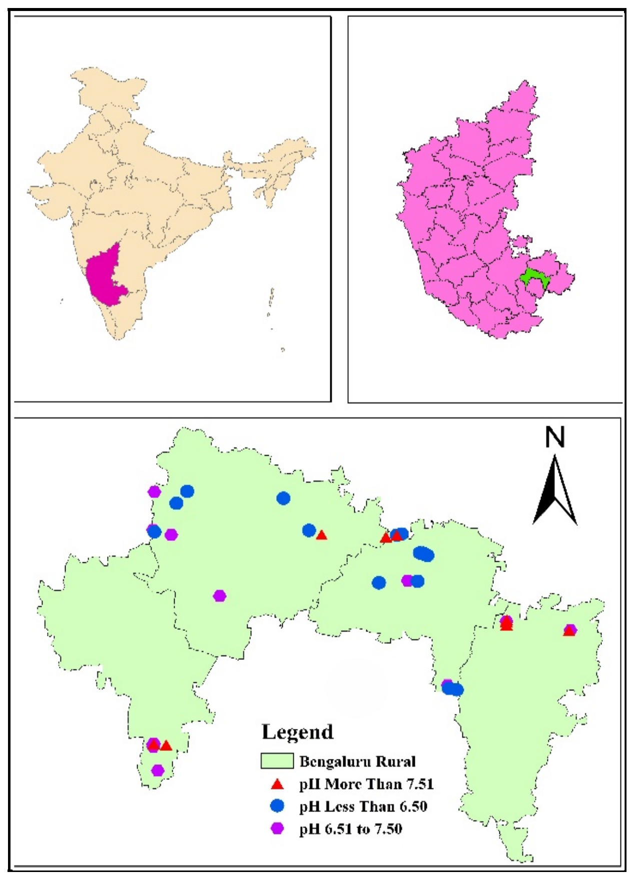

Fig 1: Map of Bengaluru Rural district showing locations of collected soil samples

Table 1: Mechanical separates (sand, silt, clay) and other properties of soils samples from Bangalore Rural district

	Particular	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (dS m^{-1})	OC (g kg^{-1})
pH < 6.50	Range	39.4-58.0	16.4-26.4	22.4-39.0	3.96-6.45	0.03-0.18	0.23-0.83
	Mean (n=20)	47.1	20.8	32.1	5.306	0.1865	0.45
	Median	45.3	22.7	32.6	5.23	0.05	0.45
	SD (±)	5.7	3.0	3.9	0.81	0.33	0.15
pH 6.51-7.50	Range	36.7-61.7	16.4-35.4	17.0-33.6	6.52-7.46	0.03-1.03	0.25-0.98
	Mean (n=20)	49.2	24.3	26.5	7.02	0.12	0.61
	Median	50.5	22.4	27.3	7.15	0.07	0.56
	SD (±)	8.4	5.6	4.1	0.30	0.22	0.25
pH > 7.51	Range	34.2-37.3	12.3-31.0	12.8-36.4	7.46-8.5	0.04-1.03	0.13-1.09
	Mean (n=20)	52.0	20.8	27.2	7.93	0.19	0.57
	Median	51.2	19.4	27.7	7.9	0.08	0.45
	SD (±)	8.9	5.0	5.3	0.27	0.28	0.36

4.3 Available phosphorus and potassium content

The mean (n = 20) concentrations of phosphorus and potassium obtained through Brays, Olsen, and NH4OAc methods surpass those extracted by alternative methods, as evidenced in Tables 2 and 3. The mean phosphorous extracted by Brays P_2O_5 is 22.9 kg ha^{-1}, while it is 16.7 kg ha^{-1} for AB-DTPA, 16.7 kg ha^{-1} for Mehlich-3 and 17.6 kg ha^{-1} for AAAc-EDTA reflecting a reduction of 27.07%, 27.07% and 23.14%, respectively (Table 2).

In soils with neutral pH, Olsen P_2O_5 averages 23.25 kg of phosphorous per hectare, compared to 19.29 kg for AB-DTPA, 17.37 kg for Mehlich-3 and 17.82 kg for AAAc-EDTA, indicating reductions of 17.01%, 25.23% and 23.36%. For alkaline pH soils, the average extraction by Olsen P_2O_5 is 29.78 kg per hectare, while AB-DTPA, Mehlich-3 and AAAc-EDTA extract 23.41, 29.78 kg and 24.04 kg, respectively, representing decreases of 21.38%, 26.27 and 19.26%. Overall, across all pH levels, AB-DTPA and AAAc-EDTA demonstrate lower extraction efficiency than both Brays P_2O_5 and Olsen P_2O_5, confirming that the latter two are more proficient in extracting phosphorous.

The study of correlation coefficients between various phosphorus extractants at different pH levels reveals significant relationships (Table 3). At a pH lower than 6.5, AAAc-EDTA and Brays-P_2O_5 exhibit the strongest correlation (0.828). In the pH range of 6.51-7.50, AB-DTPA correlates most strongly with Olsen-P_2O_5 (0.830). For pH levels above 7.5, Mehlich-3 demonstrates the highest correlation with Olsen-P_2O_5 (0.776).

The data presents a comparative analysis of potassium extraction methods across different soil pH levels (Table 2). At pH levels below 6.5, NH_4OAc-K_2O extracted an average of 101.34 kg ha^{-1}, which is significantly higher than the amounts extracted by AB-DTPA, Mehlich-3, and AAAc-EDTA, with decreases ranging from 17.85% to 26.06%. For soils with pH between 6.51 and 7.50, NH_4OAc-K_2O again led with 186.28 kg ha^{-1}, while the other methods showed a decrease of 12.18% to 20.37%. At pH levels above 7.5, the trend continued, with NH_4OAc-K_2O extracting 279.84 kg ha^{-1}, and the other methods showing a decrease of 17.66% to 22.52%. In acidic soil, potassium levels from NH_4OAc extraction correlate most strongly with AB-DTPA (0.796**), then Mehlich-3 and AAAc-EDTA. For neutral and alkaline soils, the highest correlation is with AAAc-EDTA (0.881**), followed by AB-DTPA and Mehlich (Table 3).

Table 2: The mean phosphorus and potassium (kg ha^{-1}) content from soil samples using different extractants at varied pH levels

Phosphorus (kg ha^{-1})					
Category	**Extractants**	**Brays P_2O_5**	**AB-DTPA**	**Mehlich-3**	**AAAc-EDTA**
pH <6.5 (n=20)	Mean	22.9	16.7	16.7	17.6
	Max.	28.5	24.8	26.5	22.3
	Min.	15.4	10.0	10.5	14.0
	SD (±)	3.71	3.64	4.35	2.34
		Olsen P_2O_5	AB-DTPA	Mehlich-3	AAAc-EDTA
pH 6.51-7.50 (n=20)	Mean	23.25	19.29	17.37	17.82
	Max.	29.50	25.88	27.57	22.42
	Min.	16.13	14.32	12.58	13.28
	SD (±)	3.72	3.46	4.33	2.78
pH >7.5 (n=20)	Mean	29.78	23.41	21.95	24.04
	Max.	42.69	32.30	28.34	31.16
	Min.	18.47	13.48	14.32	18.13
	SD (±)	7.98	4.82	3.40	3.70
Potassium (kg ha^{-1})					
Category	Extractants	NH_4OAc-K_2O	AB-DTPA	Mehlich-3	AAAc-EDTA
pH <6.5 (n=20)	Mean	101.34	77.51	83.24	74.94
	Max.	144.42	122.25	142.88	129.34
	Min.	81.75	50.24	61.31	43.55
	SD (±)	16.37	17.97	17.64	20.05
pH 6.51-7.50 (n=20)	Mean	186.28	154.44	163.61	148.31
	Max.	322.25	275.36	300.14	254.58
	Min.	108.56	74.61	94.61	84.02
	SD (±)	66.12	57.01	53.69	50.57
pH >7.5 (n=20)	Mean	279.84	216.81	230.41	219.87
	Max.	542.99	396.43	380.18	345.25
	Min.	112.55	113.61	134.78	117.40
	SD (±)	113.94	70.72	62.33	55.93

Table 3: The correlation coefficient of phosphorus and potassium content from soil samples using different extractants at varied pH levels

Phosphorus					
Category	**Extractants**	**Brays- P_2O_5**	**AB-DTPA**	**Mehlich-3**	**AAAc-EDTA**
pH <6.5 (n=20)	AB-DTPA	0.748**			
	Mehlich-3	0.734**	0.698**	1	
	AAAc-EDTA	0.828**	0.658**	0.749**	1
		Olsen-P_2O_5	AB-DTPA	Mehlich-3	AAAc-EDTA
pH 6.51-7.50 (n=20)	AB-DTPA	0.830**	1		
	Mehlich-3	0.656**	0.512*	1	
	AAAc-EDTA	0.761**	0.658**	0.446*	1
pH >7.5 (n=20)	ABDTPA	0.654**	1		
	Mehlich-3	0.776**	0.658**	1	
	AAAc-EDTA	0.657**	0.507*	0.623**	1
Potassium					
Category	Extractants	NH_4OAc-K_2O	AB-DTPA	Mehlich-3	AAAc-EDTA
pH <6.5 (n=20)	AB-DTPA	0.796**	1		
	Mehlich-3	0.775**	0.794**	1	
	AAAc-EDTA	0.723**	0.657**	0.727**	1
pH 6.51-7.50 (n=20)	ABDTPA	0.770**	1		
	Mehlich-3	0.750**	0.833**	1	
	AAAc-EDTA	0.881**	0.678**	0.675**	1
pH >7.5 (n=20)	ABDTPA	0.739**	1		
	Mehlich-3	0.682**	0.700**	1	
	AAAc-EDTA	0.776**	0.559*	0.591**	1

Note: Significant at 5% level of significance.
Significant at 1% level of significance, NS D non-significant.

4.4 Micronutrient cations (Fe, Mn, Cu and Zn)

The extraction efficiency of various soil micronutrient cations using different chemical extractants shows significant variation across different pH levels (Table 4). In a comparative study, the extraction of micronutrients using AB-DTPA and AAAc-EDTA revealed varying increases in content relative to DTPA extraction. Iron, manganese, copper, and zinc showed increased percentages across different pH levels. Notably, at pH levels above 7.5, AB-DTPA extraction resulted in a 35.0% increase in iron content and a 57.1% increase with AAAc-EDTA. Zinc content increased by 19.4% with AB-DTPA and 60.6% with AAAc-EDTA.

For instance, when comparing Mehlich-3 to DTPA, iron extraction increased by 42.01% to 66.55% as soil pH increased from acidic to alkaline. Similarly, zinc extraction showed a 45.52% increase under acidic conditions, but this increase was less pronounced in neutral to alkaline soils. Manganese extraction also improved with Mehlich-3, particularly in neutral soils, with an increase of up to 32.93. An elevation in pH values correlates with an enhanced extraction of micronutrient cations when utilizing the Mehlich 3 extractant. The correlation coefficients between DTPA and other extractants vary depending on the element and the pH level (Table 5). The correlation values of iron, zinc, and manganese extracted by DTPA with AB-DTPA are higher compared to other extractants in their respective pH categories. For copper, DTPA shows the highest correlation with AAAc-EDTA at pH <6.5 and with AB-DTPA at pH 6.51-7.50 and >7.5.

5. Discussion

5.1 Soil properties

The observed variations in soil composition and textural classification reflect the influence of diverse factors such as climate, parent material, vegetation, and topography on soil formation [17]. The observed variations in soil pH, EC, and organic carbon content highlight the interplay between soil chemical properties and crop tolerance. The diminished levels of organic carbon in *Alfisols* red soils are primarily attributed to certain soil properties, such as a lack of calcium carbonate and a high presence of minerals containing aluminum and iron, as noted by [18]. This condition is also influenced by prolonged use of fertilizers and manure, according to [19], as well as various land management techniques [20].

5.2 Extraction of P and K by different extractants

The AAAc-EDTA and AB-DTPA methods extracted less phosphorus from acidic soils compared to the Bray method, possibly because of the higher presence of aluminum and iron phosphates in such soils, as noted by [21]. Additionally, hydrochloric and fluoride ions have been found to be more efficient at dissolving phosphorus minerals than bicarbonate ions, which Bray extractant typically targets. These observations were similarly reported by [22]. The diminished phosphorus retrieval using Mehlich 3 extractant relative to Bray's in acidic soils could be attributed to the partial dissolution of aluminum and iron hydroxide minerals. This dissolution process releases Al^{3+} and Fe^{3+} ions, which in turn consume protons from the solution, leading to an increase in pH. Consequently, the presence of higher amounts of clay, along with iron and aluminum oxides/hydroxides, aids in the neutralization of the Mehlich 3 solution [23, 24].

The findings indicate that, in comparison to the Olsen extractant, the phosphorus retrieved by the Mehlich 3 extractant is lower at elevated pH levels. This is primarily attributed to a combination of factors such as the transformation of phosphorus forms, the neutralization of the extractant's pH, the depletion of fluoride ions, and the alteration in phosphorus forms, all of which cumulatively lead to a reduction in phosphorus extraction by Mehlich-3 as the soil pH rises [24]. The elevated levels of phosphorus detected using the AAAc-EDTA method, compared to those found with ABDTPA and mehlich methods, could be due to the chelating characteristics of the EDTA component of the extracting solution. Furthermore, the presence of the ammonium ion (NH_4^+) in the solution contributes to this effect, as it can be exchanged and substituted, according to [25].

Table 4: The Fe, Mn, Cu and Zn (mg kg^{-1}) content from different extractants at varied pH levels

Iron (mg kg^{-1})					
Category		**DTPA**	**AB-DTPA**	**Mehlich-3**	**AAAc-EDTA**
pH <6.5 (n=20)	Mean	24.51	30.91	34.81	30.26
	Max.	35.52	41.25	45.25	41.09
	Min.	14.55	16.80	20.54	20.63
	SD (±)	7.84	8.36	8.86	5.56
pH 6.51-7.50 (n=20)	Mean	18.37	23.94	26.46	28.65
	Max.	27.50	37.90	42.58	43.53
	Min.	10.60	10.22	11.59	10.63
	SD (±)	4.96	6.96	8.55	7.93
pH >7.5 (n=20)	Mean	14.50	19.58	24.15	22.77
	Max.	19.65	29.87	39.70	30.64
	Min.	10.25	11.25	14.58	14.48
	SD (±)	3.34	4.79	6.69	4.56
Zinc (mg kg^{-1})					
pH <6.5 (n=20)	Mean	1.34	1.74	1.95	2.59
	Max.	3.40	3.78	4.35	4.68
	Min.	0.40	0.54	0.59	0.54
	SD (±)	0.8347	0.9372	1.0670	1.2863
pH 6.51-7.50 (n=20)	Mean	2.36	2.89	2.58	2.76
	Max.	3.15	3.64	3.86	3.97
	Min.	0.75	1.12	1.08	1.02
	SD (±)	0.75	0.71	0.75	0.85
pH >7.5 (n=20)	Mean	1.60	1.91	2.04	2.57
	Max.	2.90	2.88	2.95	3.92
	Min.	0.25	0.38	0.45	0.69
	SD (±)	0.69	0.66	0.72	0.75
Manganese (mg kg^{-1})					
pH <6.5 (n=20)	Mean	20.74	26.27	27.30	31.10
	Max.	27.80	35.06	37.05	38.13
	Min.	10.20	16.32	19.99	20.55
	SD (±)	5.47	5.30	4.89	5.03
pH 6.51-7.50 (n=20)	Mean	18.34	24.69	24.38	26.90
	Max.	25.10	33.89	35.60	38.58
	Min.	6.58	10.07	11.92	18.23
	SD (±)	4.98	7.05	6.31	5.63
pH >7.5 (n=20)	Mean	13.21	15.08	16.11	18.90
	Max.	22.15	29.24	31.51	35.09
	Min.	4.60	2.15	2.17	3.69
	SD (±)	5.22	8.04	9.52	9.77
Copper (mg kg^{-1})					
Category		DTPA	AB-DTPA	Mehlich-3	AAAc-EDTA
pH <6.5 (n=20)	Mean	2.64	2.99	3.63	4.19
	Max.	3.79	4.36	5.58	6.28
	Min.	1.15	1.51	1.77	1.65
	SD (±)	0.83	0.77	1.27	1.46
pH 6.51-7.50 (n=20)	Mean	2.03	2.78	3.10	3.33
	Max.	3.35	4.42	4.77	5.19
	Min.	0.80	1.19	1.20	1.20
	SD (±)	0.77	1.03	1.17	1.24
pH >7.5 (n=20)	Mean	1.79	2.43	2.70	2.79
	Max.	2.95	3.87	4.11	4.43
	Min.	0.62	0.91	1.05	1.05
	SD (±)	0.58	0.82	0.95	1.05

Table 5: The correlation coefficient of Fe, Mn, Cu and Zn (mg kg^{-1}) content from different extractants at varied pH levels

Iron					
Category	**Parameter**	**DTPA**	**AB-DTPA**	**Mehlich-3**	**AAAc-EDTA**
pH <6.5 (n=20)	AB-DTPA	0.669**	1		
	Mehlich-3	0.518*	0.642**	1	
	AAAc-EDTA	0.641**	0.560*	0.507*	1
pH 6.51-7.50 (n=20)	AB-DTPA	0.660**	1		
	Mehlich-3	0.675**	0.655**	1	
	AAAc-EDTA	0.661**	0.544*	0.815**	1
pH >7.5 (n=20)	AB-DTPA	0.626**	1		
	Mehlich-3	0.467*	0.675**	1	
	AAAc-EDTA	0.682**	0.589**	0.396NS	1
Zinc					
pH <6.5 (n=20)	AB-DTPA	0.976**	1	0.995**	
	Mehlich-3	0.976**	0.995**	1	
	AAAc-EDTA	0.745**	0.786**	0.766**	1
pH 6.51-7.50 (n=20)	AB-DTPA	0.796**	1	0.648**	
	Mehlich-3	0.572**	0.648**	1	
	AAAc-EDTA	0.584**	0.522*	0.554*	1
pH >7.5 (n=20)	AB-DTPA	0.894**	1	0.935**	
	Mehlich-3	0.857**	0.935**	1	
	AAAc-EDTA	0.659**	0.714**	0.813**	1
Manganese					
pH <6.5 (n=20)	AB-DTPA	0.797**	1	0.657**	
	Melich 3	0.693**	0.657**	1	
	AAA	0.679**	0.580**	0.362NS	1
pH 6.51-7.50 (n=20)	AB-DTPA	0.913**	1	0.821**	
	Melich 3	0.786**	0.821**	1	
	AAA	0.612**	0.513*	0.379NS	1
pH >7.5 (n=20)	AB-DTPA	0.530*	1	0.960**	
	Melich 3	0.514*	0.960**	1	
	AAA	0.327NS	0.810**	0.852**	1
Iron					
Category	Parameter	DTPA	AB-DTPA	Mehlich-3	AAAc-EDTA
	Mehlich-3	0.693**	0.657**	1	
	AAAc-EDTA	0.679**	0.580**	0.362NS	1
pH 6.51-7.50 (n=20)	AB-DTPA	0.913**	1	0.821**	
	Mehlich-3	0.786**	0.821**	1	
	AAAc-EDTA	0.612**	0.513*	0.379NS	1
pH >7.5 (n=20)	AB-DTPA	0.530*	1	0.960**	
	Mehlich-3	0.514*	0.960**	1	
	AAAc-EDTA	0.327NS	0.810**	0.852**	1
Copper					
pH <6.5 (n=20)	AB-DTPA	0.643**	1	0.404NS	
	Mehlich-3	0.746**	0.404NS	1	
	AAAc-EDTA	0.874**	0.555*	0.731**	1
pH 6.51-7.50 (n=20)	AB-DTPA	0.953**	1	0.984**	
	Mehlich-3	0.887**	0.984**	1	
	AAAc-EDTA	0.856**	0.943**	0.968**	1
pH >7.5 (n=20)	AB-DTPA	0.946**	1	0.983**	
	Mehlich-3	0.872**	0.983**	1	
	AAAc-EDTA	0.783**	0.939**	0.984**	1

Note: *Significant at 5% level of significance. **Significant at 1% level of significance, NS: non-significant

Correlation findings suggest a robust association between AAAc-EDTA and Brays-P_2O_5 at a pH lower than 6.5, indicating a strong relationship. Similarly, AB-DTPA and Olsen-P_2O_5 show a strong relationship in the pH range of 6.51-7.50. Above pH 7.5, Mehlich-3 and Olsen-P_2O_5 confirm a strong relationship. These findings highlight the importance of pH in the extraction and measurement of soil phosphorus, as reported by [26]. The correlation coefficients between the different phosphorus extractants at various pH levels underscore the critical role of pH in soil phosphorus extraction and measurement.

Irrespective of the extractants, the available potassium increases with increasing the soil pH. This might be due to the solubility and availability of potassium in the soil influenced by the CEC and soil pH, leading to increased K extraction amounts in the tests [3]. Overall, NH_4OAc-K_2O proved to be the most effective potassium extraction method, consistently outperforming the others across all pH ranges. Ammonium acetate is notably more effective at extracting potassium from soil, primarily due to its higher concentration of ammonium ions which displace potassium efficiently. The process is also longer, taking 30 minutes, compared to the shorter durations of other methods like AB-DTPA and AAAc-EDTA [27]. Additionally, the soil to solution ratio differences among these methods contribute to the effectiveness of ammonium acetate, with its specific ratio allowing for a more efficient extraction process.

5.3 Micronutrient cations (Fe, Mn, Cu and Zn)

The extractants AB-DTPA and AAAc-EDTA demonstrate superior extraction of iron, manganese, copper, and zinc relative to DTPA. This might be attributed to their multifaceted nutrient extraction abilities, potent chelation that augments metal solubility, adaptability to particular soil pH levels and characteristics, and beneficial interactions with soil organic matter, all of which are instrumental in the mobilization of these crucial micronutrients from the soil matrix [28]. The presence of iron oxides and oxyhydroxide minerals, including goethite and hematite, which tend to remain partially insoluble at reduced pH levels [21], could be the reason for the enhanced extraction of micronutrient cations with the Mehlich 3 extractant. These findings highlight the importance of considering soil pH when selecting an extractant for nutrient analysis. The variations in the correlation coefficients between DTPA and other extractants depending on the element and the pH level could suggest that DTPA is more correlated with AB-DTPA in extracting iron, zinc, and manganese, and with AAAc-EDTA and AB-DTPA in extracting copper, under the given pH conditions [3].

6. Conclusion

This comprehensive study unravels the complex interplay between soil type, its reaction, chemical properties, and other factors in determining the efficiency of nutrient extraction in red soils of *Alfisols*. The research underscores the pivotal role of soil pH in the extraction of phosphorus, potassium, and micronutrient cations. It highlights how traditional methods like Brays, Olsen, and NH_4OAc outshine alternative methods in extracting phosphorus and potassium. However, the multi-nutrient extractants AB-DTPA and AAAc-EDTA demonstrate superior extraction of iron, manganese, copper, and zinc relative to DTPA, especially at higher pH levels. These findings illuminate the intricate dance of soil composition and nutrient availability, paving the way for enhanced crop yields and sustainable agriculture in the region.

7. Data availability statement

The data that support this study will be shared upon reasonable request to the corresponding author.

8. Conflict of interest

The author reported no potential conflict of interest

9. References

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