



PHOSPHORUS FORMS AND DISTRIBUTION IN TWO DIFFERENT PARENT MATERIALS IN JOS PLATEAU STATE

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ABSTRACT

The study investigates the distribution of phosphorus (P) forms in soils derived from basaltic (BPM) and granitic (GPM) parent materials in Jos, Plateau State. One profile was dug at each identified parent material. Routine field and laboratory analysis were carried out. Results demonstrate that parent material influences both the concentration and variability of P forms. Soils developed from basalt consistently exhibited higher mean contents of aluminum-bound P (Al-P: 104.56 mg/kg), calcium-bound P (Ca-P: 51.89 mg/kg), reductant-soluble P (Red-P: 118.60 mg/kg), occluded P (Occ-P: 70.89 mg/kg), available P (Av-P: 7.36 mg/kg), and total P (TP: 838.26 mg/kg) compared to their granite-derived counterparts. The distribution of these P forms down the soil profile was predominantly irregular for most forms, though Occ-P showed a consistent increase with depth in both soil types. Variability, measured by the coefficient of variation (CV), was generally low to moderate (<30%) for most P forms. However, GPM soils displayed greater variability in Al-P distribution, while Ca-P in GPM was highly variable (CV 53.94%). The overall abundance of P forms followed the order Fe-P > O-P > Red-P > Al-P > Occ-P > Ca-P > Av-P for BPM and O-P > Fe-P > Red-P > Al-P > Ca-P > Occ-P > Av-P for GPM. The higher P contents observed in this study compared to some previous works are potentially attributable to continuous fertilizer usage in the study area. A key agronomic finding is that despite these inputs, available phosphorus levels fell below the 10 mg/kg critical threshold for optimal crop production, indicating potential phosphorus deficiency.

Keywords: Basalt, Granite, Phosphorus, Forms, Parent, Material

INTRODUCTION

According to a UN report, the global population is estimated to reach 9.8 billion by 2050 (UN, 2017) and that food production must increase by 70% in order to achieve food security (Noel *et al.*, 2016). Agriculture in modern times is faced with the multifaceted challenges of time, space and increasing demand in quantity and quality. These goals must be achieved in the context of soil and water shortages, changes in global and regional land use patterns due to climate change, drought and the need to develop crop energy, and the environmental and social aspects of agricultural sustainability (Devlet, 2021). Soil has been described as the foundation of nearly all global food production as it provides anchor and support, supplies water and nutrient and a living, dynamic ecosystem essential for growing the crops and pastures that feed humans and livestock (Kopittke *et al.*, 2019; FAO, 2024).

During the World Soil Day 2024 commemorated in Kyrgyzstan, the Food and Agriculture Organization (FAO) emphasized the essential role of soil in achieving global food security, environmental sustainability, and climate resilience. Discussions centered on the necessity of protecting and enhancing soil health—a resource foundational to our food systems yet facing serious threats from degradation and erosion—through the adoption of climate-smart agricultural practices (FAO, 2024). Assessment of soil for land use planning is increasingly important due to increasing competition for land among many land uses and the transition from subsistence to market-based farming in many countries (Lu *et al.*, 2015). The coupling of soil characterization, soil classification and soil mapping provides a powerful resource for the benefit of mankind especially in the area of food security and environmental sustainability. (Olusegun *et al.*, 2021; Zitta *et al.*, 2022). Soil health



is largely determined by the soils physical, chemical and biological characteristics, along with assumptions around the productivity, or lack thereof, of plants and animals (Akinwa, 2023). Soil health is globally defined as “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans” (Duncan *et al.*, 2019). A soil that contains an adequate and balanced supply of essential nutrients, a good structure for root growth and water infiltration, and a vibrant ecosystem of microorganisms is classified as a fertile soil (Devlet, 2021).

Phosphorus (P), as a limiting nutrient, is one of the major plant nutrient elements second in importance to nitrogen (N) in terms of nutrient requirements for increased plant biomass production in ecosystem. It has been reported that plants absorb mainly inorganic phosphorus (PI) but the organic phosphorus (OP) is also an important reservoir for plant nutrition (Galadima *et al.*, 2018; Orobator and Ekpengkho, 2021; Ogunsanwo *et al.*, 2024). The OP can be found in chemically or physically protected forms, which can be slowly mineralized into available forms for plant uptake, mainly as a product of soil organic matter (SOM) decomposition or by the action of specific enzymes (Asmare *et al.*, 2015). The reddish basaltic soil sites are the major agricultural activities of thousands of small holders in the Jos Plateau highland which are characterized by sub-humid tropical climate. (Olowolafe, 2002 as cited in Owunubi, 2021). Hassan *et al.*, (2015), also reported that productivity of these soils appears to have declined drastically; a situation which calls for investigation to provide proper assessment and which will lead to better management practices to increase their yields.

As reported (Akinwa, 2023) soils derived from basalt and volcanic ashes are much more intensively and extensively utilized for agricultural purposes than the granite soils. In most Nigerian soils, nitrogen, phosphorus, potassium, and magnesium and to some extent sulphur and zinc are the nutrients whose deficiencies most frequently limit the crop yield (Ohaeri and Eshett, 2011). Differences in soil formation over a continuum result in differences in soil physical and chemical properties (Zitta *et al.*, 2022) which affect the pattern of plant and litter production, and decomposition (Mamzing *et al.*, 2022). Variation in soil properties has been known to differ in organic matter content, structure, texture, pH, base saturation, cation exchange capacity (CEC), bulk density and water holding capacity, as well as many other soil physical and chemical properties (Tijani *et al.* 2017). Studies have shown that soils differ not only in parent material but also in many important physical and chemical properties. Hence, their potential to support various types of land use are expected to differ. Several studies have been conducted on the phosphorus dynamics in some areas of Nigeria. They include Abia (Ohaeri and Eshett, 2011), midwestern state (Robert and Kingsley, 2015), Cross Rivers State (Orji and Abam, 2018), However, no documented study has been found on the form and distribution of phosphorus on Jos Plateau. The study on the distribution of various forms of phosphorus (P) in soil provides useful information in assessing the availability status and measuring the degree of weathering of element in the soil. Soil total phosphorus reserve in the soil largely exceeds crop requirements, however plants could suffer deficiencies because only a small and variable fraction is in the available form for crops (Duncan *et al.*, 2019). The content and distribution of the active forms of P in the soil is a useful index in assessing its requirement in soils. The quantification of this nutrient is necessary to better understand its mineralization-immobilization turnover under particular environments and cropping systems. Adequate knowledge of soil P is important in P management of soils and fertilizer recommendation. This study, therefore, seeks to evaluate the forms of phosphorus (P) derived from basaltic parent material (BPM) and granitic parent material (GPM) in Jos, Plateau State.

MATERIALS AND METHODS

Study Area

The study was conducted at two sites representing basaltic and granitic parent material. The basaltic site is located at the Teaching and Research Farm of the Federal college of Land Resources Technology Tahoss at Altitude 1115m, between 9.571887°N, 8.712308°E and 9.57949°N, 8.69903°. The granitic site is located at School of Home Economics behind Acha Research Station in Riyom at Altitude of 1198m, between 9.64209°N, 8.77188°E and 9.66571°N and 8.729056°E, all in Riyom Local Government Area of Plateau State. The study area falls on the Jos Plateau which is a highland

area standing above the surrounding plains in the central part of Nigeria. The area is a tropical wet and dry climate with long-term annual rainfall of 1008.6 to 2184.70 (1300mm) and annual temperature of 22°C. The area's soil moisture regime has been described as ustic while soil temperature regime is isohyperthermic (Eswaran *et al.*, 1997, as cited in Ikazaki *et al.*, 2025) describes the soils moisture regime as. It has a cool climatic condition due to its altitude. The coldest period is between November and February with an average mean daily temperature of 18°C, while it gets warm between March and April before the onset of rain. The rainy season, which is between the months of May and October, has its peak in August. The lands are for most parts used for crop cultivation mostly rain feed agriculture. The common food crops grown in the area include Irish potato, Sweet-potato, Maize, Millet, Fonio (Acha), Finger millet (Tamba) Tomato and many other varieties of vegetables (Akinwa, 2023).

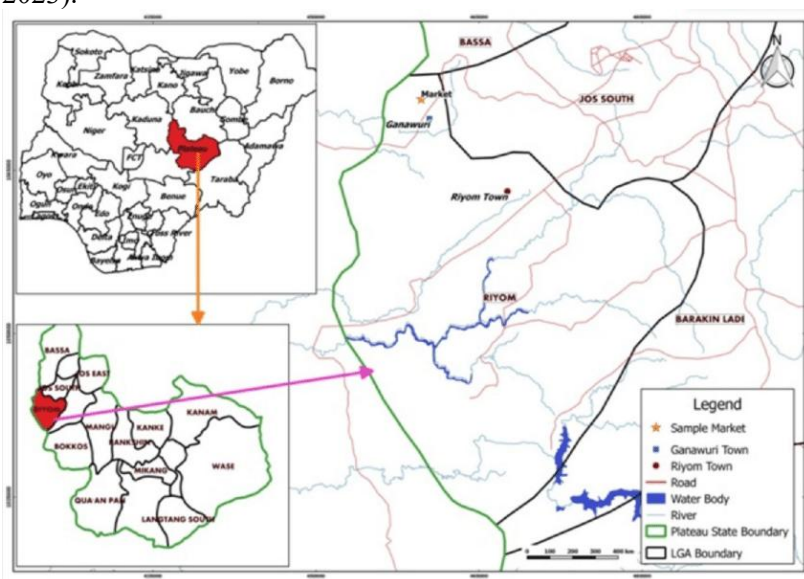


Figure 1: Map of the Study Area

Soil Profile and Sampling Techniques

The sites were geo-referenced using handheld Global Positioning System (GPS) Receiver. A free survey method was used to choose the sample sites. A profile pit was dug in each of the two parent material locations. The profile pit on the basaltic parent material (BPM) was dug at FECOLART research farm Tahoss, while the profile pit at the granitic parent material (GPM) was dug behind School of Home Economics Riyom. The horizons of each profile were clearly marked out and samples were collected from each distinguishable horizon. The BPM profile has 5 horizons while the GPM has 4.

Soil Sample Preparation and Laboratory Analysis

The soils were air dried, crushed with mortar and pistle and sieved with a mesh of 2mm which was used for all laboratory analysis. Particle size distribution was determined using the hydrometer method (NSSC, 1995). The textural class was determined using the USDA textural class triangle (USDA, 1975). Bulk density was determined by the core method (Black, 1965). Available P was extracted by the Bray-1 procedure (Bray and Kurtz, 1945) and determined by Murphy and Riley (1962). The characterization of inorganic phosphorus in soils was achieved through a sequential extraction procedure, a method designed to fractionate phosphorus into its distinct chemical forms based on their binding strengths. The specific protocol was a modification of the established Chang and Jackson (1957) method, which itself refined the initial approach of Dean (1938), involving a series of extractions with acid and alkaline reagents to target specific phosphorus pools. The phosphorus concentration in each resultant extract was then determined spectrophotometrically using the phosphomolybdate blue method of Murphy and Riley (1962). Occluded Phosphorus (Occ-P) was

calculated as the difference between the total phosphorus and the active phosphorus as $\text{Occ-P} = [\text{TP} - (\text{OP} + \text{Av-P} + \text{Al-P} + \text{Fe-P} + \text{Ca-P})]$.

Data Analysis

The result obtained were analyzed with descriptive statistics (mean and coefficient of variation)

RESULTS AND DISCUSSION

The result for bulk density is presented in Table 1. The bulk density values in BPM profile decreased with depth to the Bw2 horizon. The values ranged from 0.947- 1.227mg/m³ (1.039 mg/m³) and a change in the pattern at the Bt1 horizon which shows a sharp increased and then decreased down the profile. The same pattern was observed in BPM profile, as the values decreased with depth from surface horizon with an increased at the Bt2 and BC horizon. The Bulk Density (BD) value ranged from 1.051- 1.582 mg/m³ (1.346 mg/m³). This shows that bulk density is higher in granite-based soils than basaltic soils. The lowest BD was observed in the Bt1 horizon of GPM which could be attributed to the high clay content thus, the field evidence of clay translocation (cutans) from the surface horizons into Bt horizons of the pedons. The values obtained in this study falls within the ranges reported by Hassan *et al.* (2015) and Mamzing *et al.* (2022). They suggested that the characteristic coarse texture of granitic soils is the principal reason for the high bulk density.

Table 1: Bulk Density, Total Porosity and Particle Size Distribution of Soils in the Area

Horizon Depth	Bulk Density (cm)	Total (Mg/m ³)	Sand Porosity	Silt (%)	Clay (%)	Silt/Clay (%)	Textural Class Ratio
Basaltic Parent Material							
Ap	0-12	0.9860.3720		33 29	38	0.76	clay loam
Bw1	12-39	0.9630.3632		41 11	48	0.23	clay
Bw2	39-86	0.9470.3575		25 27	48	0.56	clay
Bt1	86-135	1.2270.4629		35 23	42	0.55	clay
Bt2	135-200	1.071 0.4043		23 25	52	0.48	clay
Granitic Parent Material							
Ap	0-19	1.3250.5001		65 21	14	1.55	sandy loam
Bt1	19-49	1.0510.3965		33 21	46	0.44	clay
Bt2	49-136	1.4270.5383		37 25	38	0.56	clay loam
Bc	136-200	1.582 0.5969		55 21	24	0.90	sandy clay loam

The particle size distribution is also presented in Table 1. The distribution of sand content was irregular down the profile in both pits. Sand content ranges from 23 – 41% in BPM with mean 31.6% and 33 – 65% in GPM with mean 47.5%, with the highest content at Bw1 horizon and Ap horizon for BPM and GPM, respectively. In both parent materials, the distribution of sand is irregular, but GPM has the highest content of sand. The results obtained in this study are higher than those reported by Zilitta *et al.*, (2022) but falls within the range reported by Akinwa (2023). They both agree that the surface horizons have the highest content of sand. Akinwa (2023), however, reported that basalt had greater sand content than granite.

In BPM, the silt content ranges from 11 - 29% with mean of 23.28%, while it ranges from 22 - 25% with mean of 22.28% in GPM. The Ap horizon has the highest content of silt (29%) in BPM and Bt2 horizon with 25% in GPM, and just like the sand fraction, the pattern of distribution is not irregular. For clay, the content ranges from 38 - 52% with a mean of 45.36% and highest content at the Bt2 horizon and the lowest at the Ap horizon. Also, for GPM, clay content has the least at the Ap horizon (13.76%) with the highest at the Bt1 horizon with. However, more clay fraction was observed on soils developed from basaltic parent material. Studies conducted on basaltic parent material revealed high clay contents with iron oxides as subsidiary weathering products. In addition, Mamzing *et al* (2022) reported that clay particles are lost to the lower depths.

The various phosphorus fraction determined in the study area from the two parent materials are presented in Table 2. Organic Phosphorus (O-P) content in the BPM ranged from 132.04 - 261.76mg/kg with a mean of 197.10mg/kg, while that for GPM ranged from 157.52 - 301.15mg/kg



(mean = 225.86mg/kg). The AP horizon has the highest O-P content and the Bt2 and Bc horizon have the lowest in BPM and GPM, respectively. The variability in the distribution of O-P content in the various profiles is rated as high $CV > 30\%$. This indicates that for both BPM and GPM, there is a high variability in the distribution of O-P down the profile. The result in the foregoing agrees with previous studies. Ohaeri and Eshett (2011) and Orji and Abam (2018) have both reported that the distribution of O-P varies widely depending on the parent material, location and depth. They suggested that the varying distribution of O-P is influenced by organic carbon content and coarse nature of soils. They however, obtained O-P values that are lower than that obtained in this study. This could possibly be due to higher fertilizer usage in the study area than their study areas.

Fe-P content in BPM increased with depth from the Ap horizon (267.96 mg/kg) and peaked at the Bw2 horizon (345.07mg/kg) before it steadily dropped to its least value at the Bt2 horizon (242.91 mg/kg). The mean of the distribution is 287.86mg/kg) with a CV 14.98. On the other hand, Fe-P for GPM also showed a steady increased from the Ap horizon to Bt2 horizon after which it declined. The values of Fe-P obtained ranged from 128.26 – 195.23mg/kg (mean =162.32mg/kg) with a CV 19.89. This result shows that soils developed from BPM has higher soil Fe-P content than soils developed from GPM. However, soils developed from GPM have the highest variability (CV 19.89%). This result agrees with that reported by Asmare *et al.* (2015) and Olusegun *et al.* (2021) that granite-derived soils have a lower Fe-P than basalt-derived soils. Furthermore, this result shows that Fe-P component has the highest content amongst all inorganic phosphorus components. This could be probably due to the fact that the soils were very strongly to strongly acidic. Also, it could possibly be attributed to the abundant Fe present in soils formed on the parent materials. This high Fe-P relative to other forms of P have been reported (Amenkienan *et al.*, 2023). The result is also in consonant with Asmare *et al.* (2015) and Ogunsanwo *et al.* (2024) who reported that it could be as a result of high oxides of iron content, low pH status, and advanced level of weathering.

The distribution of Al-P forms is also presented in table 2. Al-P content in BPM ranged from 85.78 - 123.24 mg/kg (104.56 mg/kg) and CV15.26. The Bt1 horizon has the highest Al-P content 123.24 mg/kg while the AP horizon has the lowest Al-P content 85.78 mg/kg. Al-P content distribution increases down the profile but shows a decrease at the Bt2 horizon. Al-P content of GPM ranged from 41.35 - 69.73 mg/kg (54.53 mg/kg) and CV22.20. The Bt1 horizon has the highest Al-P content 69.73 mg/kg while the BC horizon has the lowest Al-P content 41.35 mg/kg. The Al-P content distribution was irregular down the profile. The values fall within the range reported by Melese *et al.* (2015) and Orji and Abam (2018). The results indicate that soils developed from basaltic parent material have higher soil Al-P content than soils developed from granitic parent material. In addition, soils of granitic parent material show higher variability in distribution Al-P than that of basaltic parent material, however the variability is moderate $CV < 30\%$ in both soils. Ohaeri and Eshett (2013) and Amenkhenan *et al* (2023) have similarly reported such irregular distribution of Al-P in their studies. They, however, both obtained values that are lower than those reported in this study. This could be attributable to the continuous usage of fertilizer and the low rainfall in the study area as compared to those in their study.

Table 2: Distribution of P Forms in the two Parent Materials

Horizon	O-P	Fe-P	Al-P	Ca-P	Red-P	Occ-P	Av-P	TP
------(mg/kg)-----								
Basaltic parent material								
Ap		261.76	276.96	85.78	60.40	90.34	48.65	11.29
Bw1		243.23	318.96	105.40	49.05	120.46	69.50	6.93
Bw2		138.99	345.07	116.75	53.11	125.09	76.44	8.45
Bt1		209.49	255.39	123.24	45.40	143.62	85.71	5.29
Bt2		132.04	242.91	91.62	51.48	113.51	74.13	4.86
Mean		197.10	287.86	104.56	51.89	118.60	70.89	7.36
CV		30.09	14.98	15.26	10.74	16.31	19.41	35.51
Granitic parent material								
Ap		301.15	128.26	49.46	45.81	57.91	32.43	6.63
Bt1		268.71	183.88	69.73	30.40	83.40	37.06	5.24
Bt2		176.05	195.23	57.57	38.11	71.81	39.38	4.47
Bc		157.52	141.89	41.35	36.08	60.23	32.43	4.72
Mean		225.86	162.32	54.53	37.60	68.34	35.33	5.27
CV		30.95	19.89	22.20	53.94	17.18	9.84	18.33

O-P=Organic Phosphorus, Fe-P=Iron Phosphorus, Al-P=Aluminum Phosphorus, Ca-P=Calcium Phosphorus, Red-P=Reduced Phosphorus, Occ-P=Occluded Phosphorus, Av-P=Available Phosphorus, TP=Total Phosphorus

For Ca-P, it ranged from 45.40 - 60.40mg/kg (51.89mg/kg) and (CV)10.74 in BPM. The distribution of Ca-P was irregular down the profile. The AP horizon has the highest Ca-P content 60.40mg/kg while the Bt1 horizon has the lowest Ca-P content 45.40mg/kg. GPM also shows a similar irregular distribution pattern down the profile. The AP horizon has the highest Ca-P content (45.81mg/kg) while the Bt1 horizon has the lowest Ca-P content (30.40mg/kg) and a CV of 53.94%. The result obtained showed that soils developed from basaltic parent material had higher soil Ca-P content than soils developed from granitic parent material, however, soils of granitic parent material shows greater variability in the distribution of Al-P content CV>50%. The values obtained in this study are higher than those reported by Ohaeri and Eshett (2011) and those of Amenkhienan *et al.* (2023). This could be attributed to the higher fertilizer usage in the study area. The researchers have attributed their low Ca-P content to probably changes of Al-P and Fe-P in the acidic to slightly acidic natured soils.

Red-P content ranged from 90.34 - 143.62 mg/kg (118.60 mg/kg) in BPM with a CV of 16.31%. The Bt1 horizon has the highest Red-P content 143.62 mg/kg while the AP horizon has the lowest Red-P content 90.34 mg/kg. Red-P content of soil developed from granitic parent (GPM) material ranged from 57.91 – 83.40 mg/kg (68.34 mg/kg). This value is higher than the range reported by Robert and Kingsley (2015). The Bt1 horizon has the highest Red-P content 83.40 mg/kg while the AP horizon has the lowest Red-P content 57.91 mg/kg. The distribution of Red-P content was irregular down the profile and similarly has moderately low variation CV (17.18). These results imply that soils developed from basaltic parent material have higher Red-P content than soils developed from granitic parent material. However, the distribution variability in both soils is moderately low CV 30%

The results for occluded P for both parent materials is also shown in Table 2. Occ-P content in soil developed from basaltic parent material in the study area ranged from 48.65 – 85.71 mg/kg (70.89 mg/kg) and a moderately low CV (19.41). The Bt1 horizon has the highest Occ-P content 85.71mg/kg while the AP horizon has the lowest Occ-P content 48.65mg/kg. Occ-P content distribution increases down the profile this was also reported by Mustapha *et al.* (2007), Ohaeri and Eshett (2011). Occ-P content of soil developed from granitic parent material ranged from 32.43 – 39.38 mg/kg (35.33 mg/kg). The Bt2 horizon has the highest Occ-P content 39.38 mg/kg while the Ap horizon has the lowest Occ-P content 32.43 mg/kg. The Occ-P content distribution also increases down the profile with a much lower CV (9.84). The results of Occ-P content show that, soils developed on basaltic parent material has higher Occ-P content than soils developed from granitic



parent material and that Occ-P content increases with increasing depth in both the profile. However, basalt-based soils have higher variability $CV > 10$ compare to granite-based soils $CV < 10$.

The available phosphorus in BPM ranged from 4.68-11.29mg/kg (7.36mg/kg). The Ap horizon has the highest Av-P content 11.29mg/kg while the Bt2 horizon has the lowest Av-P content 4.86mg/kg. Av-P content distribution decreases irregularly down the profile and has a moderately high variation CV (35.51). Av-P content of GPM ranged from 4.47-6.63mg/kg (5.27mg/kg). The Ap horizon has the highest Av-P content 6.63mg/kg while the Bt2 horizon has the lowest Av-P content 4.72mg/kg. The distribution of Av-P in granite-based soils also decreases down the profile and has low variation CV (18.33). This result showed that basalt-based soil has higher Av-P than granite-based soils. The values obtained in this study although falls within the ranges reported by previous authors (Hassan *et al.*, 2015; Galadima *et al.*, 2018), it falls partly below the 10mg/kg recommended for crops.

The TP distribution for BPM ranged from 710.55 to 913.53mg/kg (838.26mg/kg). TP content distribution is irregularly with increasing depth and Bw1 horizon having the highest TP content (913.53mg/kg) while the Bt2 horizon has the lowest TP content (710.55 mg/kg) and a CV of (9.15). TP content of soil developed from granitic parent material ranged from 474.22 to 678.42mg/kg (589.23mg/kg). The Bt1 horizon has the highest TP content 678.42mg/kg while the Bc horizon has the lowest TP content 474.22 mg/kg. The TP content distribution decreases irregularly with depth and has low variation CV (14.62). Higher concentration of P is often found in the top soil and it decreases with depth. The changes in the root architecture, morphology and distribution pattern which helps to facilitate the uptake of P from the top soil (Orji and Abam, 2018; Olusegun *et al.*, 2021; Mamzing *et al.*, 2022). This could account for the low TP content at the Ap horizon compare to the underlying horizon in both profiles. Soils developed on basaltic parent material had higher soil TP content than soils developed from granitic parent material. The content distribution of P forms down the profile pits varied widely with their mean distributed in the following order; Fe-P>O-P>Red-P>Al-P>Occ-P>Ca-P>Av-P for basalt and O-P>Fe-P>Red-P>Al-P>Ca-P>Occ-P>Av-P for granite.

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that the parent material is a primary factor governing the concentration, distribution, and variability of various phosphorus forms in the soil. Soils developed from basaltic parent material (BPM) consistently exhibited significantly higher mean contents of all measured P forms—Al-P, Ca-P, Red-P, Occ-P, Available P (Av-P), and Total P (TP)—compared to soils derived from granitic parent material (GPM). The distribution of these P forms down the soil profile was generally irregular for most forms, with a notable trend of Available P decreasing with depth in both soil types, likely due to plant uptake from the topsoil. A key finding is the difference in variability: GPM soils showed greater variability (higher CV) in the distribution of Al-P and Ca-P, while BPM soils were more consistent. Crucially, despite the higher overall P content in BPM soils, the Available Phosphorus levels in both soil types were sub-optimal, falling partly below the critical level of 10 mg/kg recommended for crop production. The elevated P values compared to some previous studies are likely attributable to historical fertilizer use in the study area.

Based on the findings, the following recommendations are made:

- i. Agricultural management practices must account for the inherent differences in soil parent material. Fertilizer recommendations for soils on basaltic parent material should be distinct from those on granitic parent material, given their differing total P pools and availability.
- ii. For both soil types, but especially for the inherently lower-fertility GPM soils, the addition of phosphorus fertilizers is essential to raise the Available P levels above the 10 mg/kg crop requirement threshold. This is critical for improving crop yields.
- iii. Applications of fertilizer should be tailored to the distribution of P in the profile in order to optimize its efficiency. Since Available P is highest in the Ap horizon, banding or placement of P fertilizers at the root zone can enhance plant uptake and reduce fixation by other soil components.



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