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Characterization of land use influence on soil phosphate bioavailability in Usangu agro-ecosystem-Tanzania

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ABSTRACT

Phosphorus (P) is an important nutrient required for plant growth. Land use influences concentration and bioavailability of P in agricultural soils. About 198 soil samples (0-30 cm soil depth) were collected from three land-use types (maize, paddy, and conserved areas) in Usangu basin located in Southern Highland Tanzania. The concentration of soil P determined were compared among different land-use types and locations. The total P (TP), complexed (Po), and bioavailable P (B-P) were measured. The concentration of TP and B-P was determined by acid digestion and Mehlich 3 method, respectivelly, The Po concentration in soil extract was obtained by subtracting B-P from TP. TP, B-P and Po concentration in collected soils samples were in range of; Total P (63.12-1350.9 mg/kg), Bioavailable P (0.52-49.87 mg/kg), and complexed P (62.60-1301.03 mg/kg). The cropping area had high TP but very low B-P, especially in paddy farming areas indicating cropping and associated activity decrease bioavailable P in agricultural soils. Furthermore, soils from cropping areas had higher Al, Fe, and Mg concentrations than conserved areas, which caused a substantial reduction in B-P due to increased P fixation and adsorption. It is important to note that converting natural land to farming land could potentially influence soil P dynamics thus affecting P bioavailability, crop productivity, and environmental safety.

1. Introduction

Phosphate (P) is a limiting plant nutrient in most tropical soils because of high fixation as a results of high sesquioxides and weathering activity (Gatiboni et al., 2021; Guppy et al., 2005; Li et al., 2021; Uddin et al., 2021; Zhang et al., 2021). In degraded agricultural soils, P is supplemented from organic and inorganic fertilizers, but its availability is usually limited (Barrow et al., 2021; De Bolle, 2013). Highly weathered tropical soils originally have low bioavailable phosphorus for plant uptake due to rapid fixation and adsorption by metal cations to form complex forms of iron and aluminium phosphate. Therefore, phosphate fertilization for increased crop productivity is mandatory (Schoumans, 2015; Schoumans and Chardon, 2014). Fertilization increase P to an acceptable level for easy crop uptakes, but also maintain available levels during the next cropping seasons, and replace P removed by crop uptake and surface water loss (Nunes et al., 2020; Zhang et al., 2021). High Fe, Al, and clay content in agricultural soils usually drive low P availability in tropical soils (Fink et al., 2016; Guppy et al., 2005). In this kind of soil, the application of P fertilizer to the recommended rate usually has lower fertilizer returns to most farmers. The increased use of fertilizer rate than recommended is required to provide additional P to compensate the fixed P to ensure high crop productivity (Cheng et al., 2021; Nunes et al., 2020; Zhang et al., 2021). However, excessive use P fertilizer in agricultural soils may saturate the soil leading to increased P loss to the environment thus increasing production cost and environmental contamination (Sharpley et al., 2016). In terms of management practices, the soil tillage system and the physical and chemical nature of the fertilizer applied influence P bioavailability for plant uptakes. Minimum tillage promotes the accumulation of nutrients in topsoil (Calegari et al., 2008; Kihwele et al., 2021). While conventional tillage system, which involves deep tillage with extensive and frequent hallowing resulting in homogenization of agricultural soils has been reported to affect the availability of P required for plant uptake because of increased sorption sites and increased P adsorptions (Panasiewicz et al., 2020; Tiecher et al., 2012). Adoption of no-till or reduced tillage in farming areas in tropical soils is essential as it reserves the soil physics and chemistry, which ensure availability of P for plant uptake (Ge et al., 2018; Tiecher et al., 2012). Assessing the concentration of P in different fractions in agricultural soils help estimate the influence of land uses and associated management on P bioavailability in agricultural soils. The role of land use and associated management have not yet been specifically studied to check their influence on the bioavailability of P in paddy wetland soils in tropical areas. However, land uses or conversion of natural land to agriculture influence the concentration, speciation, and bioavailability of P in tropical soils remained poorly understood. This study intended to evaluate the influence of land use change and associated management on P bioavailability in agricultural soils of Usangu paddy wetland, which

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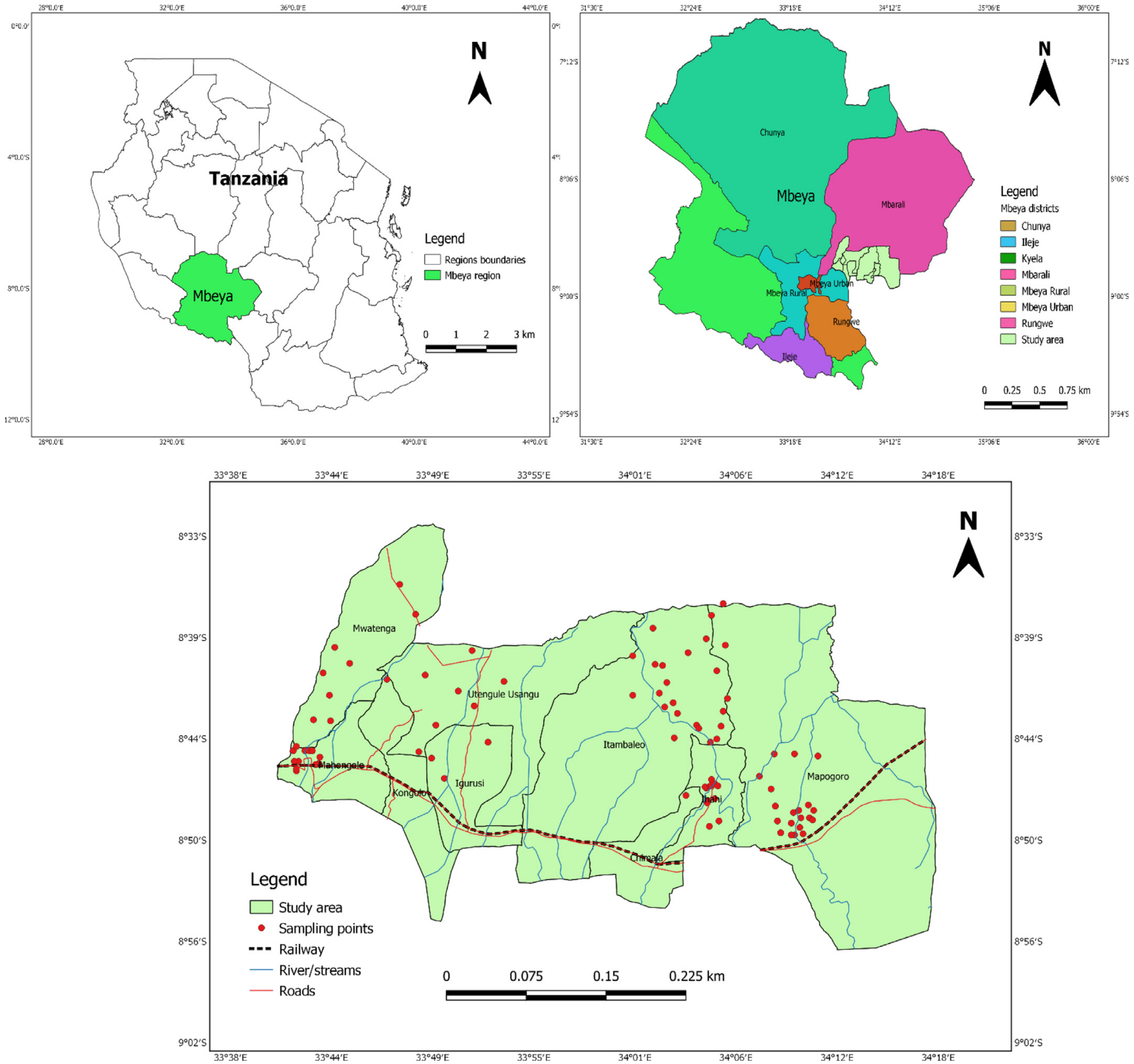

Fig. 1. The map showing study area and soil sampling points in Usangu basin Mbeya Tanzania.

is associated with highly weathered tropical soils such as eutric fluvisols, eutric leptosols, haplic acrisols, haplic lixisols, and umbric nitisols (FAO, 2014; Mng'ong'o et al., 2021; Wickama and Mowo, 2001) to generate important information required for P management.

2. Material and methods

2.1. Study area and soil sample collection

This study was conducted in Usangu agro-ecosystem-Southern Highland Tanzania, an area famous for maize and paddy production. The site has an average annual rainfall of 700-1600 mm, starting from December to May. The study area involves three land uses: the conserved area, paddy, and maize farming area. One hundred ninety-eight (198) soils samples were sampled at 0-30 cm depth in ten irrigation scheme during November to December 2019 (Figure 1). The collected soil samples were air-dried and ground to obtain fine earth (less than 2 mm) for chemical analyses. The major soil types in the study area were Eutric Fluvisols, Eutric Leptosols, Haplic Acrisols, Haplic Lixisols, and Umbric Nitisols (FAO, 2014; Wickama and Mowo, 2001).

Irrigation scheme studied are classified as (i) Group I:-purely agriculture (pure agriculture schemes) this includes only farming areas, this category includes schemes such as Utengule usangu, Kapunga, Mubuyuni, Uturo, Isenyela, Mabadaga, and Mwatenga. This group has well-established irrigation systems like concrete paved irrigation channels, highly mechanized and intensified for high yields, with high use of inorganic fertilizer, pesticides, and herbicides (Carvalho, 2015; Ngailo et al., 2016; Nonga et al., 2011). (ii) Group II:-mixed agriculture schemes include farming areas and scattered rural settlements in the area, group two scheme includes schemes such as Ihahi, Chimala, Igalako, and Mahongole. The Group II schemes are in farming areas with scattered rural settlements, which could positively or negatively

Table 1
Instrument and method detection limits (LODs) for selected elements in certified SCP EnviroMAT (S150123029) standard samples using Mehlich 3 method (M3).

S/N	Element	Instrumental LOD (mg/L)	Method LOD (mg/L)	Experimental Values-SCP (mg/L)	Reference Values- SCP (mg/L)
1	Ca	0.031	0.032	0.402	0.407
2	Al	0.001	0.021	0.069	0.102
3	Fe	0.050	0.050	0.026	0.031
4	P	0.106	0.120	0.020	0.026

influence plant nutrients concentration and availability in agricultural soils. Group II schemes are dominated by smallholder farmers with less organic manure and inorganic fertilizer application. The flooding irrigation system is common in both schemes where water is allowed to enter the field, creating a water depth up to 25 cm. Settlements around the area might influence/affect the soil quality due to waste disposals from domestic and urban effluents.

2.2. Sample extraction and analysis

The following soil parameters were determined: total P (TP), bioavailable P (B-P), complexed P (Po), Al, Fe, Ca, pH, and organic carbon.

Total P concentrations (TP). To determine total P (TP) in soil samples were determined by acid digestion with HNO_3 and HCL in a ratio of 3:1 (v/v) in a hot plate (95-100°C) for at least three hours (UoP, 2015). Approximately 0.2 g of each soil sample was weighed and placed in a 25 ml beaker. 1 ml of high purity HNO_3 was added and allowed to cold digest for 1 hour. After one hour, 3 ml of high purity HCl and additional 1 ml of HNO_3 were added and allowed to hot digest for at least 3 hours until the brown fumes stopped evolving. Then sample was allowed to cool, filtered into a 25 ml volumetric flask using an 0.42 µm acid-resistant filter, and made to the mark with 2% HNO_3 (v/v) and stored at 4°C until analysis. For each digestion, a blank was also prepared with the same amount of acids without a soil sample.

Bioavailable P (B-P), Al, Fe, and Ca, were determined using Mehlich 3 extraction method (M3) (Mehlich, 1984). Two grams of air-dried soils were weighed into 50 ml centrifuge tubes followed by 20 ml M3 solution, then shaken for 5 minutes at 180 rpm and then filtered through Whatman No. 42 filters to obtained clear filtrates. The concentration of P, Al, Fe, Ca, and Mg in extracts was determined by ICP-OES (Thermo Scientific iCAP 7400 ICP-OES Pickles) and ICP-MS (Thermo Scientific iCAP TQ MS Ermentrude). Total Po was then obtained by the difference between total P and bioavailable P. Soil pH was measured using the glass electrode method of Chaturvedi and Sankar. (2006). Soil organic carbon (SOC) were determined by method of chromic acid titration (Walkley and Black).

Quality assurance: Reagent blanks and certified standard reference soil sample SCP (S150123029) EnvironMAT obtained from SCP Science-Qmx laboratories, Thaxted-United Kingdom, were used to monitor the determination quality. Mill Q water were used to prepare all the reagents and calibration standards. All glasswares were acid-washed, then rinsed with distilled water followed by Mill Q water. The recovery of samples spiked with standards ranged from 86% to 104.1%. The instrumental and method detection limits (LOD) for Mehlich 3 extractable elements are shown in Table 1.

2.3. Statistical Analyses

Statistical methods were applied to analyze distribution and correlation among the studied parameters. All collected data were statistically analyzed by the Jamovi 1.2.25, JASP 0.6.12, and IBM SPSS Statistics 24 programs (IBM: Chicago, IL, USA). The statistical difference among irrigation schemes, land uses, and sampling points within and between irrigation schemes were determined by one-way ANOVA and Tukey post hoc tests (P<0.05). To understand the relationship of P with other studied parameters such as pH, OC, TN in agricultural soils, Pearson correlation analyses were performed. The study site and sample sampling sites maps were generated using the QGIS 3.10.7 software.

Table 2
Background soil information in the study area.

Site	EC (dS/m)	pH	N (%)	OC (%)
Chimala	8.80	7.1	0.05	0.60
Igalako	12.80	6.9	0.06	0.68
Ihahi	6.97	6.9	0.07	0.80
Ilaji	19.60	7.2	0.17	2.37
Isenyela	7.14	6.6	0.06	0.75
Kapunga	8.90	7.4	0.04	0.45
Mabadaga	7.85	7.4	0.11	1.33
Mahangole	9.17	6.4	0.11	1.37
Mubuyuni	8.30	7.5	0.03	0.37
Uturo	10.09	6.7	0.16	1.99
Mean	**10.22**	**6.4**	**0.11**	**1.51**

3. Results and discussion

The background soil characteristics in the study area were variable (Table 2), which affect the amount and distribution of B-P. The study evidenced medium to high electrical conductivity (Ec) in soil paste in the study area (6.970-19.80 dS/m). The amount determined potentially inhibits plant nutrients, including P bioavailability for agricultural uptakes. The soil pH was 6.4-7.6, the observed soil pH was around neutral with minor intersite effects (variability) on P availability. Soil pH regulates P sorption via the availability of P adsorbents such as Al, Fe, and Ca. The study found 0.02 to 0.17% of total nitrogen in studied soils which was low compared to average amounts of 2% in the tropics. The OC in the study area was 0.37 to 2.37%, where most sites had OC below 2%. These potential factors determinants of P bioavailability in agroecosystem affect P dynamics.

3.1. Total soil phosphate in Usangu Agro-ecosystem

The concentration of total phosphorus (TP) in agricultural soils varied among land uses and irrigation schemes in Usangu agro-ecosystems (Table 2 and 3). The determined TP concentration was in the range of 63.12-1350.09 mg/kg. The concentration of TP was observed to vary among land uses where; conserved areas had TP in the range of 129.54-589.63 mg/kg; Paddy farming TP was 63.12-1350.9 mg/kg; and Maize farming was 553.26-668.46 mg/kg (Table 3). It was observed that farming areas had a high total P compared to conserved areas; this might be influenced by the addition of P from phosphatic fertilizers and other P-containing materials such as manure and crop residues. Intensification in paddy farming in the area reflected high TP in paddy farming areas compared to maize farming areas (Diatta et al., 2020; Kihwele et al., 2018; Mng'ong'o et al., 2021). The spatial distribution of TP in Usangu agro-ecosystem varied among schemes (Table 4) where some schemes had high TP concentration such as Kapunga (1350.9 mg/kg), Mahongole (814.33 mg/kg), Ihahi (790.72 mg/kg),

Table 3
The availability of Total P, bioavailable P (B-P), organic P (Po), percent of P availability, and concentration of other P bioavailability determinants in soils from diverse land use.

	Land Use	Al (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	Total P (mg/kg)	B-P (mg/kg)	Po (mg/kg)	% P Bioavailability
Mean	Conserved areas	214.91	919.65	174.83	300.97	347.26	13.49	333.77	3.88
	Maize farming	193.59	1362.55	107.03	286.87	468.57	25.73	442.84	5.49
	Paddy farming	294.1	806.89	214.81	238.59	316.86	7.70	309.16	2.43
Minimum	Conserved areas	125.36	194.82	97.9	115.99	129.54	0.99	128.55	0.76
	Maize farming	124.87	1318.56	91.64	253.49	353.26	15.20	338.06	4.30
	Paddy farming	93.21	95.1	81.14	42.18	63.12	0.52	62.60	0.82
Maximum	Conserved areas	337.51	2010.72	314.08	520.2	589.63	35.79	553.84	6.07
	Maize farming	278.21	1415.24	127.75	316.9	668.46	40.32	628.14	6.03
	Paddy farming	792.97	2494.35	470.59	1069.21	1350.9	49.87	1301.03	3.69

Table 4
The availability of Total P, bioavailable P (B-P), organic P (Po), percent of P availability, and concentration of other P bioavailability determinants among irrigation schemes.

	Scheme	Al (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	B-P (mg/kg)	Total P (mg/Kg)	Po(mg/kg)	% P bioavailability
Mean	Chimala	182.19	482.61	324.08	183.49	5.98	170.43	164.45	3.51
	Igalako	320.96	1420.45	182.79	253.8	10.94	384.24	373.30	2.85
	Ihahi	188.54	1060.09	158.31	215.31	17.56	417.26	399.70	4.21
	Ilaji	277.06	422.47	248.68	180.66	4.97	354.35	349.38	1.40
	Isenyela	210.72	755.58	107.89	101.3	6.35	115.45	109.10	5.50
	Kapunga	346.16	785.38	190.58	232.22	7.55	349.69	342.14	2.16
	Mabadaga	201.95	2387.82	155.81	1031.78	1.66	172.88	171.22	0.96
	Mahangole	287.42	1126.13	154.62	291.24	13.87	374.96	361.09	3.70
	Mubuyuni	285.44	452.71	288.81	196.03	4.44	227.27	222.83	1.95
	Uturo	199.15	811.53	245.48	339.29	6.57	333.73	327.16	1.97
Maximum	Chimala	184.3	495.6	326.97	188.39	6.22	177.99	171.77	3.49
	Igalako	563.72	2467.91	235.18	296.31	22.10	536.11	514.01	4.12
	Ihahi	367.55	1627.17	289.54	409.1	49.87	790.72	740.85	6.31
	Ilaji	337.51	654.66	314.08	245.43	8.39	589.63	581.24	1.42
	Isenyela	222.35	762.25	111.38	101.86	6.93	138.07	131.14	5.02
	Kapunga	662.23	1481.94	321.6	334.16	21.50	1350.9	1329.40	1.59
	Mabadaga	214.83	2494.35	165.35	1069.21	1.86	203.47	201.61	0.91
	Mahangole	739.25	2010.72	197.24	445.81	40.32	814.33	774.01	4.95
	Mubuyuni	792.97	1558.84	470.59	707.26	15.89	435.11	419.22	3.65
	Uturo	312.28	1274.94	332.93	520.2	18.02	556.11	538.09	3.24

Ilaji (589.63 mg/kg), Uturo (556.11 mg/kg), Igalako (536.11 mg/kg), and Mubuyuni (435.11 mg/kg). The observed high concentration of TP in the mentioned schemes could be influenced by a high level of agricultural intensification and high use of phosphatic fertilizer observed in the area. But also, we found that schemes or land uses that had a high concentration of Al, Fe, Ca, and Mg was observed to have high TP (Table 4). This might be exacerbated by the high fixation and adsorption capacity of the soil in particular areas as these elements influence P adsorption and fixation in soils, limiting P for crop uptake and P loss to the environment (De Campos et al., 2018; Magnone et al., 2019; Muindi et al., 2015). This affects the availability of P to plants and the associated ecosystem. On the other hand, schemes such as Chimala (177.99 mg/kg), Isenyela (138.07 mg/kg), and Mabadaga (203.47 mg/kg) were observed to have low TP concentration in agricultural soils (Table 4). The same trend was observed to be in line with the concentration of Al, Ca, Fe, and Mg, where these schemes had a low concentration of the elements as mentioned earlier (Barrow, 2017a; Barrow et al., 2020; Kleinman, 2017). This indicates that low P fixation and adsorption can increase P availability for plant uptake and might allow more P to be lost to the environment leading to eutrophication as excess P in the environment is detrimental (Akpor and Muchie, 2011; De Villiers, 2007; Moss, 2008). We found that Al, Fe, Mg, and Ca affected the bioavailability of P in soils of Usangu agro-ecosystem. The study found that concentration of total P in different land uses were optimum (26-35 mg/kg) to high (36-45 mg/kg) such that if all were available for plant uptake there would be not need for P fertilization in the studied agro-ecosystem (Mallarino et al., 2013; Sims et al., 2002). However, total P does not directly reflect P for plant uptake as other amounts are bound and fixed in complex compounds or forms that are unaccessible by plant roots.

3.2. Soil Bioavailable P in Usangu agro-ecosystem

The concentration of easily available P for plant uptake in agricultural soils in the Usangu agro-ecosystem was determined by Mehlich 3 method (Kleinman and Sharpley, 2002; Mehlich, 1984; Nasukawa et al., 2019). The bioavailable P is the concentration of P that is available for plant uptake and other ecosystems and is easily lost to the environment if poorly handled. The determined bioavailable P concentration (B-P) in agricultural soils in the Usangu agro-ecosystem was 0.52 to 49.87 mg/kg (Table 3). The bioavailable P concentration (B-P) in agricultural soils was observed to vary among land use and irrigation schemes (Table 3 and 4). Among land use (maize, paddy and conserved areas), concentration of B-P determined were; Conserved areas (0.99-35.79 mg/kg), Maize farming area (15.20-40.32 mg/kg) and Paddy farming area (0.52-49.87 mg/kg). The analysis observed that mean concentration of B-P were very low in farming areas, especially in paddy farming areas (7.70 mg/kg) which have extensive agriculture which involves deep plowing and less incorporation of crop residues compared to maize farming areas (25.73 mg/kg) and conserved areas (13.49 mg/kg) where there is less disturbance in soil structures. As it was pointed out earlier in Section 3.1, high concentrations of Al, Fe, Ca, and Mg reduce the concentration of bioavailable P. The paddy farming areas had a higher concentration of Al (294.1 mg/kg), Ca (806.89 mg/kg), Fe (214.81 mg/kg), and Mg (238.59 mg/kg) (Table 3) which consequently impacted the concentration of available P. The concentration of Al, Fe, Ca, and Mg

Table 5
Correlation coefficient of concentration values of different elements to T-P and B-P in soils (mg/kg) from Usangu basin in Mbeya District-Tanzania.

	Al	Ca	Fe	Mg	B-P	T-P
Al	1					
Ca	0.35***	1				
Fe	0.34***	0.23**	1			
Mg	-0.04	0.45***	0.47***	1		
B-P	-0.37***	-0.18*	-0.06	-0.23**	1	
T-P	0.09	0.11	0.76***	0.28***	1.00***	1

The correlation with asterisk (*) are statistically significant at
* $P < .05$,
** $P < .01$,
*** $P < 0.001$.

was negatively correlated to bioavailable P (Table 5) because they increase the capacity of the soil to hold or fix P, making it unavailable for plant uptake (Barrow et al., 2020; Barrow and Debnath, 2015). The increased concentration of these metals is associated with fertilizer and other agrochemicals in farming areas. Therefore, land use will negatively influence the availability of P, which will cause low fertilizer returns due to increased P fixation (Mng'ong'o et al., 2021; Nunes et al., 2020; Zhang et al., 2021). The spatial distribution of bioavailable P in the Usangu agro-ecosystem was observed to vary significantly (Table 4). The study evidenced that some schemes had higher B-P concentrations such as Ihahi (49 mg/kg), Mahongole (40.32 mg/kg), Igalako (22.10 mg/kg), Kapunga (21.5 mg/kg), Mubuyuni (18.55 mg/kg), and Uturo (18.02 mg/kg) (Table 4). These values were observed to be optimal (26-35 mg/kg) to higher (36-45 mg/kg) for crop requirements in the area (Mallarino et al., 2013; Sims et al., 2002). However, other schemes recorded deficient bioavailable P in agricultural soils; this includes Chimala (6.22 mg/kg), Ilaji (8.39 mg/kg), Isenyela (6.93 mg/kg), and Mabadaga (1.86 mg/kg), these schemes were observed to be deficient in P requiring additional application of P fertilizer to accommodate plant growth. The study found that locations with high Fe and Al concentrations had a low concentration of bioavailable P due to high P fixation and sorption, indicating high Al and Fe concentration had a significant negative correlation with bioavailable P ($P<0.05$), which reduce P available for plant growth (Barrow, 2017a; Barrow et al., 2020; Kleinman, 2017). Based on the recommended level of bioavailable P in agricultural soils (Low:0-25 mg/kg, optimum:26-35 mg/kg, high: 36-45 mg/kg and very high: >46 mg/kg) (Mallarino et al., 2013); some sites were observed to have a low B-P concentration (<25 mg/kg) which affects crop growth and yield while other sites such as Mahaongole (40.32 mg/kg) and Ihahi (49.87 mg/kg) had very high B-P thus does not require additional P application to reduce production cost and loss to environment.

3.3. *Influence of Land Use on P Dynamics and Bioavailability*

The determination of P concentration in agricultural soils from different land use in the study area observed a significant variation in P present in soil samples to that available for plant uptake among land uses (Table 3 and 4). From the study, the total P (TP) and bioavailable P (B-P) were determined (Table 3 and 4). From TP and B-P the concentration of P, which was not available for plant uptake, which is either fixed or complexed by metals, was determined by subtracting B-P from TP. In this manuscript, this amount was termed as complexed P (Po). The comparison of TP and B-P in different land-use observed that Po was very high, indicating that B-P concentration compared to the TP was very low (Table 3 and 4). The determined TP and B-P concentration in three land-use were; Conserved areas (129.54-589.69 mg/kg for TP, 0.93-35.79 mg/kg for B-P), Paddy farming areas (63.12-1350.09 mg/kg for TP, 0.52-49.87 mg/kg for B-P), and Maize farming areas (353.26-668.46 mg/kg for TP, 15.20-40.32 mg/kg for B-P) (Table 3). The results show that despite the agricultural soils having high total P, it was observed to have deficient available P for plant uptake. Higher values of TP in paddy and maize farming areas and having very low bioavailable P (0.82-6.03% of the TP) indicate that paddy and maize farming activities negatively influence the availability of P in an agro-ecosystem. This was also reported by Nunes et al. (2020) and Zhang et al. (2021), who reported that conversion of natural land to agricultural land reduced the availability of P by exposing more P to adsorption surfaces in the soil which required the application of extra P to compensate for the fixed P, but also was pointed out that deep tillage harms the availability of P for plant uptake as it tends to increase the homogenization of the soil profile making the P easily leached and complexed to other forms which are not available for plant uptake (Nunes et al., 2020; Zhang et al., 2021). The tillage system used in the Usangu agro-ecosystem, especially in paddy farming, involves deep plowing (more than 30 cm) with thoroughly homogenization of the plow layer with little organic manure or crop residues addition. This activity allows the fast reaction of P to metal cations and loss to the environment; in return, what is left in the soil is tightly bound and less available for plant uptake. This is the situation observed in paddy farming areas in the study area where although the highest value of TP was observed in paddy farming areas; it is the paddy farming area that had higher Po (62.60-1301.03 mg/kg) and lower percent of bioavailable P (0.82-3.69%) compared to maize farming areas which had 4.30-6.03% of bioavailable P (Table 3), and conserved areas had a higher percentage of bioavailable P (0.72-6.07%). Thus, land-use change and tillage management significantly influence the bioavailability of P added from fertilizer and other materials in agricultural soils.

The spatial distribution of bioavailable P and percent bioavailability of P in agricultural soils were observed to vary significantly among schemes (Table 4). The general trend in percent of P bioavailability ranged from 0.91 to 6.31%; high bioavailability percent of B-P was observed in Ihahi (6.32%), Isenyela (5.02%), Mahongole (4.95%), and Igalako (4.12%). However, some schemes recorded a very low percent of B-P compared to determined TP, such as Ilaji (1.42%), Kapunga (1.59%), and Mabadaga (0.91%); this indicates that these schemes experience P deficient requiring addition of P from fertilizers and other materials.

Land-use change or conversion of natural land to agriculture significantly changes the chemistry of the soil, which is important in the bioavailability of P in agricultural soils (Barrow, 2017b; Barrow and Debnath, 2015; Sato, 2003; Van der Velde et al., 2014). In this study, we found that farming areas had a high concentration of Al, Ca, Fe, and Mg, which are likely to be introduced through fertilizer and other agrochemicals application (Bainbridge et al., 1995; Ballabio et al., 2018; Kleinman and Sharpley, 2002; Zhao et al., 2014). These elements are important adsorbents of P in surface soils that means increased concentration will complex P to forms that are not easily available for plant uptake, hence increasing the legacy P, which usually increases the production cost and P loss to the environment through soil erosion. Furthermore, we found a significant positive correlation between Al, Fe, Ca, Mg with TP (Table 5). At the same time, it was reverse in B-P, which means increased concentration of Al, Fe, Ca, and Mg increased the concentration of TP but limited the concentration of B-P in agriculture soils. Thus, land-use changes or conversion of natural land to farming areas associated with deep tillage and homogenization are likely to affect P's bioavailability from fertilizer and other fertilizing materials. It is essential to consider the use of slow P releasing fertilizer such as sulphur coated urea and reduced tillage to ensure a maximum bioavailable P for plant uptake and reduce the legacy P because it increases the production cost and poses a risk to the environment, especially if the area is prone to soil erosion which is a case in many areas of Usangu basin.

4. Conclusion

As arable land is decreasing, fertilization has become an option to increase crop productivity. However, sustainable management strategies to ensure the high bioavailability of phosphorus (P) for plant uptakes are paramount. Conversion of natural land to agriculture afffect natural nutrient cycle and soil conservation mechanisms. Thus conversion of natural land to other land uses should be treated carefully because instead of increasing land productivity, it might be a source of complicated interaction for reduced crop production and environmental contaminations. In this study, it is evidenced that land use in the Usangu agro-ecosystem directly influences the bioavailability of important plant nutrients such as phosphorus in agricultural soils by changing the nutrients cycles and soil chemistry. The estimated total P and bioavailable P in different land-use indicate that some area is experiencing P deficient because of high fixations and adsorption. Therefore, it is crucial to split apply fertilizer or minimize tillage to ensure high P availability for better crop growth and reduce legacy P and P loss to the environment. This study creates and provides awareness that land-use change and associated management can influence phosphate bioavailability in agricultural soils for plant uptake and increase P fixation leading to legacy P, which can be a source of P loss to the environment leading to eutrophication, especially in areas prone to soil erosion and strong surface runoffs like Usangu agro-ecosystem.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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