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Enhancement of phosphorus utilization and availability in the mountainous region of Man, Côte d'Ivoire

Odon Clément Ncho[*1], **Konan-Kan Hippolyte Kouadio**[2], **Gnamba Emmanuel Franck Gouedji**[1], **Dekape Josiane Karamo**[1], **Nkiruka Celestina Odoh**[3]

[1]*Département de Géologie et Matériaux, Université de Man, Côte d'Ivoire*

[2]*Département STRM, Université Félix Houphouët, Boigny, Côte d'Ivoire*

[3]*Federal University of Abuja, Nigeria*

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Abstract

The soil has a large reserve of phosphorus. However, phosphorus availability for plant nutrition is limited, and mostly in ferralitic tropical soils, determined by the geochemical distribution of elements. In the mountainous region of Man, West Côte d'Ivoire, the geology and geomorphology constitute a particular characteristic which, more or less, could significantly influence soil phosphorus distribution and availability. A study was thus setup to assess soil oxides and mineralogy, and their influence on soil phosphorous content in Man. Four different rice producing sites were selected for soil sampling; Krikouma, Dompleu, Blolé and Petit-Gbêpleu (PG). Within each site, three composite samples were taken at 0 - 20cm depth from 3 plot of 25m², each. The results of the X-ray fluorescence analysis showed the presence of large quantities of iron and aluminium oxides in the soil. In addition, these soils were rich in SiO_2. The mineralogical matrix had two dominant mineral species Berlinite and Quartz, dividing the soils into two categories. This study provides scientific base for developing strategies for a sustainable phosphorous fertilization of rice cropping soils.

* **Corresponding Author:** Odon Clément Ncho ✉ ncho_oc@yahoo.fr

Introduction

Many tropical soils are characterized by high fragility relatively to their fertility, specifically. Among the major factors that constrain tropical soil fertility and sustainable agriculture are high acidity, moisture stress, erosion, low soil biodiversity and low nutrient capital (Cardoso *et al.*, 2009). Nutrient deficiency in soil solution perturbs crop growth and results, generally, in low crop yield. Consequently, the tropical of sub-Saharan Africa constitutes the region at greatest food security risk of the world (van Ittersum *et al.*, 2016).

Improving of soil nutrient availability implies organic and inorganic fertilizers application. Due to their financial limitation, smallholder farmers mostly use either urea (N) or the composed macronutrients fertilizer (N, P and K) in cropping systems. Fertilizer consumption is, globally, averaging 14 kg/ha and surpassing 50 kg/ha in some countries of sub-Saharan Africa (Nziguheba *et al.*, 2021).

Macronutrients are soil mineral elements that are consumed by plants in large quantities for their growth, good health and productivity. Unlike some macronutrients such as C and N, phosphorus is scarce and ranked eleventh element in the lithosphere and thirteenth in seawater in the terrestrial system.

Soil P amount is evaluated to 40 - 50Mt present in two forms: inorganic (35 - 40Mt) and organic (5 - 10Mt) sources (Smil, 2000). The essential soil phosphorus is stocked in the top 50cm mostly in inorganic form, over 90%, and constitutes the largest phosphorus stock in the terrestrial system. The main source of phosphorous is apatite (calcium phosphate). Principally present in the sand and silt fractions, apatite constitutes 95% of the 0.1% of the Earth's crust, with three forms: fluorapatite [$Ca_{10}(PO_4)_6F_2$], hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$], and chlorapatite [$Ca_{10}(PO_4)_6Cl_2$]. However, soil phosphorous is not readily available for plant nutrition. In fact, phosphorous availability in soil solution is influenced by some factors like organic matter, soil pH, temperature, moisture, aeration, clay content and mineralogy (Taglieri *et al.*, 2020).

Soil clay content and mineralogy play an important role in soil inorganic P pool. Soil P interact strongly with the solid phase and various secondary minerals. Indeed, soils with higher clay content have high phosphorus retention capacity because of their very large specific surface (Batjes, 2011). Equally, soil with high content of Al^{3+}, Fe^{3+}, Ca^{2+} and Mg^{2+} tend to have the greatest phosphorus adsorption capacity (Giroux *et al.,* 1996). In the longer term, the precipitation of phosphorus and its crystallization in poorly soluble mineralogical forms (varicite, strengite and apatite) complete the retroversion of phosphates (Sample *et al.*, 1980).

In sub-Saharan Africa, where soils are highly weathered and nutrient-poor, phosphorus management remains difficult and uncontrollable (Sanchez, 2019). The abundance of iron and aluminium oxides, combined with the acidic pH of many tropical soils, greatly contributes to explain the limiting nature of P in these soils (Hinsinger, 2001). Indeed, in acidic soils, P can be dominantly adsorbed by Al/Fe oxides and hydroxides, such as gibbsite, haematite, and goethite (Peña and Torrent, 1990). The forms of phosphorus most readily accessed by plants are orthophosphate ions ($H_2PO_4^-$, HPO_4^{2-}) whose availability also depends on soil pH.

Phosphorus applied to soils is however involved in a multitude of complex reactions that remove it from the solution and incorporate it into a large variety of much less soluble, or insoluble, labile and stabile compounds (Smil, 2000). Therefore, ions phosphates are less mobile in the soil due to many processes which contribute to their retention, and become very low in soil solution.

Mostly, farmers are advised, for each agroecological zone, to apply standard rates of fertilizers with regard to the crops, while edaphic characteristics vary from one point to another (Freese *et al.*, 1992; N'cho *et al.*, 2020). Consequently, attributes related to soil phosphorus sorption capacity are less considered. The most intriguing question has been to find out the amount of P that is irreversibly fixed by soil particles soon after application and the amount of P that could become eventually available to subsequent crops (Smil, 2000).

Despite the increase in yearly phosphorus fertilizer use (Sattari *et al.*, 2012), P bio-availability remain highly problematic for sustainable crop production in SSA. Therefore, the study was setup to assess soil oxides and mineralogy, and their influence on soil phosphorous content in Man.

Materials and methods

Study area

Soil samplings were conducted around Man town, located in West Côte d'Ivoire. Four sites of smallholder farmers located respectively in Krikouma, Dompleu, Blolé and one experimental site at Petit-Gbêpleu (PG) were selected as study area (Fig. 1). These sites were used by the farmers to cultivate pluvial rice.

Soil sampling

Manual soil auger was used to collect soil samples at a depth of 0 to 20cm. It was then carefully removed to conserve the soil. The soil sample was then collected on plastic paper and transferred to a previously identified plastic bag. On each plot measuring an area of 5 x 5 m^2, two samples were taken to form a composite sample representative of the plot.

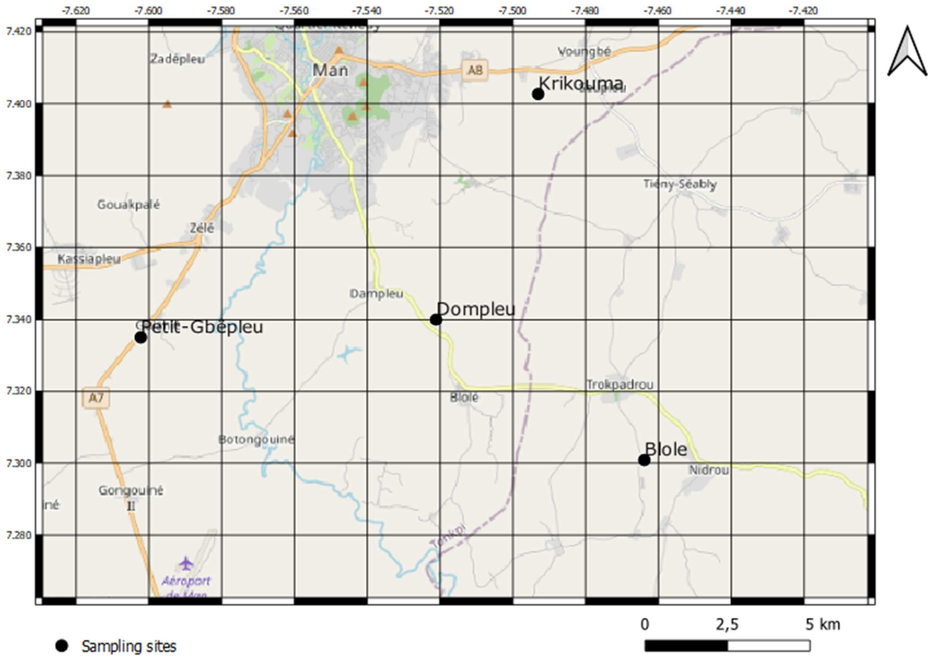

Fig. 1. Sampling sites.

The studied sites were those which had received phosphorus fertilizer application during the previous campaign, cropping season of 2019 - 2020. The second selection criterion was the distance between the sites. Based on this last criterion, four sites were selected. Finally, the last criterion was the types of fertilizers applied. For this purpose, on each site, three plots were chosen: - control, without phosphorus input; - the plot having received the phosphate rock; - the plot having received NPK 15-15-15 fertilizer (Nitrogen 15%, Phosphorus 15%, Potassium 15%). The samples were taken at the beginning of the 2021 cropping season.

Soil elemental analysis

The geochemical analysis consisted in determining the content of chemical elements existing in the various soil samples using X-ray fluorescence (XRF) (Pulungan and Sartohadi, 2018). It identified and determined most of the chemical elements that made up the samples. Then, these elements were used to determine these major soil (hydroxy) oxides: SiO_2, $A1_2O_3$, Fe_2O, P_2O_5, CaO and K_2O. The analyses of these soils were carried out at the Geology Laboratory of the University of Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire.

Mineralogical analysis

The X-ray diffraction (XRD) was run to classify and identify the different crystalline phases in the samples. These analyses were carried out at the Geological Laboratory of the University of Man with the GBC-Emma brand device. The measurement conditions for performing the analyses were as follows: 20 kV voltage, 28 mA current intensity, and 25 °C as temperature in the measurement chamber. The wavelength used for X-radiation was λ = 1.78897Å. The device's detection limit was approximately 3 %. The angular resolution in 2 Theta was 0.036 and the counting field was between 2 and 75°.

Statistical analysis

The data collected was analysed with the Minitab 17 statistical software. One-way analysis of variance (ANOVA) and pairwise means comparisons was run using the Fisher LSD Method at significance level $\alpha = 0{,}05$. Pearson correlation was run to describe the relationship among soil oxides and pH. A multivariate analysis was at the end conducted to cluster the soils based on their similarity using the major soils oxides and pH.

Results and discussion

Treatments' effects on soil phosphorous

The application effect of NPK and RP fertilizers on the contents of P_2O_5 was not significant ($P = 0.896$). The means values were 0.83 wt% for the control, 0.84 wt% for phosphate rock and 0.93 wt% for NPK treatment.

Soil acidity

The study covered the surface (0 - 20cm) of four smallholder farmers' rice cultivated sites. The soils were acidic with pH_{H_2O} varied from 5.15 to 5.49 and pH_{KCl} from 4.22 to 4.39, showing that these soils are strongly acid (USDA, 2022). The ANOVA did not show significant differences between the soils (Table 1).

Table 1. Acidity level and oxides content of the studied soils.

Sites	Soil oxides			Soil chemical measured as oxides			Acidity	
	Fe_2O_3	Al_2O_3	SiO_2	CaO	K_2O	P_2O_5	pH_{H_2O}	pH_{KCl}
Blolé	2.75 b	7.09 a	31.31 c	0.16 b	0.11 c	0.56 b	5.15 a	4.28 a
Dompleu	2.12 c	4.17 c	46.97 a	0.15 b	0.30 b	1.23 a	5.49 a	4.22 a
Krikouma	5.00 a	5.49 b	30.56 c	0.22 a	0.14 bc	1.03 a	5.41 a	4.39 a
Petit-Gbêpleu	0.42 d	4.27 c	43.14b	0.16 b	1.77 a	0.06 b	5.47 a	4.32 a
P	< 0.000	< 0.001	<0.000	<0.024	<0.000	<0.001	0.185	0.440

Means that do not share a letter are significantly different.

Spatial distribution of soil oxides

The geochemical analysis revealed a strong dominant content of silicon oxide (SiO_2) in all four soils varying from 30.56 to 46.97 wt%, respectively at Krikouman and Petit-Gbêpleu. This content was followed by that of aluminum oxide (Al_2O_3) which was 7.09 in Blolé, and 4.17 in Dompleu. Fe_2O_3 had the highest content following those of SiO_2 and Al_2O_3 except at Petit-Gbêpleu site where the K_2O content was arithmetically higher than that of Fe_2O_3. This trend was also observed by Obasi (2015) in their geochemical study.

The analysis of iron oxide, Fe_2O_3, showed significant variation between sampling site ($P < 0.000$). From the analysis, the highest mean of Fe_2O_3 was observed in Krikouma soil with 5.00 wt%. The soils of Petit-Gbêpleu (PG) showed the least content of iron oxide with 0.42 wt% (Table 1).

Concerning Al_2O_3 content, the analysis of variance showed that there was a significant variation between the sampling sites ($P < 0.001$). Dompleu soils had the lowest content of Al_2O_3 of 4.17 wt% while Blolé soil showed the highest content of Al_2O_3 (Table 1).

The SiO_2 content was significantly higher in Dompleu soils with 46.97 wt% and lower 30.56 wt% in Krikouma. The results from this geochemical analysis of Fe_2O_3, Al_2O_3 and SiO_2 revealed significant variation of soil oxides content from one farmer field to another. As well, differences in individual soil oxides content were found by some research activities (Barrón and Torrent, 2013; Suda and Makino, 2016).

These variations could be due to the nature of parental material, but also to the pedogenic processes; microclimate is the 'on-the-ground' climate that influences small areas of soil (Singer, 2015).

Spatial distribution of phosphorous, calcium and potassium

Soil Ca, P and K were measured as CaO, P_2O_5 and K_2O, respectively. The results of the analysis showed significant differences among sampling sites (Tableau 1). Calcium monoxide (CaO) content varied from 0.15 % in Dompleu to 0.22 % in Krikouma. The highest content of K_2O was obtained at Petit-Gbêpleu with 1.77% while the lowest was observed in Blolé. Concerning P_2O_5 content, it varied significantly from 0.56 % in Blolé to 1.23% in Dompleu. Spatial distribution of soil CaO, P_2O_5 and K_2O are parent material-related (Obasi, 2015).

Correlation analysis

The correlation analysis showed that SiO_2 had a strong negative correlation with Fe_2O_3 and Al_2O_3 on one side and, on the other side CaO had a significant positive correlation with Fe_2O_3 and pH_{KCl}. However, P_2O_5 was not correlated with any of the five major oxides and pH (Table 2).

Table 2. Relationship between soils oxides and pH from the studied sites.

	Fe_2O_3	CaO	K_2O	Al_2O_3	P_2O_5	SiO_2	pH_{eau}
CaO	**0.589***						
K_2O	**-0.774****	-0.201					
Al_2O_3	0.459	0.091	-0.493				
P_2O_5	0.349	0.043	-0.356	-0.437			
SiO_2	**-0.703***	**-0.529**	0.490	**-0.759****	0.369		
pH_{eau}	-0.197	0.180	0.270	**-0.683**	0.408	0.452	
pH_{KCl}	0.174	**0.784****	0.048	-0.047	-0.122	-0.283	0.475

The role of calcium oxide in pH_{KCl} increase has been already demonstrated (Wyszkowski and Radziemska, 2011). In fact, these authors by adding calcium oxide to the soil increase the pH_{KCl}. The results from this study confirmed the importance of the presence of CaO in pH_{KCl} increase, which reduces soil acidity.

Total phosphorus and P availability are highly related to soil weathering level. Soils containing high amounts of iron and aluminium oxides or amorphous aluminosilicate clays, react strongly with P, making it almost unavailable for plant uptake. As it was observed from the analysis, the soil showed high content of Fe_2O_3 and Al_2O_3. However, P_2O_5 did not correlate with any of them (Fe_2O_3 and Al_2O_3). This observation could be due to the mineral species present in the soils (Ulén and S. Snäll, 2007; Taglieri *et al.*, 2020).

Clustering analysis

The results of the clustering analysis using the major soil oxides and pH showed that the four soils could be grouped into two, relatively to their similarity at 60%; the first group was formed by Blolé and Krikouma soils and the second was constituted by Petit-Gbêpleu and Dompleu soils (Fig. 2).

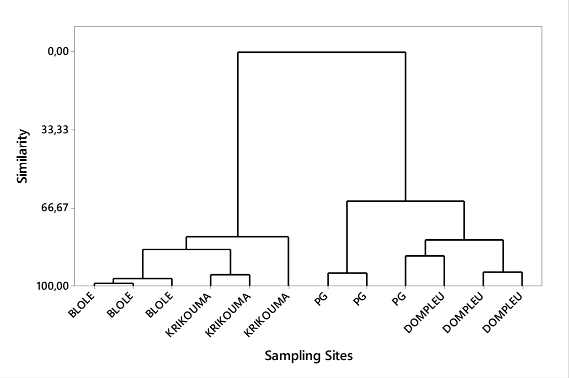

Fig. 2. soil grouping analysis result.

Soil mineralogy

The mineralogical composition of the soils from the different plots studied essentially reveals the presence of phosphate minerals (copper hypophosphite (II), anhydrous aluminium phosphate (Berlinite $AlPO_4$), Trirubidium molybdo-phosphate, aluminium metaphosphate ($Al(PO_3)_3$) and Gallium phosphate ($GaPO_4$) (Fig. 3). This result collaborated with the fact that soils naturally contain important quantity of total phosphorus (P) within the 20 first **(**Hinsinger *et al.*, 2017**).** The presence of Berlinite confirmed the fact that the soils were highly weathered and acidic (Pierzynski *et al.*, 2005).

Berlinite is one of the major Inorganic P-containing compounds in soils. Two of the sites (Blolé and Dompleu) had Berlinite as dominant mineral species, while Krikouma and Petit-Gêpleu had Quartz as dominant mineral species. This confirmed, not only, important heterogeneity among the soils, but also, somehow, relationship among these soils as revealed in the clustering result of the soils.

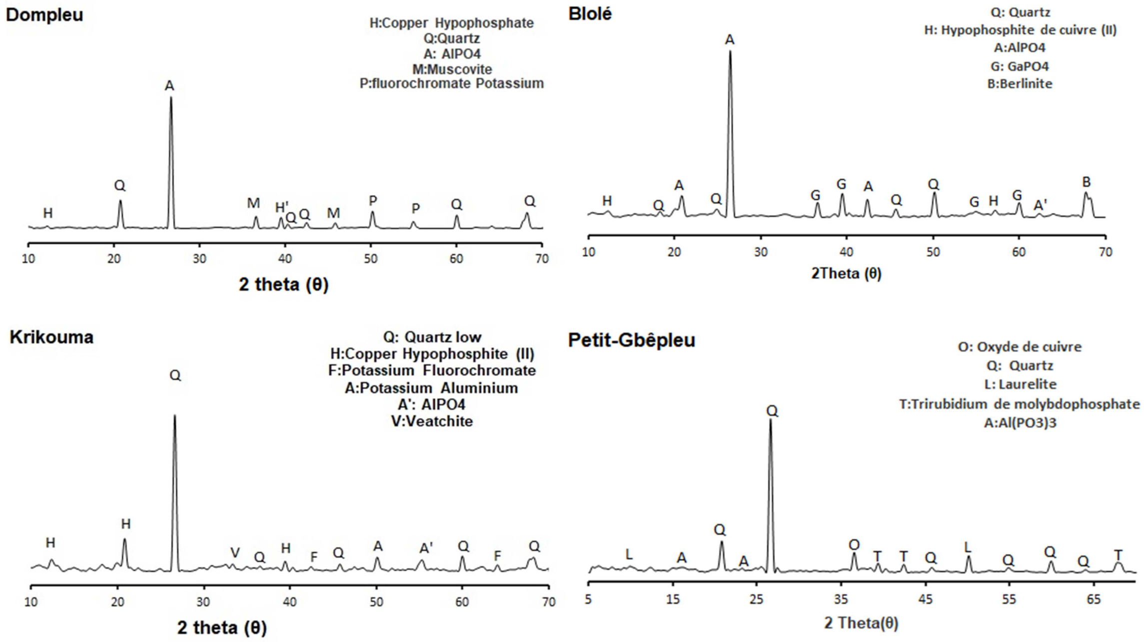

Fig. 3. Soil mineralogical content of studied sites.

Since Berlinite is a mineral species which is highly stable, quite insoluble, use of alternative method such as microbial inoculation like mycorrhiza (Liu *et al.*, 2008) and *Aspergillus niger* (Castro *et al.*, 2020) could be very important to make phosphorous available for plants use.

Conclusion

This study showed the importance of individualizing the nature and application rates of P in western Côte d'Ivoire, due to the varied levels of soils acidity, oxides and mineralogy. As available and total P depend also on these two factors, farmers and actors involved in agriculture, mainly in agroecology should take them into account to sustain soil productivity and environmental values. Further studies are also needed to profile the application of P relatively to soils properties.

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References

Barrón V, Torrent J. 2013. Iron, manganese and aluminium oxides and oxyhydroxides. Eur. Mineral. Union Notes Mineral **14,** 297-336.

Batjes NH. 2011. Global distribution of soil phosphorus retention potential. ISRIC Report 2011/06, Wageningen.

Cardoso JD, Gomes DF, Goes KCGP, Fonseca NS, Dorigo Junior OF, Hungria M, Andrade DS. 2009. Relationship between total nodulation and nodulation at the root crown of peanut, soybean and common bean plants. Soil Biology & Biochemistry **41,** 1760-1763.

Castro L, Blázquez ML, González F, Muñoz JM. 2020. Bioleaching of phosphate minerals using *Aspergillus niger*: Recovery of copper and rare earth elements. Metals **10(978).** doi:10.3390/met1007097

Freese D, van der Zee SEATM, van Riemsdijk WH. 1992. Comparison of different models for phosphate sorption as a function of the iron and aluminium oxides of soils. Journal of Soil Science **43,** 729-738.

Giroux M, Bernier D, Emond C. 1996. Utilisation agronomique et environnementale judicieuse des engrais phosphatés selon les caractéristiques des sols et des engrais. Colloque sur la fertilisation intégrée des sols, CPVQ inc., p. 49-64

Hinsinger P, Ndour Y, Becquer T, Chapuis-Lardy L, Masse D. 2017. Les enjeux liés au phosphore dans les sols tropicaux. In : E. Roose Ed. Restauration de la productivité des sols tropicaux et méditerranéens : contribution à l'agroécologie, IRD Edition, pp. 329-34.

Hinsinger P. 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant Soil **237,** 173-195. https://doi.org/10.1007/BF01073433

Liu JF, Xia RX, Wang M, Wang P, Ran QQ, Luo Y. 2008. Effects of inoculation with arbuscular mycorrhizal fungi on AIPO4 uptake by *Poncirus trifoliata*". Ying Yong Sheng Tai Xue Bao **19(10),** 2155-60. Chinese. PMID: 19123349.

N'cho CO, Ama-Abina JT, Odoh NC, Yusuf AA. 2020. Successful use of biofertilizers in sub-Saharan Africa: how soil fertility level constitutes its first step. Afrique SCIENCE **17(5),** 220 - 228.

Nziguheba G, van Heerwaarden J, Vanlauwe B. 2021. Quantifying the prevalence of (non)-response to fertilizers in sub-Saharan Africa using on-farm trial data. Nutr Cycl Agroecosyst **121,** 257-269. https://doi.org/10.1007/s10705-021-10174-1

Obasi RA. 2015. Geochemical provenance study and classification of the Agbabu soil, Ondo State, South Western Nigeria). Journal of Multidisciplinary Engineering Science and Technology **2(12),** 3420 - 3426.

Peña F, Torrent J. 1990. Predicting phosphate sorption in soils of mediterranean regions. Fertilizer Research **23,** 173-179.

Pierzynski GM, Vance GF, Sims JT. 2005. Soils and environmental quality. CRC Press, 584 p.

Pulungan NA, Sartohadi J. 2018. New approach to soil formation in the transitional landscape zone: weathering and alteration of parent rocks. Journal of Environments **5(1),** pp. 1-7.

Sample EC, Soper RJ, Racz GJ. 1980. Reactions of phosphate fertilizers in soils, In: Khasawneh FE, Sample EC, Kamprath EJ Eds. The Role of Phosphorus in Agriculture. ASA-CSSA-SSSA, Madison, WI, p. 263 - 310.

Sanchez P. 2019. Phosphorus. In: Sanchez P. Ed. Properties and management of soils in the tropics, 2nd Ed. Cambridge: Cambridge University Press. pp. 370 - 414. DOI:10.1017/9781316809785.016

Sattari SZ, Bouwman AF, Giller KE. Van Ittersum MK. 2012. Residual soil phosphorus as the missing piece in the global phosphorus crisis puzzle. Proceedings of the National Academy of Sciences of the United States of America **109(16),** 6348-6353.

Singer MJ. 2015. Basic Principles of Pedology. Reference Module in Earth Systems and Environmental Sciences, Elsevier. https://doi.org/ 10.1016 /B978-0-12-409548-9.09290-3

Smil V. 2000. Phosphorus in the environment: Natural flows and human interferences. Annu. Rev. Energy Environ. **25,** 53-88.

Suda A, Makino T. 2016. Functional effects of manganese and iron oxides on the dynamics of trace elements in soils with a special focus on arsenic and cadmium: a review. Geoderma **270,** 68-75.

Taglieri P, Milham P, Holford P, Morrison RJ. 2020. A methodology to estimate net proton: phosphorus co-adsorption ratios for acidic soils. Advances in Chemical Research **2(2).** DOI: 10.21926 /acr.2002005

Ulén B, Snäll S. 2007. Forms and retention of phosphorus in an illite-clay soil profile with a history of fertilisation with pig manure and mineral fertilisers. Geoderma **137,** 455-465.

USDA. 2022. Soil Quality Indicators: pH. USDA Natural Resources Conservation Service, 2p, 1998. [online] Available: March 2022 https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052208.pdf (February 21, 2022)

Van Ittersum MK, van Bussel LG, Wolf J, Grassini P, van Wart J, Guilpart N. 2016. Can sub-Saharan Africa feed itself?. Proceedings of the National Academy of Sciences **113,** 14964-9.

Wyszkowski M, Radziemska M. 2011. Effect of some substances on content of selected components in soils contaminated with chromium. Ecological chemistry and engineering A **18(11),** 1497-1504.