

Relationship between phosphorus fractions of some selected Sudanese soil orders to phosphate availability

Abdel Wahab Ahmed Mohamed Ahmed, Mohammed Abdalla Elsheikh *,
Yousif El Gorashi El Mahi

Department of Soil and Environment Sciences, Faculty of Agriculture, University of Khartoum Shambat, Sudan

Abstract

A laboratory experiment was conducted to determine the extent and the importance of phosphorus (P) fractions of some agriculturally important Sudanese soils on P availability. The soils were gathered from different locations in Sudan, to represent three different orders: Aridisols (Um Dum soil, North Kordofan state), Alfisols (Hagu soil, Senar state), and Vertisols (Hosh soil, Gezira state). The soil P was fractionated using an authenticated procedure. The results showed that the soils had low total, organic and available P contents. Most of the inorganic soil P was present in the Fe-Al fraction in Um Dum soil (> 50%), and about 40% of this fraction in Hagu soil, but, only 20% in alkaline Hosh soil. The Ca-P fraction constituted > 60% in Hosh soil, about 40% in Hagu soil and 20 % in Um Dum soil. The available P in the top soils studied was positively related to the percent sum of Al+Fe -P of the total P, and was negatively related to the percent Ca-P fraction content of the total P. It has been proposed that the P sorption starts by exchange with singly coordinate Fe or Al- OH clay (OH⁻ edge group) and quickly reorganizes into more stable and less soluble ring forms especially at pH more than 7.0, Alkaline pH more than 8.0 in soil like Hosh, will in presence of Ca, favour with time, the formation of inactive less soluble form like octacalcium phosphates and apatites at expense of the initial Al and Fe-P forms which are less stable at alkaline pH.

Keywords: Phosphorus forms, total phosphorus, organic phosphorus, inorganic phosphorus, available soil phosphorus, Sudanese soils.

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Introduction

Phosphorus is an important element for all living organisms and, second to nitrogen as a limiting factor in plant growth and production (Arai and Sparks, 2007). The main P source is phosphate rocks, which are non-renewable. Consequently, it is high time to undertake new strategies to use P efficiently to conserve available P in soil. There are many factors that contribute to make plant available P below demand for optimum crops production such as very low total P in soil, the human activities causing imbalance between inputs and outputs of P nutrient in soil, precipitation of P with calcium (Ca), iron (Fe), and aluminum (Al), and adsorption of P in soil (Hunt et al., 2007; Melese et al., 2015). These factors become serious, especially in soils of inherently low P status. The Sudanese soils, similar to many agricultural soils of the world, are generally deficient in the amount of soil P. Although, several authors have reported independently that Sudanese agricultural soils are deficient in P, fertilizer experiments, conducted under Sudan soil condition, have shown erratic response of crops to the application of P, with few exceptions (Elsheikh et al., 2007; Abuswar and Omer, 2011). Plants take up P from the soil solution, which is replenished by various insoluble

* Corresponding author.

Department of Soil and Environment Sciences, Faculty of Agriculture, University of Khartoum Shambat, Khartoum North 13314 Sudan

Tel.: +249 907199250

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E-mail address: mohmedelsheikh@gmail.com

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P pools in the soil (Mengel and Kirkby, 2001). Thus, knowledge and information about the different P pools are useful parameters to assessing P available to plant and can be helpful to provide proper management of fertilizer, leading to increase in P use-efficiency in the soil-plant system (Mostashari et al., 2008; Halajnia et al., 2009). Extensive research has been conducted on the subject worldwide, whereas, there is a paucity of studies on P status of most tropical soils and indeed Sudanese soils. Therefore, the objective of this research was to characterize the extent of P in different P fractions of some major Sudanese soil orders and their impact on P availability.

Material and Methods

Soil materials

The study was conducted on three Sudanese soils, gathered from different locations that represent the main dominant soil orders, having different physical and chemical characteristics. These soils belong to three major orders: Aridisols (Um Dum soil, North Kordofan state), Alfisols (Hagu soil, Senar state), and Vertisols (Hosh soil, Gezira state). Some physical and chemical properties of these soils were presented in Table 1. Particle size distribution was measured by pipette international method. Other soil properties were determined according to the procedures of Estefan et al. (2013).

Table 1. Characteristics of three Sudanese soils studied

Depth		Soils					
		Um Dum		Hagu		Hosh	
		Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface
Saturation, %		25.10	22.50	49.30	48.00	62.50	66.70
pH		7.10	7.00	7.90	7.80	8.20	8.20
ES, dS m ⁻¹		0.80	0.70	1.15	1.25	1.00	2.00
Soluble cation, me/l	Ca ²⁺	5.00	6.00	6.00	6.00	1.00	1.00
	Mg ²⁺	2.00	4.00	2.00	3.00	2.00	4.00
	Na ⁺	0.87	1.74	9.57	6.70	9.57	20.00
	CO ₃ ²⁻	0.75	0.25	1.00	1.00	1.00	0.75
Soluble anion, me/l	HCO ₃ ²⁻	4.00	4.50	5.25	9.00	6.25	6.75
	Cl ⁻	3.50	3.50	6.25	6.50	5.25	7.00
	Coarse sand, %	0.45	0.40	17.5	18.20	4.90	3.20
Particle size distribution	Fine sand, %	90.10	90.30	31.10	32.70	15.20	18.60
	Silt, %	1.36	1.30	9.50	9.10	24.90	22.20
	Clay, %	8.00	8.00	40.00	42.00	50.00	56.00
	CEC, cmol _c kg ⁻¹	5.40	6.00	33.70	36.20	56.50	60.40
CaCO ₃ , %	0.20	0.22	1.10	0.94	2.00	2.00	

Phosphorus fraction

The procedure of Chang and Jackson (1957) as modified by Petersen and Corey (1966) was used for determination of different forms of phosphorus. Saloid P was extracted by NH₄Cl and Al-P by 0.5M NH₄F. The letter was followed by extraction of Fe-P using 0.1 M NaOH, saturated NaCl plus a few drops of concentrated H₂SO₄. Occluded P was extracted by 0.1M NaOH and Ca-P by 0.25M H₂SO₄. Residual P was extracted by a mixture of HNO₃, HCl and H₂O. Organic P was determined by the ignition method of Legg and Black (1955). Reductant soluble P was estimated as the difference between total P and the sum of the organic P and inorganic P fractions. Available soil phosphorus was extracted by NaHCO₃ according to the procedures of (Olsen et al., 1954).

Results and Discussion

Total P

The surface soils under study varied in their total P amounts, which were: 537.0, 299.0 and 165.0 mg kg⁻¹, for Hosh, Hago and Um Dum respectively; the amount of subsurface P were 595.5, 279.5 and 169.0 mg kg⁻¹ (Table 2). The soils under study could be classified according to their total P concentrations: Hosh >Hago >Um Dum, similar to order of percentage clay contents. The total phosphorus contents of normal soils vary from 100 to 2000 mg kg⁻¹ (Kabata-Pendias and Pendias, 1992). The studied soils can be classified according to Tripathi et al., (1970) as low in P (<600 mg kg⁻¹). Because total P is an inherent property of soils, the generally low total P values in studied soils could be related to the nature of the parent material. Soil P occurs in inorganic and organic forms and their relative distribution varies with climate, vegetation, parent material and soil management practices.

Table 2. Total, organic, inorganic and NaHCO₃ extractable phosphorus

Soil	Total		Organic		Inorganic		NaHCO ₃ extractable P	
	Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface
Um Dum	165.00	169.00	9.50	7.25	155.50	161.75	5.30	3.10
Hagu	299.00	279.50	38.25	37.50	260.75	242.00	3.25	3.50
Hosh	537.00	595.50	30.00	27.00	507.00	568.50	2.50	2.75

Organic P

As shown in Table 2 the organic P for Um Dum soil are 9.5 and 7.5, for Hago soil are 38.3 and 37.5, whereas, for Hosh soil are 37.5 and 27.0 mg kg⁻¹ for the top soil and subsurface, respectively. This amount consists of 5.6% – 4.4%, 12.8% – 13.4% and 5.6%–4.5 % of the total P of Um Dum, Hago and Hosh for the top and subsurface soil, respectively. The three soils were low in soil organic P values and these findings were expected as the organic matter is very low. In general, organic P content decreased with depth, as shown in Table 2. Under tropical conditions, organic P is readily mineralized into inorganic P (Tisdale and Nelson, 1995) and can thus be an important additional P source to plants.

Inorganic P

The amounts of inorganic P for top soil and subsurface were 155.5-161.7, 260.7-242.0 and 507.0-568.0 mg kg⁻¹ for Um Dum, Hago, and Hosh, respectively (Table 2). This amount consists of 93.8-95.7, 87.2-86.6 and 94.4-95.5 percent of total P for top and subsurface soils for Um Dum, Hago and Hosh, respectively. According to Thomas and Peaslee (1973) there are three forms of inorganic P, the first is most available (precipitated) or chemisorbed on surface, and the second is somewhat available discrete particle (Ca-P, Al-P, Fe-P and Fe, Al-P) and the third is little available (occluded Ca-P in CaCO₃ or silica, occluded Al -P and Fe-P in iron oxides and redundant soluble Fe P occluded in Fe Oxides).

The large amount of the second form of the somewhat available discrete particle inorganic P forms, is a sign of high chemical weathering of the soils (Chang and Jackson, 1957). The form is called by many workers including Thomas and Peaslee (1973) as the active P forms which is the major sources of available P. It amounts to 81.0, 80.0, and 87.0% of total P of Um Dum, Hago, and Hosh, respectively, for topsoil, whereas it is 83.0, 71.0, and 87.0 % for subsurface of the three soils, respectively. The somewhat available discrete particle, constituted to 87.0, 86.0, and 92.0 % of the total inorganic P in the three of top soils, respectively, whereas, it is about 87.0, 82.0, and 92.0 % in sub-surface soil of the three soils, respectively. The somewhat available discrete particle P form, in Um Dum soil, in both top soil and subsurface soil was about 30% of total inorganic P, present as Fe-P, followed by Ca-P and then Al-P (Table 3). For both Hago and Hosh soils, most of inorganic P was present as Ca-P, followed by Fe-P, and then Al-P. Similar results were found (Uriyo and Kasseba, 1973; Udo and Ogunwale, 1977). Some of the inorganic P may be present in the lattices of silicate minerals and as inclusions in minerals, e.g., in quartz crystals (Black, 1968). The largest form of inorganic P in Hosh soil may be predominantly some form of the mineral apatite, perhaps most commonly calcium hydroxy or fluorapatite (Larsen, 1967). This means that most of the soil P may be in an unavailable form which the plants cannot use. Only the somewhat available discrete particle is generally accepted to be the main source of available inorganic P for plants (Thomas and Peaslee, 1973). The content of the three somewhat available discrete particles P forms varied among soil orders, reflecting the effect of different climatic and geographical conditions in which they were formed.

Table 3. Phosphorus inorganic fractions of three Sudanese soils

Parameters	Soil					
	Um Dum		Hagu		Hosh	
	Topsoil	Subsurface	Topsoil	Subsurface	Topsoil	Subsurface
Saloid P	5.00	3.50	0.00	0.00	0.00	0.00
Al-P	35.00	30.00	49.25	43.75	45.50	61.25
Fe-P	52.80	61.25	52.5	47.25	50.00	52.50
OcclFe-P	8.00	9.00	20.00	20.00	19.00	21.00
OcclAl-P	7.50	7.50	16.50	22.50	17.50	23.75
Ca-P	47.70	50.50	122.50	108.50	375.00	410.00

Regarding the third form, the little available inorganic P, the amount of the reductant-soluble Fe -P, for top soil and subsurface were found 8.0-9.0, 20.0-21.0, and 19.0-21.0 % for Um Dum, Hago, and Hosh, respectively. In addition to this, the amount of occluded Al-P were 7.5- 7.5, 16.5 - 22.5, and 17.5-23.8% for Um Dum, Hago, and Hosh, respectively. The results clearly show that the occluded Fe and Al-P level were

low. The reductant-soluble Fe-P is a semi active form which may be dissolved under anaerobic conditions. The occluded Fe-P and Al-P form, being inert to reactions with the soil solution is, therefore, of limited contribution as a source of plant available P.

Available soil P

Available P of Um Dum are 5.3 and 3.1 and for Hago 3.25 and 3.25, while in Hosh was 2.5, and 2.75 mg kg⁻¹ for top and subsurface, respectively (Table 2). The soil available P, is low, indicating that the soils are infertile with respect to P. This may be due to the high clay contents of the latter soils which cause high P fixation. Figure 1 shows that the available P in top soils was positively correlated to the percent of sum of (Al-P+Fe-P) of the total P, and was negatively related to the percent Ca-P fraction content of the total P.

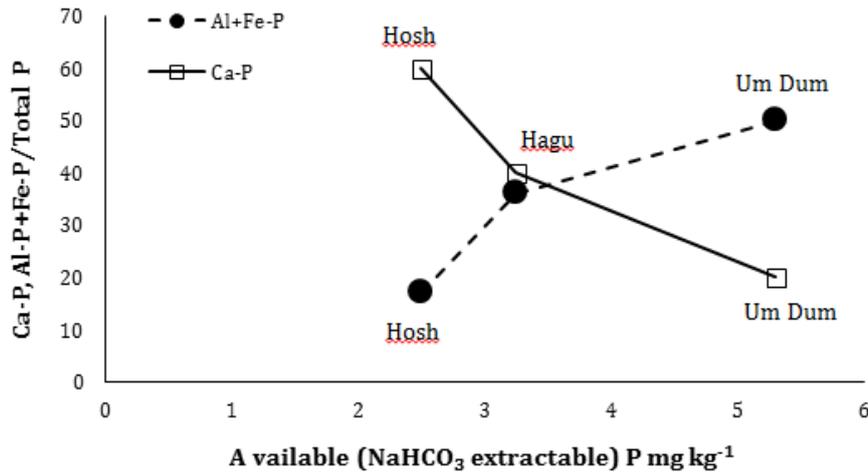
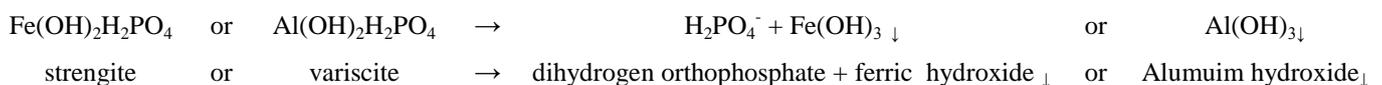


Figure 1. Relations between inorganic P fractions and available P in soils

Effect of phosphorus fractions on phosphate availability

Table 2 shows that the NaHCO₃ extractable P was highest in the sandy Un Dum soils (5.3 mg kg⁻¹ in top soil and 3.1 in the subsurface soil), very close to the amount of saloid P fraction (Table 3). It is noteworthy that Um Dum had the lowest active P fraction (Ca-P, Fe-P and Al-P) of the three soils studied. On the other hand, Hosh clay soil had the lowest NaHCO₃ extractable P, but the highest (523 mg kg⁻¹) active P, more than twice the active P of Um Dum, which was 240 mg kg⁻¹. It seems that the difference in available P between the two soils is not related to the magnitude of the active P, thought to be the source of available P, but rather to the nature and properties of the of individual constituents of active P fraction. It is logical to propose that Hosh soil with pH= 8.2 will push its high Ca-P fraction faster towards more stable forms of low solubility than Um Dum pH=7.1 (Lindsay and Moreno, 1960). Hosh Ca-P will more quickly ends up into sparingly soluble forms of apatite of very low activity. The third soil is Hago of pH 7.9-7.8 may lie in between the two above mentioned soils.

It is relevant to note that despite the low NaHCO₃ extractable P in central Sudan soils of 2-3 mg kg⁻¹, many crops showed erratic response to P fertilization (Dawelbeit et al., 2010). The American Soil Science Society of Agronomy set a limit of 5 mg kg⁻¹ between sufficiency and deficiency of soil P (Olsen and Sommers, 1982). It is known that the Sudan central clay plain soils originated from deposits carried by the Nile from Ethiopian high lands, having high rainfall and intensive vegetative cover. The soils there are organic, acidic and should fix considerable amount of Fe and Al phosphates. Particles of these phosphates which are transported by muddy waters of annual Nile floods are deposited on soil irrigation by Nile water of central clay plain fields (including Hosh). The Fe-Al phosphate particles will react with the alkaline central Sudan soils, producing sustained, but slow release of available P. Bohn et al. (1985) stated that both strengite and variscite would be good P fertilizer in basic soils.



Ahmed (1980) studied the fate of P applied to the alkaline Hosh and Hago soil using conventional methods and radioactive ³²P. He found that about 80 % of the added P fertilizer was recovered after 12 months with Al-P fractions followed by Fe-P, but only about 6% were recovered in calcium form. However, P availability

was not, governed by retained strengite and variscite, suggesting that the retained phosphate was present in forms less soluble than either of the two compounds Figure 2. Ahmed (1980) found that removal of sesquioxides from Hosh and Hagu soils slightly reduced the P adsorption maximum and concluded that most of the P adsorbed has been held by chemisorption Al and Fe clays edges. Ryden et al. (1974) suggested that phosphate first replaces singly coordinated Al or Fe OH groups and then quickly reorganizes into very stable and less soluble binuclear bridge between cations. Presence of the available Ca favor the formation and accumulation of the most stable phosphate form at high pH, hydroxyl apatites. This does not contradict with initial formation of Al and Fe phosphates as latter are soluble at high pH and will transform during long centuries of the soil genesis to the more stable and less soluble calcium phosphates observed today in alkaline soils.

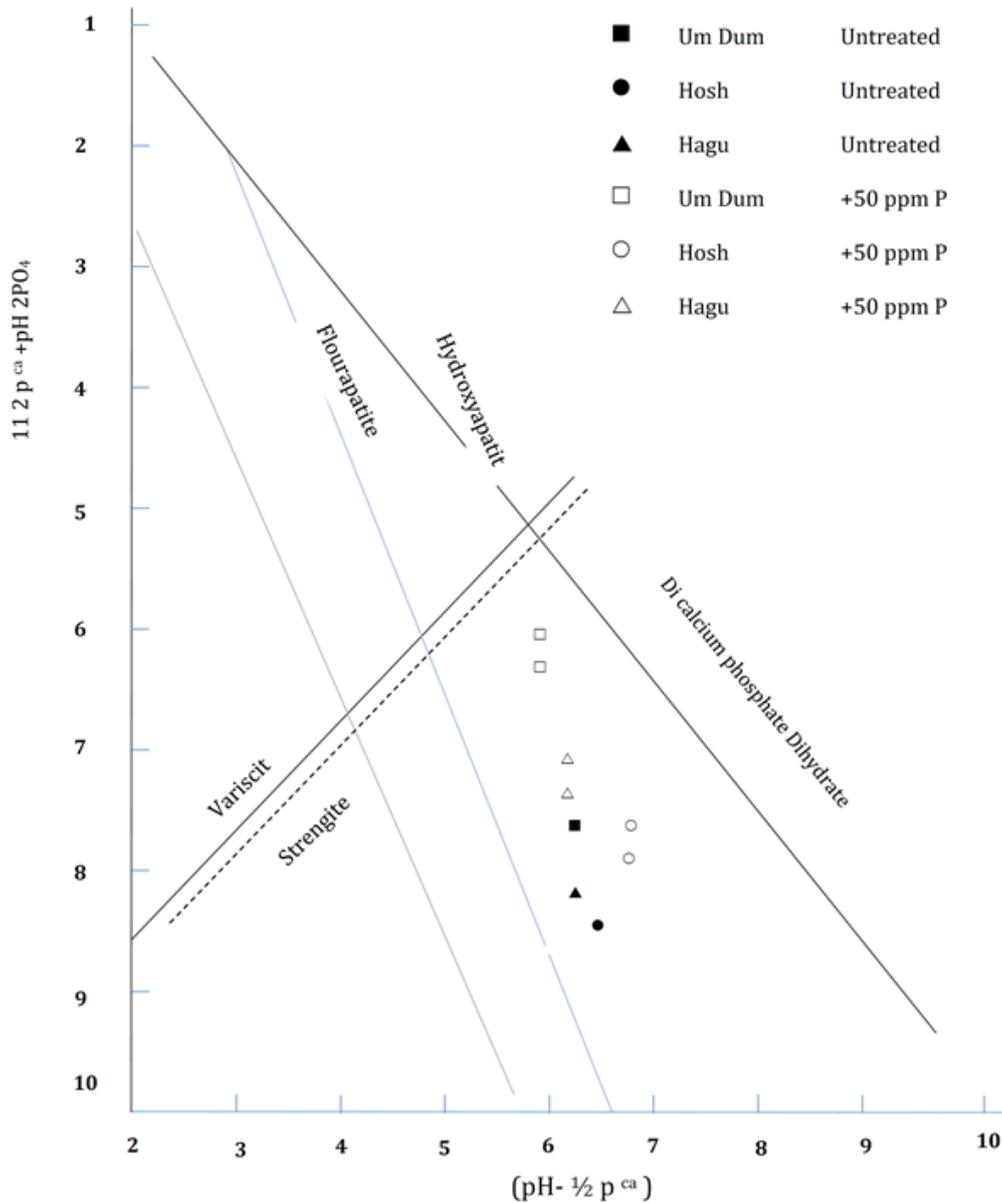


Figure 2. Solubility diagram for three soils

Conclusion

The study showed a wide range of differences in P status of major Sudanese soils orders. The three soils under study varied in the total P and were low in soil organic P values due to the very low organic matter content. Furthermore, the soil available P of above mentioned soils is low, indicating that the soils are infertile with respect to P. Available P was directly proportional to Al-P fraction and was inversely proportional to the larger Ca P fraction in alkaline Hosh soil, indicating that P was present in inactive forms at high pH.

References

- Abusuwar, A.O., Omer, E.A., 2011. Effect of intercropping, phosphorus fertilization and rhizobium inoculation on the growth and nodulation of some leguminous and cereal forages. *Agriculture and Biology Journal of North America* 2 (1): 109-124.
- Ahmed, A.M., 1980. Studies on the native and applied phosphorus in some Sudan soils. M.Sc. Thesis. University of Khartoum, Faculty of Agriculture, Department Biochemistry and Soil Science, Khartoum, Sudan. 120p.
- Arai, Y., Sparks, D.L., 2007. Phosphate reaction dynamics in soils and soil components: A multiscale approach. *Advances in Agronomy* 94: 135-179.
- Bohn, H.L., McNeal, B.L., O'Connor, G.A., 1985. Soil Chemistry. Second edition. John Wiley & Sons. New York, USA. 193p.
- Chang, S. C., Jackson, M. L., 1957. Fractionation of soil phosphorus. *Soil Science* 84(2): 133-144.
- Dawelbeit, S.E., Salih, F.M., Dahab, O.A., Ahmed, E.H., 2010. Status of fertilization and crop nutrition in irrigated agriculture in Sudan: Fertilizer use in Sudan. *Research Findings: e-ifc No. 22*, International Potash Institute. Available at [access date : 26.02.2018]: https://www.ipipotash.org/udocs/eifc_no22-rf1.pdf
- Elsheikh, M.A., El-Tilib, A.M.A., Elsheikh, E.A.E., Awad El Karim, A.H., 2007. Effect of phosphate rock and triplesuperphosphate on growth and leaf N, P and K contents of groundnut (*Arachis ltypogaea* L.) grown on a clay soil. *Arab University of Journal of Agricultural Science* 15: 197-202.
- Estefan, G., Sommer, R., Ryan, J., 2013. Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region. Third Edition. International Center for Agricultural Research in the Dry Areas (ICARDA), Beirut, Lebanon. 244p.
- Halajnia, A., Haghnia, G.H., Fotovat, A., Khorasani, R., 2009. Phosphorus fractions in calcareous soils amended with P fertilizer and cattle manure. *Geoderma* 150(1-2): 209-213.
- Hunt, J.F., Ohno, T., He, Z., Honeycutt, C.W., Dail, B.D., 2007. Inhibition of phosphorus sorption to goethite, gibbsite, and kaolin by fresh and decomposed organic matter. *Biology Fertility Soils* 44(2): 277-288.
- Kabata-Pendias, A., Pendias, H., 1992. Trace elements in soils and plants. Second edition. CRC Press, Boca Raton, Florida, USA. 365p.
- Larsen, S., 1967. Soil phosphorus. *Advance in Agronomy* 19: 151-210.
- Legg J.O., Black, C.A., 1955. Determination of organic phosphorus in soils: II. Ignition method. *Soil Science Society of America Journal* 19(2): 139-143.
- Lindsay, W.I., Moreno, E.C., 1960. Phosphate phase equilibria in soils. *Soil Science Society of America Journal* 24(3): 177-182.
- Melese, A., Gebrekidan, H., Yli-Halla, M., Yitafaru, B., 2015. Phosphorus status, inorganic phosphorus forms, and physicochemical properties of acid soils of Farta District, Northwestern Highlands of Ethiopia. *Applied and Environmental Soil Science* Article ID 748390.
- Mengel, K., Kirkby, E.A., 2001. Principles of plant nutrition. 5th edition. Kluwer Academic Publishers, Dordrecht, The Netherlands. 454p.
- Mostashari, M., Muazardalan, M., Karimian, N., Hosseini, H.M., Rezai, H., 2008. Phosphorus fractions of selected calcareous soils of Qazvin province and their relationships with soil characteristics. *American-Eurasian Journal Agricultural and Environmental Sciences* 3(4): 547-553.
- Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. U. S. Department of Agriculture Circular No. 939.
- Olsen, S.R., Sommers, L.E., 1982. Phosphorus. In: Methods of soil analysis. Part 2 Chemical and microbiological properties. 2nd edition. Page, A.L. (Ed.). American Society of Agronomy, No. 9, Madison, WI, USA. pp. 403-430.
- Petersen, G.W., Corey, R.B., 1966. A Modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphates. *Soil Science Society of America Journal* 30(5): 563-565.
- Ryden, J.C., Syers, J.K., Harris, R.F., 1974. Phosphorus in runoff and streams. *Advances in Agronomy* 25:1-45.
- Thomas, G.W., Peaslee, D.E., 1973. Testing soils for Phosphorus. In: Wash, L.M., Beaton, J.D., (eds.) Soil Testing and Plant Analysis. Soil Science Society of America, Madison, Wisconsin pp. 115-132
- Tisdale, S.L., Nelson, W.L., Beaton, J.D., Halvin, J.L., 1995. Soil fertility and fertilizers. 5th Edition. Macmillan Publishing Co., Inc. New York, USA. 634p.
- Tripathi, B.R., Tandon, H.L.S., Tyner, E.H., 1970. Native inorganic phosphorus forms and their relation to some chemical indices of phosphate availability for soils of Agra district. *Soil Science* 109(2): 93-101.
- Udo, E.J., Ogunwale, J.A., 1977. Phosphorus fractions in selected Nigerian soils. *Soil Science Society of America Journal* 41(6): 1141-1146.
- Uriyo, A.P., Kasseba, A., 1973. Phosphate fractions in some Tanzania soils. *Geoderma* 10(3): 181-192.