Middle-East Journal of Scientific Research 17 (2): 245-251, 2013
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2013.17.02.12197

Phosphorus Desorption Patterns of Soils from Different Land Use Systems of East Wollega, Ethiopia

[1]Achalu Chimdi, [2]Heluf Gebrekidan, [3]Abi Tadesse and [2]Kibebew Kibret

[1]Wollega University, College of Natural and Computational Sciences,
P.O. Box 395, Nekemte, Ethiopia
[2]Haramaya University, College of Agriculture and Environmental Sciences,
P.O. Box 138, Dire Dawa, Ethiopia
[3]Haramaya University, College of Natural and Computational Sciences,
P.O. Box 138, Dire Dawa, Ethiopia

Abstract: In this study the amount of P release patterns from acidic soil with and without added P were assessed by a successive soil Ñ extraction procedure using iron (Fe) oxide-impregnated paper strips to characterize effects of iron oxide induced filter paper in desorbing of added P from surface soils of forest, grazing and cultivated land. The study was conducted in the Guto Gida District located in western Oromia, Ethiopia. The P desorption study was measured in laboratory by incubation of the soils-solution mixtures of varying initial concentration of P (0, 5, 25, 50, 100 and 150 mmol P/L) for 90 days in which the iron oxide–coated strips served as a sink to continuously remove phosphorus (P) from the soil solution. The amount of P extracted by the pi method was significantly correlated with other extractants. From each land use system, the extractable Al, Fe and Mn ions were evaluated using different extractants. Soils of the cultivated land with high clay and extractable Al contents had high Pdesorption capacity after incubation than soils of the remaing land use systems. For all the land use systems an average of 96-97% of the total P was released during the first two extraction cycles. However, the higher percentage was for the cultivated land and lower in the forest land. Results of the study indicated that soils phosphorus desorption capacity decreased with the increase of extraction cycles after incubation the soils for 90 days.

Key words: Acidic soil · Land uses · P- desorption

INTRODUCTION

Desorption is fundamental to defining the bioavailability of soil phosphorus (P). The ability of a soil to desorb P is important when considering the availability of P to plants, fertilizer and soil P use efficiency. Among the different forms of P, the inorganic P which is the available form of P is released to the soil solution through desorption from the surfaces of the solid particles and dissolution of relatively soluble P compounds [1]. Soil P desorption study have been widely used to provide information on P movement and its availability [2, 3]. Numerous procedures have been developed over the past several decades to extract and estimate plant-available P in the soils system. But the search for a method capable of predicting plant responses under a wide variety of soil conditions and suitable for use in routine soil testing has so far been unsuccessful [4].

A new desorption technique for soil P has been recently proposed, in which iron oxide-coated paper strips were used as a P sink to continuously remove P from soil solution, in this way simulating the mechanism of P absorption by plant roots [5]. The use of iron oxide-impregnated filter paper has been found to be an effective approach to the extraction of P from soils. The surface of iron oxides has a high affinity for P and the phosphates are rapidly adsorbed onto these surfaces [6]. The method is based on the principle of P sorption on to the Fe-oxide strip and subsequent removal of P by dilute acid. It gives an assessment of the reversibly adsorbed soil P and has

---

Corresponding Author: Achalu Chimdi, Wollega University, College of Natural and Computational Sciences,
P.O. Box 395, Nekemte, Ethiopia.

been successfully applied to estimate plant-available P in a wide range of soils and management systems [4].

Several researchers have carried out studies clarifying the relationship between the forms of inorganic P and available P status and on the transformation of inorganic fractions in relation to different levels of added P, time of incubation and soil properties [7, 8, 9]. Although soil P status and its sorption have been studied in some Ethiopian soils [10, 11] the P desorption characteristic of these soils are not known. Therefore, the objectives of this study were to characterize the P desorption characteristics as affected by land use systems, to predict the soils' desorption patterns using successive extraction using iron oxide induced filter paper and to relate the desorption parameters to selected soil physicochemical properties.

MATERIALS AND METHODS

Description of the Study Site: The study was conducted in the Guto Gida District (East Wollega Zone) of Oromia Regional State, western highlands of Ethiopia (Figure 1).

The District is situated at a road distance of 320 km from the capital, Addis Ababa, within 08° 59'and 09° 06` north latitude and 37°09` and 37° 51`east longitude. According to the local and the Ethiopian agro-climatic zonation the study area belongs to the humid (Baddaa) and sub-humid (Badda Darree) climatic zones.

As per the climate data recorded at the Nekemte Meteorological Station, the ten years average annual rainfall of the study site is 1300 mm and the monthly mean minimum and maximum temperatures range between 11.25 and 14.50 and 25.00 and 29.00°C respectively. The topography of the study site is mountainous and has a gentle sloping landscape. According to FAO classification, the soil class of most of the study area is Nitosols. The economic activities of the local society of the study area are primarily mixed farming system that involves animal husbandry and crop production. The major crops are coffee (*Coffee arabica* L.*)*, teff *(Eragrostis tef),* barley *(Hordeum vulgare* L*)*, maize (*Zea mays* L.) and potato *(Solanum tubersoum* L.). These major crops are produced usually once in a year.

Site Selection, Major Features of the Land Uses and Sampling Procedures: A preliminary survey and field observation were carried out using topographic map (1:50,000) in order to have general information about the land forms, land uses, topography and vegetation cover of the study site. Accordingly, three major representative land use systems (natural forest, grazing and cultivated lands) were identified from the Guto Gida district of East Wollega Zone, Western Oromia Region. The forest land is covered by indigenous natural forests with long and dense trees forming canopies, the grazing land comprises of communal and private grazing areas whereas the cultivated land is covered by rainfed annual crops and bounded by few scattered trees and settlements. Nine sub-samples from (0-20 cm depth) different sites of each of the representing land use systems of the Guto Gida District were collected and composited accordingly. The composited soil samples were air dried, ground, passed through a 2 mm sieve, packed and transported for laboratory analysis.

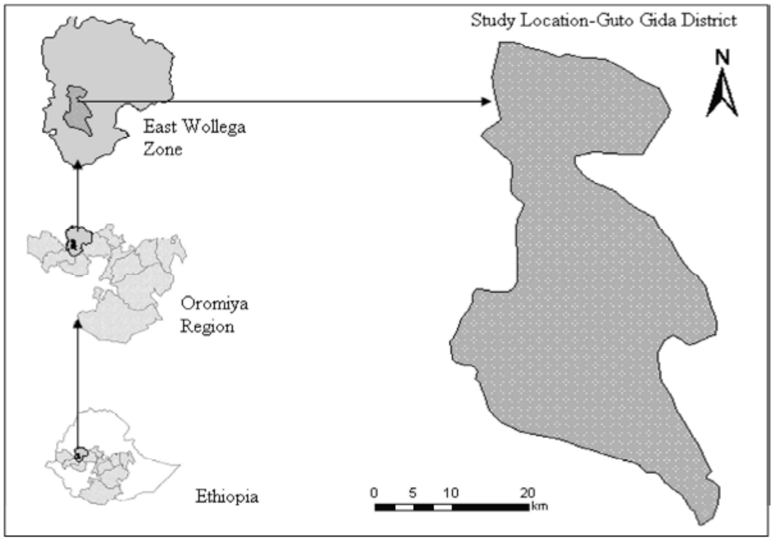

Fig. 1: General location map of the study area

Analysis and Characterization of Soil Samples: Soil particle size distribution was analyzed by the Bouyoucos hydrometer method as described by [12]. Soil pH was measured using 1:2.5 soil to water ratio [13]. Organic carbon content was determined by the dichromate oxidation method as described by [14] and organic matter content was estimated from the organic carbon content by multiplying the latter by 1.724. The dithionite-citrate-bicarbonate-extractable forms of crystalline Al, Fe and Mn were determined by extraction method described by [15]. Acid ammonium oxalate-extractable forms of amorphous Al, Fe and Mn were determined by the extraction method described by [16]. Organically bound extractable Al, Fe and Mn were determined by extraction method described by [17]. The extracted Al, Fe and Mn were separated by centrifuging at 5000 rpm for 20 minutes and were filtered through a millipore filter with a 0.45 μm membrane filter. Finally, the concentrations of Fe, A1 and Mn extracted by various extracting solutions were then measured using AAS.

Soil Sample Incubation and Phosphate Desorption: Five rates of P in the form of $(0, 25, 50, 100 \text{ and } 150 \text{ mg kg}^{-1})$ were applied to 100 g of soil and the soil solutions were incubated for 90 days. Soils samples were wet to field capacity for four days at 24 °C and air dried for three days and this was repeated for thirteen wet-dry cycles with mixing of the soil samples for uniform distribution of P. At the end of the incubation period, soils were air dried again and consecutive extraction processes of soil P using iron oxide induced filter paper was conducted. The latter was prepared by immersing hardened Whatman filter paper number 42 circles 15 cm diameter in a solution containing 10 gm $FeC1_3.6H_2O$ in 100 mL of distilled water [18]. The paper circles were air dried for three hours and put in a bath containing 2.7 M NH_4OH to convert $FeCl_3$ into the oxide form to produce amorphous iron (hydr)oxide (ferrihydrite, denoted as FeO). The circles were then cut into strips of 2 x 10 cm. Phosphorus was extracted by shaking 1g soil sample and one paper strip in 40 mL of 0.01 M $CaC1_2$ end-over-ends shaker for 16 hours at 24 °C as described by [19]. The induced filter paper was then removed, rinsed free of adhering soil particles and air dried. Phosphorus retained on the induced filter paper was removed by shaking it end-over-end with 40 mL of 0.1 M H_2SO_4 for 2 hours. One new induced filter paper was immersed to the remaining soil suspension and the bottle was shaken again. The procedure was repeated six times. Finally, the filtered solution was taken for the measurement of the concentration of P desorbed in solution using a spectrophotometer at a wave length of 880 çm [20].

Data Analysis: Data generated from analysis were subjected to statistical analysis using SAS software [21]. The phosphate desorption patterns of the soils were described by an exponential type relationship using the Sigma plot software version 8.0.

RESULTS AND DISCUSSION

Contents of the Extractable Al, Fe and Mn Ions and Selected Soil Properties: Soils with relatively high clay fraction like the cultivated land in the present study attained low pH and higher extractable Al using acid ammonium oxalate, dithionite-citrate-bicarbonate and sodium pyrophosphate (Table 1).

This may be attributed to the fact that, phosphate anion in acidic soils can form strong bond with the oxides and hydroxides of Al generating H ion through hydrolysis reaction that lowers the pH. The presence and domination of the oxide and hydroxide forms of Al and Fe tie-up plant nutrients like P in the soils. According to the research finding by [22] the lower pH soils of cultivated land influences both the degree of ionization of orthophosphate ions and the oxide surface charge which is the main factors lowering the P desorption capacity of the soils. As the soil pH increases, the relative proportion of $H_2PO_4^-$ decreases and that of HPO_4^{2-} in the soil increases [23]. In the present study, presence of higher soil OM in the forest land may inhibit Fe and Al oxides from formation of complex compounds and decrease the releasing capacity for the phosphates.

When comparisons are made among the three extractants, contents of extractable Al ion removed using acid ammonium oxalate (Al_{AAO}) in soils were higher than dithionate citrate bicarbonate extracted aluminum (Al_{DCB}) and sodium pyrophosphate (Al_{SPP}) extractable Al, but within the land use it was higher in soil of cultivated land than the remaining land use systems. This shows that, amorphous forms of Al ions accumulated in lower pH of the cultivated land than forest and grazing lands. The domination of the amorphous forms of oxalate-extractable aluminum (Al_{AAO}) and organically bound aluminum contents (Al_{SPP}) decreased the decrease in soil OM content from forest, grazing and to cultivated land. The extractable Al and Mn in amorphous forms and crystalline forms of Fe in soils of the forest and grazing lands but amorphous forms of Al, Mn and Fe in the cultivated land are the dominant and principal metal ions (Table 1).

Table 1: Selected analytical properties of soils of the different land use systems

	Land use type		
Soil Parameters	Forest land	Grazing land	Cultivated land
Clay (%)	46.25	56.25	61.50
pH (H_2O)	5.25	5.15	4.65
OM (%)	8.01	4.02	3.64
Extractable Al_{AAO} (mg kg^{-1})	1.40	3.11	9.62
Extractable Fe_{AAO} (mg kg^{-1})	1.07	0.23	1.14
Extractable Mn_{AAO} (mg kg^{-1})	0.11	0.16	0.89
Extractable Al_{DCB} (mg kg^{-1})	0.30	0.34	8.50
Extractable Fe_{DCB} (mg kg^{-1})	4.41	5.10	0.45
Extractable Mn_{DCB} (mg kg^{-1})	0.09	0.10	0.30
Extractable Al_{SPP} (mg kg^{-1})	0.75	1.78	5.49
Extractable Fe_{SPP} (mg kg^{-1})	1.03	0.13	0.89
Extractable Mn_{SPP} (mg kg^{-1})	0.06	0.10	0.42

OM = Organic matter, AAO = Acid ammonium oxalate, DCB = Dithionite-citrate-bicarbonate, SPP = Sodium pyrophosphate

Table 2: Correlation coefficients describing relationships of selected soil properties with P sorption parameters for soils studied

	Clay (%)	pH (H_2O)	OM(%)	Al_{AAO}(mg kg^{-1})	Al_{DCB}(mg kg^{-1})	Al_{SPP}(mg kg^{-1})
Clay						
pH	-0.84					
OM	-0.96	0.67				Al_{AAO}
	0.87	-0.99*	-0.71			Al_{DCB}
	0.77	-0.97*	-0.57	0.98*		Al_{SPP}
	0.88	-0.99*	-0.72	0.99*	0.92	

OM = Organic matter, AAO = Acid ammonium oxalate, DCB = Dithionite-citrate-bicarbonate, SPP = Sodium pyrophosphate, * = Significant at $P < 0.05$ probability level

Among the three land use systems, the value of the contents of acid ammonium oxalate dithionite-citrate-bicarbonate and sodium pyrophosphate extractable Al increased from soils of natural forest and grazing to cultivated lands. The higher value of the contents of oxalate extractable Al in soil of cultivated land with low soil pH implies that, the content of the amorphous form of Al oxides played a leading role and is primarily responsible for the decrease of P solubility in acidic soil systems.

Relationship of the Contents of Extractable Ions and Selected Soil Properties: The simple correlation coefficients (Pearson r) of selected soil properties and extractable ions are presented in (Table 2).

The output of the correlation coefficient demonstrated the negatively significant ($P < 0.05$) correlation of the soils pH and acid ammonium oxalate, dithionite-citrate-bicarbonate and sodium pyrophosphate extractable Al ion but these associations were insignificantly negative ($P > 0.05$) with the soils OM. These inverse relationships are most likely attributed to the domination of the concentration of Al ions in the soil exchange site which further acidify the soil by lowering the soil pH. Similarly, the clay fraction of the experimental soils showed negatively insignificant ($P > 0.05$) correlation with pH and OM. The acid ammonium oxalate, dithionite-citrate-bicarbonate and sodium pyrophosphate extractable Al ions showed insignificantly positive ($P > 0.05$) relationship with each other. Statistically insignificant negative association was recorded between OM and the acid ammonium oxalate, dithionite-citrate-bicarbonate and sodium pyrophosphate the extractable Al ions.

Phosphorus Desorption Patterns of Soils: Under each land use system, the capacity of the soil to supply P decreased with the increase in extraction cycles. This is mainly due to the exhaustion of applied P and sorption of the soils. It was high in soils of the cultivated land and low in the forest land. The concentration of P released during the first extraction cycle under each land use system gave high amount of P, ranging from 0.013-120 mg kg^{-1} than the sixth (final P) desorption cycle which ranged from 0 to 0.35 mg kg^{-1}. The release of higher P concentration during the first extraction time may be due to the presence of additional indigenous soil P.

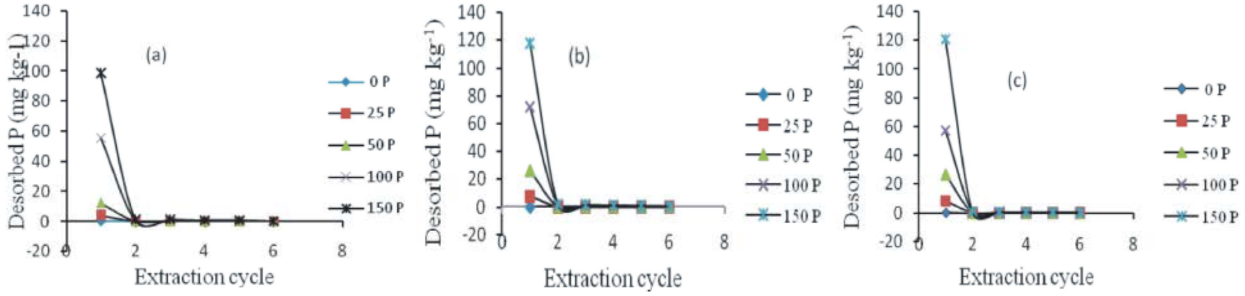

Fig. 2: Phosphorus desorption patterns after 90 days incubation with different rates of applied P to soils of (a) forest land, (b) grazing land and (c) cultivated land

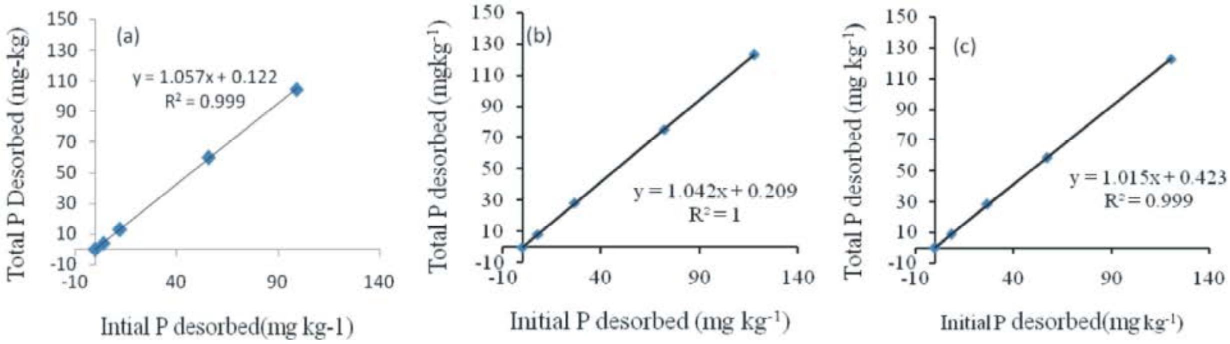

Fig. 3: Phosphorus sorption isotherms fitted to the Langmuir equation in soils of (a) forest land, (b) grazing land and (c) cultivated land

In addition, results of the experimental data across the three land use systems showed that, releasing patterns of added P using iron oxide-induced filter paper decreased rapidly with the increase of consecutive extraction time for both P added as KH_2PO_4 and the untreated soils (Figure 2).

For all the land use systems an average of 96 - 97% of the total P was released during the first two extraction cycles. However, the higher percentage was for the cultivated land and lower in the forest land. Under each land use system, addition of the different rates of P to soils increased the amount of P released from the soils [24]. The higher and lower amount of P desorbed in the soils of the cultivated and forest lands, respectively, could be due to the lower and higher P sorption characteristics of these soils after the 90 days equilibrations [25-27]. The total amount of P released during the six consecutive extraction cycles for both the treated and untreated experimental soils of the different land use systems ranged from 0.03-122.8 mg kg^{-1} (Figure 2). When comparisons are made for both treated and untreated soils of each land use system, results of the finding indicate that higher amount of P was released during the first-two extraction cycles.

In the case of untreated soil, amount of P released using iron oxide induced filter paper in soils of the cultivated and grazing lands were by 0.082 and 0.015 mg kg^{-1} higher than the adjacent soils of the forest land. Similarly, for the case of 150 mg kg^{-1} applied P, the amount of added P released in soils of cultivated and grazing lands were by 18.5 mg kg^{-1} higher than soils of forest land. In addition to the applied P, desorption of high amount of P concentration from soils of cultivated land may be due to the greater release of originally sorbed P during the 90 days incubation period. Mineralization of the sorbed P, which forms a major fraction of the soil P capital, is essential for the enhancement of available P in the soils. When comparisons are made among the land use systems, soils with originally high sorbed P before 90 days incubation period like in soils of the cultivated land in the present study had higher P desorption rate (Figure 3).

Results of the study indicated variations in amount of P released were observed between the first and last extraction cycle, there was a linear and direct relationship between patterns of release of the initial P and final P from the soils during the six consecutive extraction cycles of the applied P using iron oxide induced filter paper. However, the different rates of P added as KH_2PO_4 to soils during the 90 days incubation were not completely released and some portion of the added P was sorbed during the consecutive extraction. In this case, soil P which disappeared from the soil solution after the 90 days equilibration can indirectly be considered as P sorbed.

When comparisons are made among the land use systems, a substantial amount of added P was released during the first consecutive desorption from soils of the cultivated land. This implies that, low percentage of added P disappeared from soil solution of the cultivated land than the remaining land use systems. The disappearance of relatively low portions of added P from soil solution of the cultivated land may be considered to be due to the presence of originally higher sorbed P getting released from the soil after the 90 days incubation. In addition, a linear relationship was observed between the total P and initial P released from soil during consecutive extraction using iron oxide induced filter paper (Figure 3). Because, as the rate of added P to the soil increases, the amount of initial and total added P released from the soils using induced filter paper also increases.

That means, as the rate of applied P (0, 25, 50, 100 and 150 mg kg^{-1}) across the three land use systems increased, desorption of P with consecutive extraction have also increased. The increase of P released during the extraction processes with the increase of the added P rates in to the soils implies its direct relationship with the rate of added P in the soils of each land use system.

CONCLUSIONS

Phosphorus (P) desorption patterns play a vital role in devising appropriate soil P management practices for its use efficiency in order to ensure better crop yields and environmental health. Soils of the cultivated land with high clay and extractable Al contents had high Pdesorption capacity after incubation than soils of the remaing land use systems. For all the land use systems an average of 96 -97% of the total P was released during the first two extraction cycles. Results of the soil P desorption patterns after the 90 days incubation revealed the previously sorbed P getting released more P from soils of the cultivated land than that of the forest and grazing lands.

ACKNOWLEDGEMENTS

The author is grateful to the financial grant of the Ministry of Education through the Haramaya University, Ethiopia. He also acknowledges the Staff and Technicians of the Chemistry Department of Ambo University and MTT Agrifood Research (Finland) for their logistic supports and unreserved cooperation during analysis of the soil samples.

REFERENCES

1. Hinsinger, P., 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes a review. Plant and Soil, 237: 173-195.
2. Iramuremye, F., R.P. Dick and J. Baham, 1996. Organic amendments and phosphorus dynamics; 1. Phosphorus chemistry and sorption. Soil Sci., 161: 426-435.
3. Sibbeson, E. and A.N. Sharpley, 1997. Setting and justifying upper critical limits for phosphorus in soils. pp: 151. In: H. Tunney, O.T. Carton, P.C. Brookes and A.E. Johnson, (eds) Phosphorus loss from soil to water. CAB international, Guildford, UK.
4. Menon, R.G., S.H. Chien and L.L. Hammond, 1990. Development and evaluation of the Pi soil test for plant-available phosphorus. Communications in Soil Sci. and Plant Anal., 21: 1131-1150.
5. Van der Zee, S.E.A.T.M., L.G.J. Fokkink and W.H. Van Riemsdick, 1987. A new technique for assessment of reversibly adsorbed phosphate. Soil Sci. Soc. Am. J., 51: 599-604.
6. Beek, J. and W.H. Van Riemsdijk, 1982. Interaction of orthophosphate ions with soil, pp: 259-284, IN: G.H. Bolt (ed.) Soil Chemistry, B. Physico-chemical models. Elsevier Science Publication BV, Amsterdam.
7. Debnath, N.C. and S.K. Mandal, 1982. Evaluation of the relationship of inorganicphosphate fractions of soil with available phosphorus determined by some chemical and biological methods. J. Indian Soc. Soil Sci., 30: 489-493.
8. Tekalign, M. and J. Haque, 1991. Phosphorus status of some Ethiopian soils: Forms anddistribution of inorganic phosphate and their relation to available phosphorus. Trop.Agric. (Trinidad), 68: 1-8.
9. Indiati, R., C. Izza, A. Figliolia and R. Ambroselli, 1992. Effetto della fertilizzazionefosfatica sul pool del fosforo inorganico. Atti X Convegno Societa' Italiana di Chimica Agraria, Rome, Italy.
10. Duffera, M. and W.P. Robarge, 1999. Soil characteristics and management effects on phosphorus sorption by highland plateau soils of Ethiopia. Soil Sci. Soc. Am. J., 63: 1455-1462.

11. Tekalign, M. and I. Haque, 1987. Phosphorus status of some Ethiopian soils I. Sorption characteristics. Plant and Soil, 102: 261-266.
12. Day, P.R., 1965. Hydrometer method of particle size analysis. *In:* C.A. Black (Ed.). Methods of Soil Analysis. Agronomy Part I, No. 9. Am. Soc. Agro, Madison, Wisconsin, USA, 1965, pp: 562-563.
13. Baruah, T.C. and H.P. Barthakur, 1997. A Textbook of Soils Analysis. 2ndedition, Vikas Publishing House Private Limited, New Delhi, India.
14. Walkley, A. and C.A. Black, 1934. An examination of the degrjareff method of determining soil organic matter and a proposed modification of chromic acid titration method. Soil Sci., 37(1934): 29-38.
15. Mehra, O.P. and M.L. Jackson, 1960. Iron oxide removal from soils and clays by a dithionate-citrate system buffered with sodium bicarbonate. Clays and Clay Minerals, 7: 317-327.
16. Warren, G.P., 1987. Influence of soil properties on the response to phosphorus in some tropical soils: I. Initial response to fertilizer. European J. Soil Sci., 45(1994): 337-344.
17. McKeague, J.A. and J.H. Day, 1996. Dithionite and oxalate extractable Fe and A1 as aids in differentiating various classes of soils. Canadian J. Soil Sci., 46(1996): 13-22.
18. Menon, R.S., S.H. Chien and L.L. Hammond, 1989. Comparison of Bray I and Pi tests for evaluating plant-available phosphorus from soils treated with different partially acidulated phosphate rocks. Plant and Soil, 114: 211-216.
19. Guo, F., R.S. Yost and P.C. Jones, 1996. Evaluation of iron-impregnated paper strips for assessing available soil phosphorus. Commu. Soil Sci. and Plant Anal., 28(1996): 483-495.
20. John, L.K., 2009. Methods of phosphorus analysis for soils, sediments, residues and Water. Southern Cooperative Series Bulletin, 408: 1-131.
21. Statistical Analysis System (SAS), 2004. SAS/STAT user's guide. Proprietary software version 9.00. SAS Inst., Inc., Cary, NC.
22. Eze, O.C. and P. Longanthan, 1990. Effects of pH on phosphorus sorption of some Paleudults of southern Nigeria. Soil Science, 153(1990): 279-288.
23. Tisdale, S.L., W.L. Nelson, I.D. Beaton and J.L. Halvin, 1993. Soil fertility and fertilizer, 5th (Ed.) Macmillan Publishing Company, USA.
24. Lin, T.H., S.B. Ho and K.H. Houng, 1991. The use of iron oxide impregnated filter paperfor the extraction of available phosphorus for Taiwan soils. Plant Soil, 133: 219-226.
25. Abou-Deif, M.H., M.A. Rashed, M.A.A. Sallam, E.A.H. Mostafa and W.A. Ramadan, 2013. Characterization of Twenty Wheat Varieties by ISSR Markers, Middle-East Journal of Scientific Research, 15(2): 168-175.
26. Kabiru Jinjiri Ringim, 2013. Understanding of Account Holder in Conventional Bank Toward Islamic Banking Products, Middle-East Journal of Scientific Research, 15(2): 176-183.
27. Muhammad Azam, Sallahuddin Hassan and Khairuzzaman, 2013. Corruption, Workers Remittances, Fdi and Economic Growth in Five South and South East Asian Countries: A Panel Data Approach Middle-East Journal of Scientific Research, 15(2): 184-190.