Characteristics of phosphorus sorption under different land use systems at Agarfa, South Eastern Ethiopia

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Abstract

Determination of the Phosphous (P) sorption characteristics of soils is important for a better understanding of P, economic fertilizer application and to recommend appropriate management strategies for high P-fixing soils. The phosphorus adsorption-desorption behavior of soils from four land use patterns of central Ethiopia was studied. The study was conducted to determine the effects of land-use systems on selected soil physicochemical characteristics and soil P sorption capacities. Five major representative land-use systems (forest, grazing, homestead, traditionally cultivated land, and mechanized land) were identified. Composite soil samples were collected at 0-20 and 20-40 cm depth. Sorption data were obtained by equilibrating 3.0 g of each sample with 25 mL of 0.01 M $CaCl_2$ *containing various amounts of* KH_2PO_4*. The resulting data were fitted with Langmuir and Freundlich equations. Sorption maxima (Xm) and The Freundlich coefficient (Kf) values of soils ranged from 104-295mg P kg-1 and 44-70.5 mg P kg-1 based on Langmuir and Freundlich models, respectively. The SPR values ranged between 11 to 22 mg P kg-1 and 14 to 28 mg kg-1 based on Langmuir and Freundlich models, respectively in 0-20 cm depth. In general, P-sorption models can effectively be used to discriminate soils based on P-fixation ability. Moreover, the amount of fertilizer based on EPR estimation is greater than the amount of fertilizer practiced both by traditionally cultivated and mechanized land uses. Thus, it is recommended that this dose of P fertilizer should be revised and the proper amount of fertilizer based on EPR values estimated for each soil be applied.*

Key words: Freundlich model, Langmuir Model, P fixation, Standard P requirement

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INTRODUCTION

Soil Phosphorus deficiency is one of the major factors limiting crop yields worldwide (McLaughlin et al., 2011). This deficiency may be due to low P containing parent material from which soil was formed or low inherent P content, high weathering incidence and soil reaction, long term anthropogenic mismanagement through an imbalance between nutrient inputs, and P losses by erosion and surface runoff (Ravikovitch, 1986). To adequately supply P to crops, the addition of P containing fertilizer (or other sources) becomes necessary in most agricultural soils especially in highly weathered tropical acidic soils (McLaughlin et al., 2011).

Langmuir and Freundlich's models are the most widely used models to describe P-sorption characteristics of soils and draw external P-requirements (Freundlich, 1988). These models can discriminate soils based on their ability to sorb/adsorb P from soil solutions. They also give an insight into the strength of P-adsorption on the surface of a particular soil. However, in Ethiopia previous studies of soil P sorption and desorption processes have tended to focus on the P sorption potential of different soil types and the effects of soil physico-chemical properties (Achalu et al., 2013). There is little information on soil P sorption under different crop systems in Ethiopia in general and Agarfa in particular. Moreover, factors affecting the adsorption capacity of the soils and the appropriate amount of P fertilizer required by the soils of the study area have not yet been investigated. Therefore, to resolve the problem studying the sorption capacity of the soils and identifying high and low sorbing soils have important implications for future fertilizer management and recommendation. Thus, the objectives of this study were to investigate P sorption characteristics and physicochemical properties of soils as affected by land-use systems.

MATERIALS AND METHODS

Description of the Study Area and Land Use

This study was conducted at Agarfa ATVET College which is located in Agarfa Woreda of Bale Zone in the Oromia National Regional State, Ethiopia. It lies at an altitude of 2350 m.a.s.l. between 60 58' 40" and 70 20' 0" N, and 390 44' 0" and 400 26' 40" E. The average annual rainfall of the area based on 10-years meteorological data is 799.05 mm, with a bimodal pattern and two growing seasons. The mean annual temperature is 15.3°C while the mean maximum and mean minimum are 15.77 and 15.02°C, respectively. A preliminary survey and field observation was carried out by visual observations to have general information about land use and cultivation history. Accordingly, the five major representative land-use systems (forest, grazing, homestead, traditionally cultivated and mechanized land uses) were identified.

Soil Sampling and Preparation

After the site selection, from the representative fields, ten subsamples per one composite sample (3 composite soil samples per one land use) were collected at the depth of 0-20 and 20-40 cm in a Zigzag sampling scheme using an auger. The soil samples were mixed, air-dried, and passed through a 2 mm sieve for the analysis of selected soil physical and chemical properties.

Physico-Chemical Properties of Soil

Soil particle size distribution was determined by the Bouyoucos hydrometer method (Van Reeuwijk, 1992). The pH of the soils was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combined electrode (Van Reeuwijk, 1992). Walkley and Black (1934) wet digestion method was used to determine soil carbon content and percent. Available soil P was analyzed according to the standard procedure of the Olsen method (Olsen et al., 1954). Cation Exchange Capacity (CEC) and exchangeable basic cations (Ca, Mg, K, and Na) were determined in the leachate using 1N neutral ammonium acetate adjusted to a pH of 7. Available micronutrients (Fe, Cu, Zn and Mn) were extracted by DTPA and all these micronutrients were measured on AAS, as described by (Lindsay and Norvell, 1978).

P-sorption

Phosphorus sorption characteristics were determined by batch equilibrium methods in which soil samples were agitated with P solutions of known concentrations (Graetz and Nair, 2008). Phosphorus as KH_2PO_4 was dissolved in a 0.01M solution of Calcium chloride in distilled water. According to Graetz and Nair (2000), to study the sorption of P by soils, 3 g air-dried samples of each soil were placed in a 100 mL plastic bottle in which the final volume was adjusted to 25 mL. A stock solution of P for each rate (0, 2, 4, 10, 20, 30, and 40 mg L^{-1} P) was added (Carter and Gregorich, 2008). The P sorption data for the soils were fitted into the following forms of Langmuir and Freundlich models because linear regression is convenient and the best of the data-fitting process.

Langmuir equations:

$C/X = 1/K.Xm + C/Xm$………. (Equation1)

Where C (mg L^{-1}) is the equilibrium concentration, X (mg kg^{-1}) is the amount of P adsorbed per unit mass of adsorbent, K (L mg^{-1}) is a constant related to the energy of sorption, and Xm (mg kg^{-1}) is P sorption maximum.

Freundlich equation:

$X = KCb$ or $\log X = \log kf + b\log C$ …… (Equation 2)

where, K and b ($b<1$) are constants, X (mg kg^{-1}) is the amount of P adsorbed per unit mass of adsorbent, and C (mg L^{-1}) is the equilibrium concentration.

Data Analysis

By using SAS software (SAS, 1997) P-sorption was described as influenced by land use and cultivation, and Mean comparisons (LSD) were calculated for the different land uses systems to see the relationship between parameters.

RESULTS AND DISCUSSION

Physicochemical Properties of the Soil

The studied land use had OM content ranging from 1.94 to 7.39%, for 0-20 cm depth and 1.82 to 6.02 % for the 20-40 cm depth (Figures 1). Higher total nitrogen (TN) and available phosphorus were observed in forest land followed by that of grassland at both ranges of depth, which could be related to the higher organic matter content in the soils of forest land as reported by Alemayehu and Sheleme (2013) where a significant correlation between organic carbon and total nitrogen were reported at 0-15 cm and 15-30 cm depth, respectively.

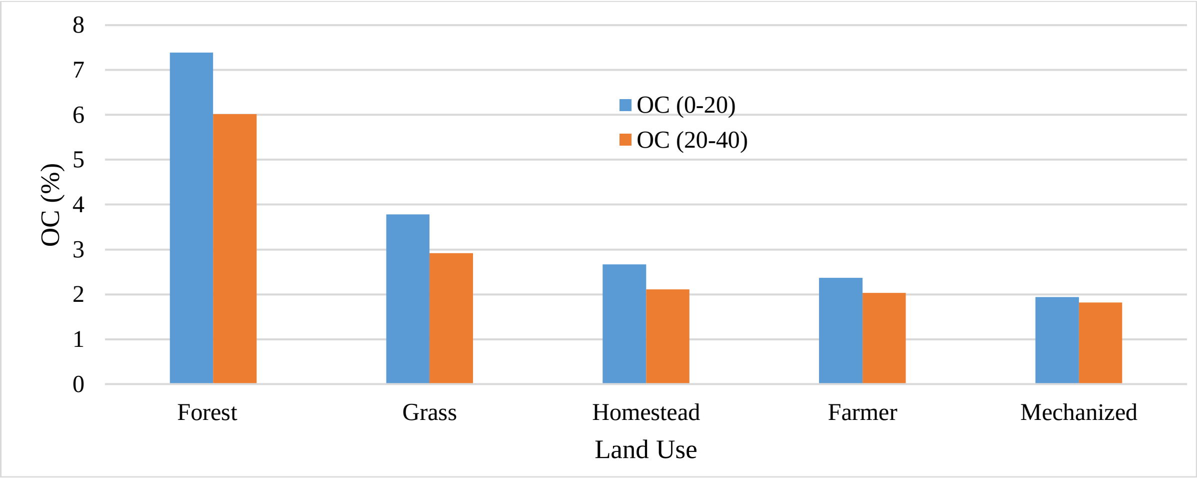

Figure 1: Organic matter content of soils under different land use systems at studied area.

The mean exchangeable cations Ca and Mg content were significantly (P<0.05) different among the land-use systems. The exchangeable calcium (Ca) was highest under homestead land use (Table 1) and lower under grass land in both ranges of depth. Higher concentrations of exchangeable Mg were found under homestead and forest land systems in 0-20 cm and 20-40 cm depths, respectively. The lowest exchangeable Mg were recorded under traditionally cultivated land in both depth (Table 1). Relatively, the highest cation exchange capacity (CEC) values were observed under forest land (52.44 cmol (+) kg^{-1}) followed by that of homestead (51.20 cmol (+) kg^{-1}) at 0-20 cm depth (Table 1) and higher CEC value at 20-40 cm depth were also recorded under the forest land use type.

Table 1. Physical and chemical properties soils at 0-20 and 20-40 cm depths under different land use systems, at Agarfa woreda.

Land use	pH	sand	Silt	Clay	CEC	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
					Cmol (+/kg)				
				0-20 cm					
Homestead	7.09a	43a	30b	27	51.20a	23.47a	7.02a	5.59a	4.79
Forest	6.49c	22c	50a	28	52.44a	23.35a	6.27b	3.62c	4.67
Traditional	6.79b	40ab	27b	33	50.66a	23.18a	5.45c	4.91b	4.82
Mechanized	6.63bc	35b	34b	31	41.33b	19.62b	5.94bc	5.53a	4.62
Grassland	6.80b	40ab	30b	30	42.33b	12.94c	5.48c	5.18ab	4.84
LSD (0.5)	0.2	5.1	8.2	NS	3.5	1.7	0.6	0.6	NS
CV (%)	1.2	7.5	12.3	12.2	3.9	4.5	4.8	6.7	3.4
				20-40 cm					
Homestead	7.11a	43a	30bc	27	51.25a	23.38a	6.44b	4.61	4.83
Forest	6.30c	23bc	51a	26	52.08a	21.62ab	8.04a	3.53	4.54
Traditional	6.87ab	31b	35b	34	50.13a	22.87a	5.04c	4.51	4.83
Mechanized	6.64b	44a	25c	31	40.43b	19.42b	6.17b	4.86	4.64
Grassland	6.78b	39ab	34b	27	41.60b	12.77c	6.65b	4.87	4.92
LSD (0.05)	0.3	9.7	7.5	NS	5.7	3	0.9	NS	NS
CV (%)	2.4	14	11	15	6.3	7.9	8	15	2.6

Means values within a column followed by the same letter(s) are not significantly different at $p \leq 0.05$.

Significant variations ($p < 0.05$) in available iron (Fe) at both depths were exhibited. Accordingly, the highest available Fe was recorded under forest followed by traditionally cultivated land at both depths, whereas the lowest value was recorded under grassland at both depths. At both depths, available Mn concentrations were higher in forest land soils followed by that of traditionally cultivated system. Moreover, significant variations ($p < 0.05$) in available manganese in both depths were observed among different land-use systems. The highest concentration of available Zinc (Zn) was found in both depths under homestead, whereas the lower concentration was recorded under grass and mechanized land use in 0-20 and 20-40 cm ranges of depth, respectively. Relatively higher available Cu content was observed in forest land (Table 2), which could be due to the relation of copper with organic matter (Alemayehu and Sheleme, 2013).

Table 2. Total nitrogen, available P and extractable micronutrients of soils as influenced by different land uses at different depths, at Agarfa

Land use	TN%	Av. P	Fe	Zn	Cu	Mn
		Mg kg^{-1}				
			0-20cm			
Homestead	0.13c	1.70ab	16.24c	1.33a	2.23bc	17.96c
Traditional	0.12cd	1.76a	19.18b	0.63b	3.01ab	23.73b
Forest	0.37a	1.89a	46.04a	0.57b	3.15a	28.96a
Mechanized	0.1d	1.86a	15.83cd	0.56b	2.43b	21.89b
Grass	0.19b	1.45b	11.40d	0.55b	1.64c	1.59d
LSD (0.5)	0.03	0.3	2.9	0.2	0.7	2
CV (%)	8.5	9	7.2	14.4	14	5.8
			20-40cm			
Homestead	0.12bc	1.56b	16.95cd	1.41a	2.41b	22. 19c
Traditional	0.1c	1.86a	22.95b	0.68c	2.98a	27.25a
Forest	0.3a	1.75ab	50.95a	1.01b	3.00a	28.73a
Mechanized	0.09c	1.77a	18.57c	0.57c	2.58ab	25.27b
Grass	0.15b	1.40bc	11.29d	0.58c	1.88c	1.88d
LSD (0.05)	0.05	0.3	2.2	0.3	0.5	1.7
CV (%)	15	9.1	4.8	19	10.6	4.3

Means values within a column followed by the same letter(s) are not significantly different ($p \leq 0.05$)

Phosphorous Adsorption Characteristics

P Sorption indices

Sorption behavior was described by the linearized Langmuir sorption model (with regression coefficient of $R^2 > 0.93$) for mechanized, grassland and homestead land-use systems (Table 3). All land uses had sorption maxima ranging from 104 to 295 mg P kg^{-1} with a mean value of 199.5 mg kg^{-1}. The highest sorption maximum was observed under traditionally cultivated land system at 20-40 cm depth range, which might be attributed to the higher clay content of the soil. Furthermore, sorption affinity constant (k), which is the dominant factor showing the bonding energy of the soil to retain P, ranged from 0.32 to 0.74 (L mg^{-1}), with a mean value of 0.53 L mg^{-1}, indicating that the studied soils had variable adsorption energy coefficients.

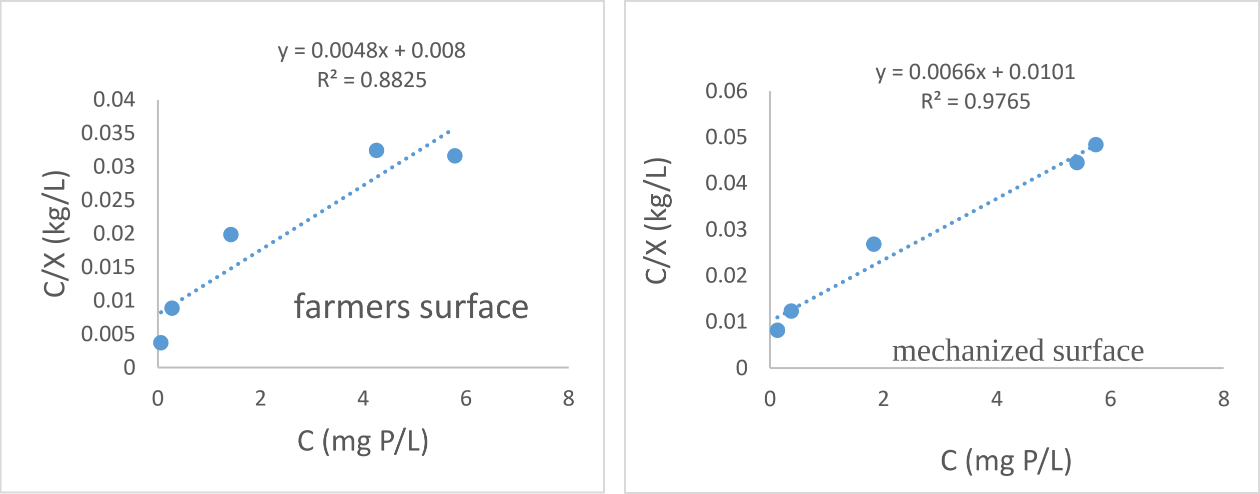

Figure 2: Organic matter content of soils under different land use systems at studied area.

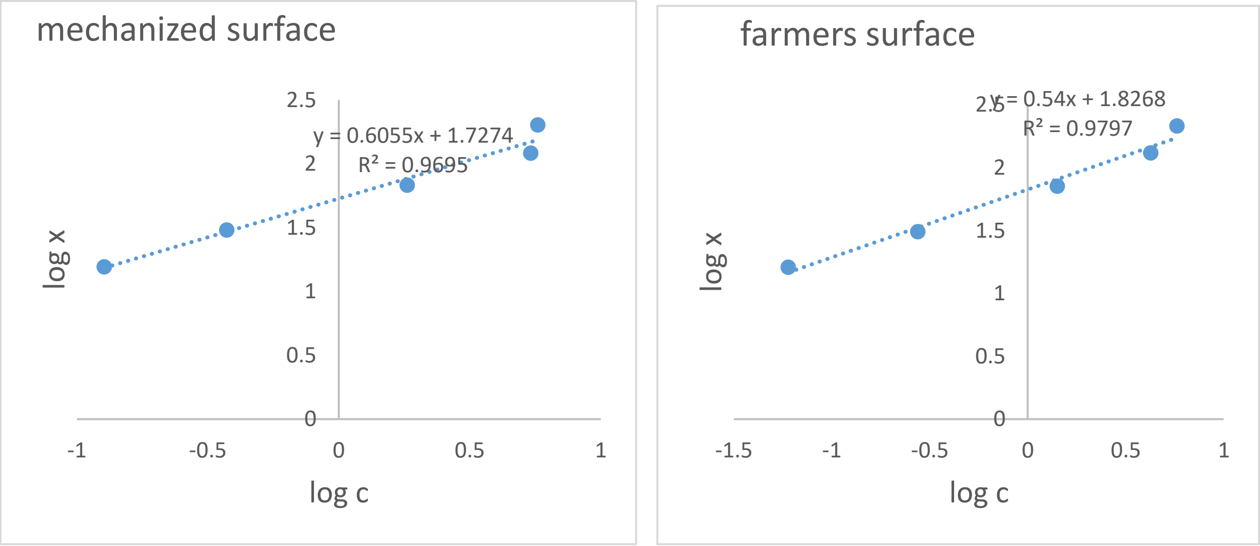

Figure 3: Freundlich P adsorption isotherms of mechanized and traditionally cultivated land use systems.

Table 3. Langmuir and Freundlich sorption parameters and R values of the regression analysis.

	P sorption indices LE				P sorption indices FL			
Land use	Xm (mg kg^{-1})	K (L mg^{-1})	SPRL (0.2) mg kg^{-1}	R^2	b (L kg^{-1})	Kf (mg kg^{-1})	SPRF (0.2) (mg kg^{-1})	R^2
				0-20cm				
Forest	104	0.61	11	0.86	0.61	46.6	17.4	0.86
Mechanized	152	0.65	18	0.97	0.61	52.5	19.8	0.96
Grassland	217	0.36	15	0.97	0.72	52	16.4	0.98
Homestead	179	0.4	13	0.93	0.74	47	14	0.90
Traditional	208	0.6	22	0.88	0.54	67.1	28	0.97
				20-40cm				

Forest	143	0.74	19	0.87	0.48	53.4	24.6	0.91
Mechanized	213	0.63	24	0.86	0.5	70.5	31.6	0.96
Grassland	175	0.35	12	0.91	0.65	44	15.3	0.95
Homestead	238	0.35	16	0.96	0.69	55.5	18	0.99
Traditional	295	0.32	18	0.90	0.69	61.7	20	0.92

LE= Langmuir equation, FL= Freundlich equation, Xm=Langmuir sorption maximum, K=bonding energy, b= constant of Freundlich equation, SPRL= standard P requirement estimated based on Langmuir model, SPRF= standard P requirement estimated based on Freundlich model, Kf=Freundlich surface coverage.

Standard phosphorus fertilizer requirements (SPR)

The soil solution P of 0.2 mg L^{-1} is considered as the amount of available P in the soil solution for optimum plant growth (Bolland et al., 2001). The P required to maintain a soil solution concentration of 0.2 mg P L^{-1} (P 0.2) ranged from 11 to 22 mg P kg^{-1} at the surface depth of the soil in the study soils (Table 3). The amounts of added P required in maintaining the concentration of 0.2 mg P L^{-1} in solution (EPR) were generally lower than the ranges reported in previous studies. For instance, Duffera and Robarge (1999) reported values ranging from 50 to 201 mg P kg^{-1} for surface samples from non-cultivated and non-fertilized areas in Ethiopia. On the other hand, the results of the current study are comparable with the findings of Gichangi et al. (2008) which indicated that the amount of P required to maintain a soil solution concentration of 0.2 mg P L^{-1}(P 0.2) ranged from 2 to 28 mg P kg^{-1} for selected South African soil samples.

The amount of fertilizer applied on traditionally cultivated and the mechanized farm was 100 and 150 kg DAP per hectare, respectively, which are equivalent to 20.3 and 30.4 kg P ha^{-1} for traditionally cultivated and the mechanized farms, respectively. The reason for the low EPR value might possibly be due to early P saturation following repeated applications of P fertilizers. Soils that adsorb less than 150 mg P kg^{-1} soil to meet the SPR value of 0.2 mg L^{-1} solution are considered to be low sorbing soils and those adsorbing greater than this value are high P sorbing ones (Sanchez and Goro, 1980). Accordingly, all the land uses were low P fixers (Table 3) in the present study.

At the 0.2 mg P L^{-1} of equilibration, the EPR of different land uses were calculated based on the estimated value from the Langmuir equation. Accordingly, the EPR of 44 kg P ha^{-1}, 100.8 kg P_2O_5 ha^{-1}, and 219 kg DAP ha^{-1}) for traditionally cultivated farms, 36 kg P ha^{-1}, 82.5 kg P_2O_5 ha^{-1}, and 179 kg DAP ha^{-1} for mechanized farms, 26 kg P ha^{-1}, 59 kg P_2O_5 ha^{-1}, and 129.5 kg DAP ha-1for homestead land were estimated by Langmuir model. The EPR of traditionally cultivated land and mechanized farm were 22 and 18 mg P kg^{-1} respectively, which are equivalent to the application of 44 kg P ha^{-1} on traditionally cultivated and 36 kg P ha^{-1} on the mechanized farms and are greater than the amount of fertilizer application practiced on both land use systems by a factor of 2.2 for traditionally cultivated and 1.2 for the mechanized farms. Moreover, the rate of P being applied currently on the traditionally cultivated land is low compared to mechanize farm with respect to the EPR estimated from the Langmuir equation for each land use in this study. Thus, the application of P fertilizers based on the blanket recommendation in the study area might have resulted in a substantial yield deficit, i.e., which likely remained much below the maximum, owing to P deficiency.

Freundlich constants Kf and b, which represent the intercept and slope of the log-transformed sorption isotherm, may be taken as a measure of the extent of and energy of adsorption for the studied land use systems, respectively. The Kf could also be considered as capacity factor implying that a soil having a larger Kf value has superior adsorbing capacity than others and slope (b) show the effect of concentration on the adsorption capacity and represents adsorption intensity. Therefore, sorption capacity in Freundlich model determines whether the soil is high sorber or not relative to each other. The Freundlich coefficient Kf ranged from 44 to 70.5 mg P kg^{-1} with a mean value of 57.25 mg kg^{-1} (Table 3).

P sorption energy (b), which is also an indicator of the heterogeneity of the soil, ranged from 0.41 to 0.79 L kg^{-1}. The Kf values of the land use were in decreasing order of traditionally cultivated land >

mechanized > homestead > grassland > forest land systems.

Relationship between Soil and P Adsorption Parameters

The data revealed that P sorption maxima were positively correlated with clay content in both depths (r = 0.46) and (r =0.81) for 0-20 and 20-40 cm depth respectively (Tables 3 and 4). An increase in adsorption maxima values with an increasing clay content of the soil could be attributed to the availability of more surface for adsorption of added and native P as reported by (Bopari and Sharma, 2006).

Soil organic matter content was significantly ($p \leq 0.05$) and negatively correlated with Xm (r = -0.66) in 0-20 cm depth and (r = -0.75) in 20-40 cm depth. A significant ($p \leq 0.01$) negative correlation (r = -0.78) was observed between the soil available P and P adsorption maxima in 0-20 cm depth. Furthermore, sorption isotherm indices showed that Xm was negatively correlated with sorption energy of Langmuir (k) in both ranges of depth (r = -0.55) and (r = -0.65 for surface and sub-surface soils, respectively), showing that the soils might have high sorption sites but low sorption energy to hold P on the surface since it is a determinant factor for the soil to have high sorption capacity (Table 3).

Xm was positively correlated with SPR at both depth ranges indicating soils having high sorption maximum may also have high SPR. Soil pH was positively correlated with Xm in both ranges of depth, indicating that P sorption increases with increasing pH. Significant correlations were also observed between Freundlich adsorption indices and some soil physicochemical properties. There was a positive correlation between clay particle and Kf (r= 0.93 and r = 0.67) at 0-20 and 20- 40 cm depth respectively, illustrating that soil texture plays a major role in P adsorption of the soils types considered in the present study.

CONCLUSION

It is concluded that the selected soil physicochemical properties studied in the experiment varied widely in response to different land-use systems at Agarfa, southeastern Ethiopia, indicating that land-use systems have a profound impact on soil quality, fertility, and soil health in general. Soils in all land use systems are N and P deficient, which must be added to increase productivity.

The results of the P-adsorption isotherm study revealed that the P-adsorption data of soil samples taken from all land-use systems fitted well with both Langmuir and Freundlich equations suggesting that both equations can be equally employed to discriminate the soils of the study area with respect to P adsorption characteristics. The P-requirements of all experimental soils at P concentration of 0.2 mg L^{-1} were below 150 mg ha^{-1} indicating that all of them are low P-fixing soils. The blanket recommendation of P fertilizer in the study area may result in a substantial yield deficit, i.e., yield remaining much below the maximum, owing to P deficiency. Moreover, compared to the EPR estimated from the Langmuir equation for each land use in this study, the rate of P being applied currently on the traditionally cultivated land is low compared to mechanize counterparts. Therefore, the revision of fertilizer recommendation has to be considered for the different land-use types.

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