Greener Journal of Agricultural Sciences
ISSN: 2276-7770
Vol. 12(2), pp. 131-140, 2022

https://gjournals.org/gjas

Influence of Lime and Phosphate Fertilizer on Phosphorus Sorption and Desorption Property of Acid Soil: Review

Musefa Redi

Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, Ethiopia.

ARTICLE INFO

Article No.: *052822956*
Type: *Review*
Full Text: PDF. HTML, PHP, EPUB

Accepted: *31/05/2022*
Published: *01/06/2022*

***Corresponding Author**
Musefa Redi
E-mail: *musefaredi@ yahoo.com*

Keywords: *Acid soil; lime; phosphorous; sorption; desorption.*

ABSTRACT

A proper understanding of phosphorous (P) sorption-desorption property in acidic soils is very important for P fertilizer management practices. Soil acidity can be ameliorated with application of lime while phosphate fertilizer often applied to raise concentrations of available soil P to an adequate level. High levels of exchangeable Al3+ and clay minerals such as kaolinite, gibbsite and goethite are responsible for P sorption in tropical acid soils. Especially acid soils with a pH < 5.0, Al minerals hydrolyze to form octahedron hexahydrate (Al3+) and mononuclear hydroxides (Al(OH)2+ and Al(OH)2+) which are responsible for P sorption. Phosphate desorption in a soil can be enhanced by increasing the negative charge on the surface of soil particles either by raising the solution pH or by introducing a competitive anion. Raising pH through liming is an effective and dominant practice. According to this review, liming acid soil increases pH level but its influence on increasing P bioavailability with decreasing sorption and increasing desorption of P is still controversial especially on high exchangeable Al3+ acidic soils. When the soil exchangeable Al3+ is initially high, the formation of amorphous hydroxyl Al with highly active sorbing surfaces may exceed any decrease in the sorption capacity of the original sorbing surfaces, resulting in increasing P sorption as pH increases. This indicated that liming with the aim of increasing available soil P without application of P fertilizer should, therefore, be treated with caution as it may not always produce the desired effect.

1. INTRODUCTION

Acid soils are widespread and occupy about 4 billion hectares of the total world soils (vonUexkull and Mutert, 1995) with 58% of the land area suitable for agricultural production inhabited by 73% of the world's population. Under acid conditions, exchangeable Fe and Al come into solution presenting some toxicity problems and causing the deficiency of nutrients especially phosphorus (P). The deficiency of P occurs through adsorption reactions making it one of the most limiting nutrients for food production (Jubrin *et al*., 2000). The low P status of highly weathered acid soils is a particular problem and large amounts of P need to be applied in order to raise concentrations of available soil P to an adequate level (Sanchez and Uehara, 1980). Unfortunately, when P fertilizers are added to the soil, only a small fraction comes into solution for crop utilization. A large proportion which is variable amongst soils is retained through adsorption reactions by the soil constituents. The concentration of soluble reactive P in soil and P fixed by acid soil is thus controlled by Sorption- Desorption process.

Phosphate sorption (the loss of orthophosphate from soil solution to solid phases) is a process affects P fertilizer use efficiency. The estimation of P demands that allowance always be made for portion of soil P adsorbed by the soil constituents. This is necessary since adsorbed P is directly related to soil solution P (Agbede 1988). Phosphorus adsorption isotherm technique that uses the relationship between adsorbed P (capacity factor) and soil solution P (intensity factor) has been successfully used in predicting P requirement of crops in different soil systems (Agbede, 1988). Phosphorus desorption (the passage of phosphate from the solid phase to the solution, either by dissolution or desorption process) is also a key process determining inorganic P bioavailability. However, in order to use the desorption process; by using agriculture-based extraction indices, and correlating them with plant P uptake, a P desorption isotherm is required (Martin *et al*., 2002).

Liming is an effective and widespread practice for correction of pH and improving crop production on acid soils. In tropical regions, liming is frequently used to raise soil pH and increase P bioavailability (Sanchez and Uehara, 1980). However, published results regarding the effect of liming on P sorption and bioavailability are conflicting (Haynes, 1982). Phosphorus sorption has been shown to both decrease (Holford *et al*., 1994; Mora *et al*., 1999); and increase (Pereira and De Faria 1998, Curtin and Syers 2001) with increasing pH. Still other reports have shown no significant influence of pH (Jones and Fox 1978, Arias and Fernandez 2001). The objective of this paper is informative review on the influence of lime and P fertilizer (inorganic and organic) on P sorption and desorption property of an acid soil based on the available evidence currently in the literature.

2.1. Phosphorus in Acid Soil

Soil acidity is associated with hydrogen (H), aluminium (Al), iron (Fe) and manganese (Mn) toxicities and corresponding deficiencies of available P, molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium (K) (Jorge & Arrunda, 1997). The deficiency of P occurs through adsorption reactions making it one of the most limiting nutrients for food production (Jubrin *et al*., 2000). As a result, large amounts of P need to be applied in order to raise concentrations of available soil P to an adequate level (Sanchez and Uehara, 1980). Unfortunately, when phosphorus fertilizers are added to the soil, only a small fraction comes into solution for crop utilization due to high P sorption capacity of acid soils.

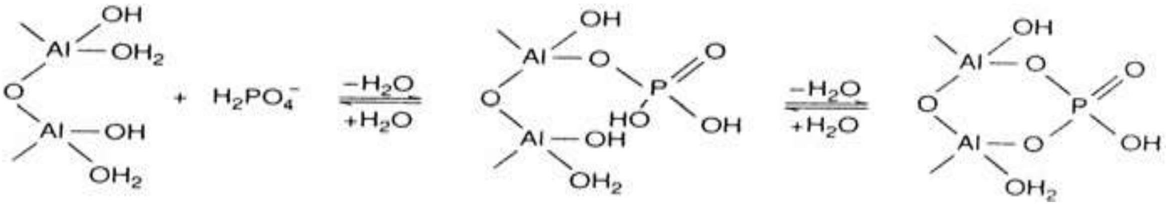
High P sorption in acid soils make crops to utilize only about 10-25% of the P fertilizer applied (Bahl and Singh, 1986). This is because of high levels of exchangeable Al^{3+} and Fe^{3+} in acid soil leads to P sorption through their reaction with phosphate ions and it forms insoluble compounds (Tisdale *et al*., 1990) such as variscite $AlPO_4{\times}2H_2O$ and strengite $FePO_4{\times}2H_2O$ (Smeck, 1985). Furthermore, in acid soils with a pH < 5.0, Al minerals hydrolyze to form octahedron hexahydrate (Al^{3+}) and mononuclear hydroxides ($Al\,(OH)^{2+}$ and $Al\,(OH)_2^{+}$) which are responsible for P sorption (Kochian, 1995). Also, P sorption can occur on the surfaces of soil particle such as positive edges of kaolinite clay in highly weathered acid soils. In general, the concentration of soluble reactive P in soil is thus controlled by sorption- desorption processes.

2.2. Phosphorus Sorption- Desorption Mechanisms.

Inorganic soil P (Pi) can be found in four operationally defined soil fractions; (i) Pi in the soil solution (Pi_1), (ii) Pi on the mineral surfaces in a pool where P is exchangeable in response to a disequilibria between the solid and solution phases (Pi_2), (iii) Pi on the mineral surfaces in a pool where Pi is released due to ligand exchange or congruent dissolution by a ligand that has more affinity for the mineral surface than does Pi (Pi_3), and (iv) Pi in the non-labile pool (which is not released for plant use; Pi_4). The relationship between the sorbed and solution forms of labile Pi_2 has been described by adsorption and desorption isotherms, however the relationship between adsorption and desorption is commonly hysteretic (Bhatti and Comerford, 2002). Raven and Hossner (1993) showed that the isotherm slope is generally steeper for adsorption than for desorption.

Phosphate sorption (the loss of orthophosphate from soil solution to solid phases) is a continuous sequence of adsorption and precipitation and consists of two processes, one relatively fast, reversible adsorption process and a relatively slow, practically irreversible precipitation-like process (van der Zee and van Riemsdijk, 1988) and it is difficult to distinguish adsorption and precipitation reactions from one another, they are usually referred to collectively as P sorption or fixation (Sposito, 1984).

Sorption of P seems to increase over time, apparently due to slow precipitation processes that are superimposed on the more rapid chemisorption. The amount of P in the soil solution appears to determine which reaction dominates. Chemisorption dominates at low solution P; while precipitation proceeds when the concentrations of P and associated cations in the soil solution exceed the solubility products (Ksp) of the relevant P compounds. In many situations, however, specific adsorption reactions are the main regulators of soil solution P concentrations (Parfitt, 1978).



Mechanism of P adsorption on Al oxide surface.

Desorption of sorbed P (i.e., the passage of phosphate from the solid phase to the solution, either by dissolution or desorption process) is markedly hysteretic. Similar to sorption, desorption occurs through ligand exchange with OH^-. However, desorption of P from soil surfaces is a much slower process than sorption. Phosphorus desorption studies determined bioavailable P by using agriculture-based extraction indices and correlating them with plant P uptake (Martin *et al*., 2002).

Nutrient uptake models commonly incorporate the adsorption or desorption isotherm as a way of representing Pi movement between the solution and solid phases (Barber, 1984) with P desorption being the preferred process (Yang *et al*., 1991). Several experimental techniques have been used to investigate P desorption. These include extraction of soil P with P-free solution (Barrow, 1983), addition of materials with high capacities to bind P in order to deplete P in soils (Amer *et al*., 1955), leaching of soil columns with P-free solutions (Sawhney, 1977), and sequential extraction and dilution (Raven and Hossner, 1994). During a sequential extraction of a soil sample, an extracting solution is added at a constant soil to solution ratio and the sample is shaken for a constant equilibration time. The extraction solution is replaced and the procedure is repeated a number of times. For the dilution method, soil samples are extracted over a range of soil to solution ratios at a constant equilibration time. In both cases, P is desorbed from the solid labile form in response to a low solution P concentration.

2.2.1. Use of sorption isotherms for describing sorption and desorption process

Phosphorus sorption isotherms are graphical tools for visual comparison of P sorption- desorption characteristics in soils. It describes the relationship between concentration of adsorbed and dissolved species under specified conditions i.e., temperature, time, and shaking period etc. Phosphorus sorption isotherms usually measured by mixing a known amount of soil with a solution containing a range of known P concentrations. Soil solutions are equilibrated (by shaking) for 24 hours at a constant temperature (Nair *et al*., 1984). The amount of P remaining in the solution is then analyzed. The differences in amounts of P added and P recovered in solution at each concentration after equilibration are considered P sorbed by soil (Pant and Reddy, 2001). These values are then plotted in a graph that forms the sorption isotherm.

This approach has an advantage over conventional method of soil testing in that it integrates P intensity, capacity and quantity aspect of the soil, all of which play important role in controlling the P flux to most of the growing plants. Moreover, fertilizer requirement can be estimated directly from P sorption curves. Soil solution P is an immediate source for plant P uptake (Holford, 1997) and standard solution P concentration (0.2 mg L^{-1}) provides adequate P for many crops if it is continuously maintained in the medium (Beckwith, 1965). Many equations e.g., Langmuir, Freundlich, Tempkin, Van Huay and Gunary have been used to describe P sorption in most recent work and have successfully confirmed phosphate sorption/adsorption relationships (Huang, 1998). The Freundlich and Langmuir adsorption isotherm models are usually used to describe sorption of different compounds by soils.

The Langmuir isotherm model: The Langmuir equation is an accepted and widely used means to describe the solid-solution reactions in soils. Olsen and Watanbe (1957) originally demonstrated the potential of the equation in studying P sorption, which was also supported by Vadas and Sims (1999). This model applies to relatively smaller amounts of adsorbed P and when more dilute equilibrium P concentrations are used (Olsen and Watanabe, 1957; McGechan, 2002).

The Langmuir equation implies that sorption occurs in a monolayer on the soil surface and that a further increase in P concentration above P sorption maximum would not result in an increased sorption. Even if this is not true in most cases, the sorption maximum derived from the Langmuir equation is useful for estimating P sorption capacity and for comparing different soils. Langmuir sorption isotherm equation provides both an estimate of sorption capacity and an estimate of the average sorption strength of the soil (Olsen and Watanabe, 1957; Pant and Reddy, 2001). It also provides a quantitative estimate of the effect of soil conditions on P sorption (Vadas and Sims., 1999). Phosphorus sorption maximum (S_{max}) values and bonding energy (K) can be determined using a modified Langmuir model (Reddy *et al*., 1998).

The common form of the Langmuir equation written as:

$$\boxed{\frac{C}{X} = \frac{1}{K\,S_{max}} + \frac{C}{S_{max}}}$$

The Langmuir model is often described in the linear form:

Where, C is solution equilibrium P concentration (mg l^{-1}), X (mg kg^{-1}) is the amount of P sorbed per unit mass of adsorbent, S_{max} (mg kg^{-1}) is the adsorption maximum, and k is a constant related to energy of sorption.

The Linear Langmuir isotherm constructed by plotting C/X Vs C, such that slope is equal to $1/S_{max}$ and the intercept is equal to 1/(k S_{max}) (Pant and Reddy, 2001). In the equation the sorption constant k, which is related to bonding energy of the soil for phosphate, is equal to the reciprocal of equilibrium P concentration at one half saturation (Olsen and Watanbe, 1957).

The Freundlich isotherm model: The Freundlich model is the oldest adsorption model in the literature on soil phosphate, first used by Russell and Prescott (1916). It is an empirical model and corresponds to a model of adsorption in which the affinity term decreases exponentially as the amount of adsorption increases. Over a limited range of concentration, the Freundlich model often describes adsorption well (Barrow, N.J., 1978). This model applies to a wide range of equilibrium P concentration (EPCo) and large amounts of adsorbed P and does not calculate the S_{max} value unlike Langmuir isotherm (Olsen and Watanabe, 1957).

The Freundlich equation has the form: $X = aC^{b}$

Where X and C have the same meaning as in the Langmuir equation, and a and b are empirical parameters.

Freundlich equation is often used in its linear form: $lnX = lnK + n\,lnC$

Where, K and n (n < 1) are adsorption constants, X (mg kg-1) is the amount of P sorbed per unit mass of adsorbent, and C (mg kg^{-1}) is equilibrium solution P concentration (mg l^{-1}).The parameters, lnK and n (mg kg^{-1}) determined as intercept and slope, respectively from the curve plotting the quantity of sorbed P against the P concentration in the equilibrium soil solution (Fox, 1981).

2.2.2. Soil properties affecting P sorption-desorption property

The P sorption capacities of soils are influenced by many factors. These include the soil organic matter, type of clay minerals, clay contents, oxides of Fe and Al, sesquoxides, exchangeable Fe and Al and pH (Hakim, 2002). The predominant clay minerals responsible for P sorption in tropical acid soils are kaolinite, gibbsite, goethite, Al and Fe oxides (Obura, 2008; Tisdale *et al*., 1990). It has also been reported that factors relating to exchangeable Ca and Mg, texture, porosity, bulk density, hydraulic conductivity, pH, ionic strength of competing ions (Bubba *et al*., 2003), soil temperature, time of reaction, soil redox condition and root exudates (Sanchez and Uehara 1980) also affect soil sorption capacity. All these factors are interactive rather than additive, which makes it difficult to predict inorganic P fixation under a wide range of soil conditions. Furthermore, the higher the Al and Fe oxide contents of soil clay and the less crystalline (more amorphous) the soil minerals, the greater is an acid soil's P fixation capacity. This is largely attributed to the greater surface area which these conditions represent higher clay contents also result in greater P fixation (Sanchez and Uehara 1980).

On the other hand, desorption is dependent on the nature of the adsorption complex. For example, Al and Fe compounds of variscite ($Al\,PO_4.2H_2O$) and strengite ($Fe\,PO_4.2H_2O$) are more stable than Ca compounds ($Ca_3\,(PO_4)_2$) of phosphorus and are expected to be prominent in acid soils, desorbing P at a slow rate. But phosphate desorption in acid soil can be enhanced by increasing the negative charge on the surface of soil particles either by raising the solution pH, or by introducing a competitive anion. Unequal ion distribution in the charged colloid surfaces surrounded by diffuse double layer causes anion repulsion or negative adsorption (Ahmed *et al*., 2008).

Several researchers tested the P adsorption on acid soils to find out the most important soil properties related with P sorption. For example, Mozed *et al*. (2010) studied P-adsorption characteristics on some acidic soil with pH 5.0 determined using Langmuir equation (Table 1). It was reported that the pH, clay and exchangeable Al were goodly indicate amount of sorption P while negative relationship between P adsorption capacity and Ca also observed.

Table 1: Simple correlation (r) between Langmuir adsorption constants, selected soil characteristics (n =5)

Soil Properties	S_{max}	K
pH-KCl	0.25**	0.68*
SOC (g Kg^{-1})	2.1NS	3.3NS
Ca ($cmol_c$ Kg^{-1})	-0.60*	0.53NS
Exch. Al (g Kg^{-1})	0.56**	0.78**
Clay (g/ Kg^{-1})	0.53**	0.35*

SOC: Soil organic carbon, Ca: Calcium, Exch. Al: Exchangeable Aluminum, S_{max}: Adsorption maxima, k: Affinity constant, **Significant at p = 0.01, *Significant at p = 0.05, NS: Not significant

Birru *et al*. (2003) also studied P sorption characteristics on some acidic soils from north western highlands of Ethiopia (Table 2). The magnitude of P required satisfying the sorbing sites of soils (Sorption maximum) was larger in soils 43 and 44 than the others. The sorption energy (lnK, Freundlich model) was found to be strong for the high P-sorbing soils. The energy of P sorption (affinity term) was consistently stronger for soils that absorb more P per unit gram of soil than for the low P-Sorbing soils. Moreover, the soil with high Al content (2.55 $cmol_c$ Kg^{-1}) had higher sorption capacity and sorption energy.

Table 2. Slope intercept and coefficient of determination (r^2) of the isotherm models of soils with some properties.

soil ref. no.	Location	pH-H_2O	Exch. Al ($cmol_c$ Kg^{-1})	OM[1] (%)	Langmuier equation[2]			Freundlich equation[2]		
					S_{max}	K	r^2	n	lnK	r^2
43	Dembecha	5.00	0.39	2.8	59.3	-20.4	0.09	1.16	7.9	0.95
44	Dembecha	4.36	2.55	3.0	58.8	-18.6	0.07	1.04	8.0	0.88
79	Machkel	4.75	0.49	3.3	16.6	-17.6	0.07	0.78	6.7	0.91
97	Enawga	5.76	0.13	3.9	6.3	-17.7	0.10	0.8	5.7	0.88

[2] S_{max} = slope (Sorption maximum); K= a constant for the Langmuir sorption equation; n = constant; lnK = intercept (Sorption energy) of the Freundlich equation; OM = Organic Matter; Exch. Al = Exchangeable Aluminum

The energy of P sorption, which plays the significant role in P sorption, was influenced by the direct and indirect effects of soil pH where the sorption maximum was due to the concentration of exchangeable Al (Birru *et al*., 2003). In general, the authors Mozed et al. (2010) and Birru *et al*. (2003) result revealed that exchangeable Al, clay and pH were the most important factors that influenced the P sorption capacity of acid soils.

2.3. P Sorption and Soil P Availability

A soil with a high sorption power will tend to release P slowly to the soil solution and vice versa, but clearly it is the quantity of P in the soil that ultimately affects P intensity. Buffer capacity of a soil can be estimated from the initial slope of a P sorption isotherm, which relates the quantity of P sorbed from a solution containing different amounts of P to the P intensity or P concentration remaining in solution. A sorption isotherm is also known as a quantity- intensity (Q/I) plot. Soil solution P is usually quite low due to complex interactions of phosphate with various soil components. Thus, plants must either employ mechanisms to increase the solubility or availability of these components or else rely on diffusion. Since sorption is to some degree reversible, sorbed P is a source of plant-available P either immediately or over a longer term (McDowell *et al*., 2001).

It is based on the principle that crop P requirement is directly related to the amount of P sorbed at a critical supernatant solution P known to be non-limiting to plants. This critical solution P concentration has been arbitrarily suggested to be 0.2 ppm and when continuously maintained in solution can provide adequately for crop production. The amount of P sorbed at the critical solution P concentration of 0.2 ppm is an important statistic for comparing the P adsorption capacity of soils with varying buffering capacities (Nnadi and Haque, 1985).

2.4. Influence of Lime on P Sorption-Desorption Property of Acid Soils

In acid soils and P deficient tropical soils where the plant capacity to scavenge the native or use added P with efficiency is critical (Swift *et al*., 1994), correcting soil acidity and P fertilizer addition are important. Liming is an effective and dominant practice to raise soil pH and reduce acidity-related constraints to improve crop yields (Fageria and Baligar, 2008). Its direct effect is soil pH increase (The *et al*., 2006).

As the soil surface charge can be managed by liming, it has been the focus of research on a variety of acidic soils. Lime contains Ca and /or Mg compounds that displace H^+, Fe^{3+} and Al^{3+} ions from acid soil colloids and reduces P sorption in acid soils resulting to increase in soil available P (Tisdale *et al*., 1990). Sanchez and Uehara (1980) also indicated that liming is frequently used to raise soil pH and increase P bioavailability. However, liming influence on increasing P bioavailability with decreasing sorption and increasing desorption of P need to be seen carefully.

The influence of liming on some Kenyan acid soils reported by Kisinyo *et al*. (2013) revealed that lime increased soil pH and decreased P sorption due to reduction in Al levels. The studied soils were strongly acidic with low base cations, CEC and available P with corresponding high Al levels and P sorption (Table 3). Application of lime increased soil pH and led to the observed reduction in P sorption at all the studied site soils.

Table 3. Langmuir P sorption parameters of some Kenyan acid soils

	pH-H_2O	Exch. Acidity (cmolc Kg^{-1})	Without Lime			With Lime		
			q (mg kg^{-1})	B (mg kg^{-1})	K (mg L^{-1})	q (mg kg^{-1})	b (mg kg^{-1})	K (mg L^{-1})
Sega	4.65	2.07	258.04	589.7	3.89	92.64	695	0.77
Bumala	4.62	2.01	106.83	956.0	0.63	73.71	805	0.50
Kuinet	4.55	2.24	138.60	818.0	1.02	69.21	794	0.47
Lavatory	4.07	4.29	401.91	655.0	7.94	161.45	605	1.82
Kangema	4.69	3.32	343.36	602.3	6.63	126.29	653	1.15
Kerugoya	4.85	2.71	388.43	610.9	8.73	120.17	660	1.11

q = P sorbed per unit soil mass at equilibrium concentration of 0.2 mg L^{-1}, b =adsorption maximum (mg kg^{-1}) and k = a constant related to the energy of bonding between soil phosphate ions and the surface of soil particles (mg L^{-1}).

Phosphorus sorption and desorption of a Brazilian Ultisol limed to pH of 5.9 and 7.0 was studied by Sato (2003). He reported that P sorption decreased by up to 21% when pH was increased from 4.7 to 5.9; and decreased by up to 34% when pH was increased from 4.7 to 7.0. Liming to pH values of 5.9 and 7.0 resulted in 2.8 to 4.5 kg P fertilizer ha^{-1} (calculated at 0.2 µg P mL^{-1} soil solution concentration) that was not sorbed and remained in the soil solution ready for plant uptake. Similar studies have reported increased soil pH, available P, reduction in Al levels and P sorption in acid soils due to lime application (Kanyanjua *et al*., 2002; The *et al*., 2006).

In spite of these, results concerning P sorption or solution P concentrations as influenced by liming have been conflicting (Haynes, 1982; Anjos and Rowell 1987). Phosphorus sorption has been shown to both decrease (Holford *et al*., 1994; Mora *et al*., 1999); and increase (Pereira and De Faria 1998; Curtin and Syers, 2001) with increasing pH. For example, Chen & Barber (1990) also showed that adjusting acid weathered acidic soils from pH 4.2 up to pH 8.3 increased sorbed P up to pH of about 6.0, and then decreased sorption at higher pH values. Haynes (1984) said that one should expect liming to increase P sorption in soils that are initially high in exchangeable Al^{3+}, but to decrease P sorption in soils with low exchangeable Al^{3+} content. When soils with low exchangeable Al^{3+} are limed, the neutralization and precipitation of Al^{3+} ion and of hydroxy-Al species to form Al hydroxide reduces the number of P-sorption sites. Where exchangeable Al^{3+} is initially high, the formation of amorphous hydroxyl Al with highly active sorbing surfaces may exceed any decrease in the sorption capacity of the original sorbing surfaces, resulting in increasing P sorption as pH increases. Haynes (1984) also said that, if an acid soil is reacted with lime and then phosphate, without intervening air drying, liming can increase phosphate adsorption. Air drying alters the surface characteristics of recently limed soils, probably by promoting the crystallization of the hydroxy-Al cation polymers as gibbsite.

Several studies focused on the effect of soil pH on P desorption (Hingston *et al*., 1974; Rupa *et al*., 2001). However, the results have been inconsistent; with some findings in increasing P desorption with increasing pH (Madrid and Posner, 1979; De Smet *et al*., 1998) and others with decreasing pH (Barrow, 2002). He *et al*. (1994) reported that P desorption decreased until pH was raised to about 4.8; and then increased with further pH increases for most of the acid soils from China which contained high Fe and Al oxide and/or kaolinite levels. In contrast, for three representative surface soils of India, both the amount and rate of P desorption initially increased with pH increase from 4.25 to 5.5; and then decreased at higher pH values of 6.75 and 8.0 (Rupa *et al*., 2001). Sato (2003) studied P sorption and desorption of a Brazilian Ultisol as influenced by liming. The author reported that P desorption increased as soil pH increased when a soil with pH-H_2O (4.7) and exchangeable Al^{3+} (0.07 $cmol_c$ kg^{-1}) limed to pH of 5.9 and 7.0. The result was because of total P desorbed; the ratio of P desorbed to P sorbed values increased as pH increased for all levels of P addition when soil pH was raised to 7.0. This resulted in an additional 0.2 to 1.0 and 0.7 to 2.7 kg p ha^{-1} that was desorbable at pH 5.9 and 7.0, respectively, which can be attributed to the effect of liming. In general, liming with the sole aim of increasing available soil P should, therefore, be treated with caution as it may not always produce the desired effect.

2.5. Influence of Lime and P Fertilization on P Sorption-Desorption Property of Acid Soils

When inorganic P is added to soil, sorption reactions proceed until a new equilibrium is reached as the sorption process is controlled by the concentration of P in solution (intensity) and the ability of solid phase to replenish P into solution (capacity). It is possible that when the adsorption sites are filled by phosphate ions, the percentage of extra added phosphate that is adsorbed may decrease with the increasing level of added P.

Opalla (2013) evaluated application of lime and organic materials on an acid soil. The researcher reported that application of phosphate fertilizer (TSP) in combination with lime slightly depressed the availability of P compared to application of TSP alone at the same P rate. When lime applied alone, it did not significantly increase the Olsen P above that of the control implying that lime was not able to mobilize or prime the P already fixed in the soil. Many other studies have investigated the effects of lime application on P retention and extractability, but consistent improvements in the availability of soil P have not been obtained (Curtin and Syers., 2001).

The results of Opalla (2013) further indicated that the amount of P adsorbed in equilibrium (q) with a solution P of 0.2 mg P L^{-1} as determined from the Langmuir equation, ranged from 162 mg kg^{-1} (Lime + TSP (60 kg P ha^{-1})) to 285 mg kg^{-1} (control) (Table 4). All treatments, apart from TSP applied alone, significantly lowered the P adsorption capacity of the soil compared to the control. This reduction in P adsorption was accompanied by a reduction in adsorption affinity, k, but not the adsorption maxima which were not significantly influenced by the treatments (Table 4). As mentioned earlier, lime applied in combination with TSP gave the lowest P sorption capacity (162 mg kg^{-1}) and was more effective than lime when applied alone (243 mg kg^{-1}). The result emphasizes that application P fertilizer after liming is useful in decreasing p adsorption (Table 4). In addition, organic fertilizer of FYM application in acid soil also decreases P sorption capacity. The mechanism behind may include complexation and competition for sorption sites by the products of OM decomposition such as the low molecular weight organic acids (Nziguheba, 1998).

Table 4. The Langmuir estimates i.e. adsorption affinity (k), adsorption maxima (b), and P adsorbed at 0.2 mg P L^{-1} (q) obtained from the Langmuir equation for the various treatments in the pot experiment.

Treatment	k (mg L^{-1})	Smax (mg kg^{-1})	q (mg kg^{-1})
Control (0 P)	3.51	691	285
Lime (0 P)	2.85	670	243
FYM (20 kg P ha^{-1})	2.8	689	209
TSP (60 kg P ha^{-1})	3.27	676	272
FYM (20 kg P ha^{-1}) + TSP (40 kg P ha^{-1})	2.13	703	247
Lime + TSP (60 kg P ha^{-1})	1.54	697	162
SED	0.35	NS	17
CV%	13.1	5.5	6.3

FYM is farmyard manure, TSP is triple superphosphate. SED = standard error of difference between means.

Application of organic fertilizers can play the dual role of providing nutrients and mitigating the deleterious effects of soil acidity and in this respect are therefore likely to be more cost effective than lime, which controls mainly only the soil acidity. Several studies have demonstrated that addition of organic amendments to soils can significantly increase the availability of P to plants and decrease the P adsorption capacity of soils (Easterwood and Sartain, 1990; Hue *et al*., 1994). The reduced P adsorption and increased P availability following applications of organic amendments of acid soils is thought to be the cumulative result of several mechanisms (Iyamuremye and Dick, 1996). These include release of inorganic P from decaying residues, blockage of P adsorption sites by organic molecules released from the residues, a rise in soil pH during decomposition and complexion of soluble Al and Fe by organic molecules.

3. CONCLUSION

A proper understanding of P sorption in acidic soils is very important for P fertilizer management practices. Soil acidity can be ameliorated with application of lime while inorganic P fertilizers are commonly used to mitigate P deficiencies. According to this review, liming acid soil increases pH level but its influence on increasing phosphorus bioavailability with decreasing sorption and increasing desorption of P is still controversial especially on high exchangeable aluminum acidic soils. When the soil exchangeable Al^{3+} is initially high, the formation of amorphous hydroxyl Al with highly active sorbing surfaces may exceed any decrease in the sorption capacity of the original sorbing surfaces, resulting in increasing P sorption as pH increases. Hence, liming with the sole aim of increasing available soil P should, therefore, be treated with caution as it may not always produce the desired effect.

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Cite this Article: Musefa, R (2022). Influence of Lime and Phosphate Fertilizer on Phosphorus Sorption and Desorption Property of Acid Soil: Review. *Greener Journal of Agricultural Sciences*, 12(2): 131-140.