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Review

Phosphorus in Sub-Sahara African Soils - Strategies and Options for improving available Soil Phosphorus in Smallholder Farming Systems: A Review

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In the Sub-Saharan Africa, soil-fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production. In the soils of this region, Phosphorus deficiency is widely considered the main biophysical constraint to food production in large farmland areas. Therefore there is a need to adopt measures in order to build up soil P capital especially among smallholder farmers who are economically poor. It has been reported that use of inorganic fertilizers is a fast and immediate way to avail P mostly for plant uptake and boost crop yields. Meanwhile organic fertilizers either alone or combined with inorganic fertilizer have also shown its importance in rising up soil available P and other adjacent contribution to promote nutrient uptake and lastly increase crops yield. This review paper explores the different alternatives which may be adopted by the smallholder farmers in SSA in order to build up soil available P and increase the yields of their crop.

Key words: Soil fertility, Soil available P, Fertilizer, Crop yields.

INTRODUCTION

For some time, the research community has recognized low soil fertility, particularly N and P deficiencies, as one of the major biophysical constraints affecting African agriculture (Sanchez et al., 1997). However, soil fertility in Africa has seldom been considered a critical issue by the development community, who until very recently have focused primarily on other biophysical constraints such as soil erosion, droughts, and the need for improved crop germ plasm (Sanchez et al., 1997). From nutrient balance studies and some field observations across Africa, it was concluded that soil fertility depletion in smallholder farms is the fundamental biophysical root cause of declining per capita food production in Africa, and soil fertility replenishment should be considered as an investment in natural resource capital (Sanchez et al., 1997).

Phosphorus deficiency is widely considered the main biophysical constraint to food production in large areas of farmland in Africa. Phosphorus dynamics in soils are complex, because they involve both chemical and biological processes and the long-term effects of sorption (fixation) and desorption (release) processes. The low concentration and low solubility of P in soils frequently make P a limiting factor. Phosphorus (P) is one of the major essential plant nutrients which is required in relatively high amount since it contributes not only for the growth and uptake of water and other plant nutrient as also is involved in maturity phase of most crops. However, smallholder farmers are faced with low crop yields, income and food scarcity due to low soil available P in most of Sub-Sahara African (SSA) soils. This is mainly due to diverse causes which include inherent poor soil fertility, soil acidity, over cultivation with no adoption of good management measures, soil erosion among others (Buresh and Smithson, 1997). These factors affect soil available P in different manners which include sorption of P by Al, Fe oxides and clay materials (Buresh and Smithson, 1997), physical lose through erosion and last by removal by crop through over cultivation (Jama et al., 2000).

The soil P pools in the soil include inorganic P and organic P which influence the labile forms of P in the soil and therefore the uptake by plants. The lower the amount of labile P in the soil solution the lower the uptake of crops and consequently the yields are low. It has been reported that use of inorganic fertilizers as also organic fertilizer have contributed to increase soil available P and yields of crops. Another alternative is the bio-fertilizers which include symbiotic mychorizas which contribute to P fertilization. The present review aims summarizing different alternatives which may be adopted by the smallholder farmers in SSA in order to build up soil available P and increase the yields of their crop.

Soil Phosphorus pools

In nature P pools include inorganic and organic phosphorus.

Inorganic phosphorus

The original soil source of soluble inorganic P is dissolution of primary P minerals, mainly apatite. Primary P minerals decrease in soil with increasing soil weathering and are relatively unimportant in highly weathered soils (Buresh and Smithson, 1997). The fate of inorganic P can be (i) taken up by plants, (ii) immobilized by soil micro-organisms and then converted to organic P, and (iii) sorbed onto soil minerals. Inorganic P in soil solution is partly replenished by mineralization of organic P.

Organic phosphorus

Total organic P decreases with continuous cropping without P fertilization (Adetunji, 1994), and total organic P as a fraction of the total soil P tends to increase with soil age. Total organic P is lower in sandy soils common in the semi-arid tropics than in medium-and fine-textured soils. A small fraction of total organic soil P is labile in the short term; the vast majority of soil organic P occurs in stabilized soil organic matter (SOM) and is not rapidly mineralized. Use of available soil P by plants and soil biota is the driving force for the conversion of inorganic P to organic compounds and the subsequent mineralization of organic P (Buresh and Smithson, 1997). Much of the P associated with soil biota is contained in bacteria and fungi. Amoebae, nematodes, and soil fauna generally contain only a small fraction of the P in soil biota, but they can be very important in the mineralization of organic P and the availability of P.

Options for rising up soil available P

Use of organic resources

Organic fertilizers are derived from plants and animal parts and have a wide role in agricultural production system (Gachene and Kimaru, 2003). When added to the soil they increase its organic matter content and improve soil physical properties. Furthermore, improvement in soil organic matter (SOM) leads to slow release of crop nutrients Nitrogen (N), Phosphorus (P) and Potassium (K)); improve buffering capacity of the soil and cation exchange capacity (Gachene and Kimaru, 2003). In addition, manures contribute to improve physical soil conditions contributing then for improved structure which in return improve water storage, infiltration capacity and reduce erosion and loss of nutrients (Rasoulzadeh and Yaghoubi, 2010; Liang et al., 2011; Salahin et al., 2011). However, manure quality and its P content depends more on the quality of manure which is then related to the feeding regime of the animal (Risse et al., 2006). Manure obtained from animals fed with supplements and grains are more expected to provide manure of high mineral composition.

Apart from animal manures, crop residues are incorporated in the soil in order to replenish the up taken nutrients by the crop. The use of organic resources requires presence of soil microorganism to decompose the organic material and make P contained in them available through mineralization process. Though it has been a common practice in most smallholder farmers to collect and burn crop residues. This practice in medium and long term contributes for reduced soil fertility through soil degradation and high risk for soil erosion.

Studies conducted by Maerere et al. (2001) and Odedina et al. (2011) have reported that application of manures increased soil available P in Tanzania and Nigeria, respectively. Manure applied to the soil affects the soil available P in different ways which include, forming complex with ions of Fe and Al in soil

Table 1. Soil status (pH and available P) resulting from lime and phosphate applications at Nyabeda, Siaya in season I and II during 2004.

Treatments	Season I		Season II	
	pH	Available P	pH	Available P
Control	5.02^{d}	1.06^{a}	4.87^{d}	2.20^{a}
Lime1	5.45^{h}	2.81^{c}	5.27^{g}	6.77^{c}
Lime2	5.50^{i}	2.81^{c}	5.22^{f}	6.41^{b}
Lime3	6.06^{l}	3.35^{d}	5.33^{h}	6.39^{d}
DAP1	4.96^{c}	8.46^{e}	4.49^{a}	9.36^{f}
DAP2	4.94^{b}	8.63^{g}	4.54^{b}	9.65^{l}
DAP3	4.91^{a}	9.37^{k}	4.59^{c}	9.59^{h}
DAPLime1	5.40^{f}	9.37^{i}	5.01^{d}	10.21^{e}
DAPLime2	5.68^{j}	11.44^{l}	5.23^{f}	10.61^{b}
DAPLime3	5.79^{k}	14.1^{m}	5.20^{e}	10.38^{g}
RP1	5.46^{h}	8.01^{f}	5.54^{k}	13.13^{j}
RP2	5.42^{g}	8.45^{h}	5.45^{i}	12.97^{k}
RP3	5.38^{e}	9.06^{i}	5.46^{j}	12.87^{m}
SE	0.00628	0.00076	0.00618	0.0012

Adapted (Nekesa et al., 2005)

solution, preventing the precipitation of phosphate (Suge, Omunyin and Omami, 2011), gradually neutralization of the soil acidity hence makes fixed phosphorus available in the soil solution (Onwonga et al., 2008; Mwangi et al., 2002), and create conditions for mineralization (Toor, 2009). Manure also may provide more favourable environments for microbial activities and possibly results net mineralization of soil organic P. In a study conducted in UK Hooda et al. (2001) reported that high P accumulation was observed high under manured treatments than in mineral fertilized ones.

Inorganic resources

Inorganic sources of P include mineral fertilizers and Rock Phosphate (RP). Mineral fertilizers used to supplement soil P and are of immediate availability to the plant uptake. Most of P fertilizers used in SSA include Triple Super Phosphate (TSP), Mavumo, Single Super Phosphate (SSP), Diammonium Phosphate (DAP) which are mostly manufactured and commercialized by agricultural input companies; and the Rock Phosphate.

Some of these fertilizers, such DAP, apart from supply of P they also contain Nitrogen nutrient. Most researches have reported the influence of mineral P fertilizers on crop yields but less changes are observed in the soil available P. In part this is due to the application method adopted which consists on band placement that is justified by the low or immobility of P in the soil. Therefore such application method does not contribute with significant increase in soil available P (Kamara et al., 2008). It has an explanation which stands on the fact that when the fertilizer P is applied as placement and the nutrient is immobile within the soil but the sampling for soil P analysis is done between the row of crops naturally will result in very low P than when it is done within the row with the risk of sampling the fertilizer.

However, the efficiency of mineral fertilizers may be affected by the application method, clay content of the soil and soil acidity (Buresh and Smithson, 1997). Under acid soils with high content of Al and Fe oxides, P is held and its availability reduced. Also under high clay content soils P is sorpted. RP is a naturally occurring rock containing P which may be used to supply P to the soil. This is more adequate under soils with moderate to high acidity level to ensure rapid dissolution and release of P to the soil. Nekesa et al. (2005) when working in acid soils of Western Kenya reported that RP increased significantly soil available P (Table 1).

Adoption of Integrated management practices

Integrated management of soil to rise up soil available may be seen as the best option. The use of small amounts of inorganic P fertilizers (in band placement) combined with organic resources as broadcast and incorporated in the soil. The use of organic will also promote micro-organism development with increased mineralization. Moreover, organics will contribute to increased soil physical conditions which will result in improved soil conditions and reduced risk of erosion. This combined effects will result in the increased soil available P in a sustainable manner. As result of this the soil will not only benefit from P but also other crop nutrient required.

As stated before that soil acidity contributes for low soil available and to the success on programmes implemented with the objective of promoting soil available P. Under this conditions it's recommended the use of lime to raise soil pH to an adequate level and (i) increase availability of P which was immobilized by Al and Fe oxides, (ii) create soil conditions for micro-organism's development to enhance then organic matter decomposition and mineralization of nutrients, (iii) development of good conditions for root development.

Thus, integrated application of mineral fertilizer with lime as resulted in improved soil available P (Table 1). However it is expected to cause a slow increase in soil P when lime is combined with RP which may be due to the need of acidic soil conditions to enhance RP dissolution.

Combined use of organic and inorganic soil amendments has been investigated, recommended and adopted. It has shown the positive effects on soil fertility management such as rise up of soil available P. Panneerselvam et al. (2000) reported increased soil available P under application of manure together with inorganic fertilizers.

CONCLUSION

Soil P is a controversial nutrient required by the crop which is affected mainly by soil conditions. In order to build up the soil P farmers should adopt the use of organic resources which supply nutrients in a long term manner. Since smallholder farmers lack financial resources to purchase inorganic fertilizer they can successfully replace them with organic manures. Although, where the financial resources are available the integrated use of organic and inorganic P resources may be the best option.

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