Review Article

Phosphate Fertilizer Sources and Use in Africa: Challenges and Opportunities

ABSTRACT

Most African soils are low in phosphorus (P) and farmers are increasingly using more P fertilizers to improve crop production. Phosphate rocks (PR) deposits which are the major source of P are unfortunately finite. This is likely to cause world food crisis, especially in Africa due to its high human population growth rate. Conflicting information on the quantity of existing PR reserves has made it difficult to accurately predict how low they would last so as to plan for its judicious use. World PR deposits are currently estimated at 290 billion tonnes and potentially 490 billion tonnes. These reserves at the current production rate of 160 - 170 million tonnes per year are likely to be depleted between years 2311 and 2411 and Africa will be most affected due to high human population grow rate. With the eminent threat of PR deposits depletion, African therefore needs to adopt farming practices that will reduce the use of P fertilizers without negatively affecting its crop productivity. Practices such as soil erosion control, use of P efficient crop germplasms, P solubilizing organisms and organic materials are perceived to reduce soil P loss and increase its use efficiency by plants.

Key words: Soil fertility, phosphorus, phosphate rocks, depletion, reserves,

1. INTRODUCTION

1.1 Importance of Phosphorus in Plant Nutrition

Phosphorus (P) is an essential plant nutrient and as a result crop response to P fertilizer applications are widespread. Total P in plant tissue ranges from about 0.1 to 1% and it plays both metabolic and structural roles in plants [1]. Metabolic roles include: photosynthesis, synthesis and breakdown of carbohydrates and energy transfer processes within the plant. The energy obtained during photosynthesis and carbohydrate metabolism is stored in energy rich phosphates compounds namely; adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Phosphorus is a structural component of nucleic acids, coenzymes, nucleotides, phosphoproteins, phospholipids and sugar phosphates [2]. Large amounts of P are deposited in reproductive cells; therefore, it is essential for seed and fruit formation, faster grain maturity, quality and strong cereal straws. Phosphorus is also important for good root development and growth [2, 3]. Common P deficiency symptoms include purple or bronze colouration appearing on lower leaf tips, progressing along the leaf margins until the entire leaf is discoloured. Since P is mobile within the plant, its deficiency symptoms are first expressed on lower leaves [3]. Phosphorus deficiency in soils therefore interferes with photosynthesis, protein synthesis, respiration and biomass production in plants.

Crop responses to application of various P sources in Africa soils are enormous. Inorganic P fertilizers have increased soil P levels and crop productivity in many African countries [8].

1.2 The Process of Soil Phosphorus Depletion in Africa

The major contributing factors to soil fertility depletion in Africa are breakdown in traditional practices and low priority given to the rural areas. Increasing pressure on land due to high human population has led to breakdown in traditional farming systems whereby fallowing, cereal-legume intercropping, mixed crop-livestock farming and opening of new lands maintained soil fertility [4]. Limited attention is given by African governments to rural areas where farming is carried out. As a result most smallholder farmers, who produce about 90% of its food, lack the credit to purchase fertilizers to replenish soil fertility. In 30 years (i.e. from the year 1967 – 1997), about 75 kg P/ha was lost from about 200 million cultivated land in 37 African countries [5]. The continent is now loosing 0.5 million tons of P every year from its cultivated lands which is much higher than its annual consumption of 0.26 million tons P [6].

Nearly three-quarters of farmlands in Africa are nutrient depleted, lowering crop yield to one-quarter of the global average [7]. At the same time, more nutrients continue to be removed each year than are added in the form of fertilizer, crop residues and manure. Nutrient balance studies in the 1990s suggested average annual P depletion of 2.5 kg P/ha [5]. Intensively cultivated highlands in East Africa loose an estimated 5 kg P/ha year, whereas croplands in the Sahel loose 2 kg P/ha [8]. Therefore, most African soils have low levels of soil available P to support high crop production required for its already high and increasing human population.

1.3 Sources of Phosphorus for Soil Fertility Replenishment

Phosphorus is the second most limiting nutrient to crop production after nitrogen (N) in many tropical soils including Africa [9]. While soil N can be replenished through biological nitrogen fixation from atmospheric sources, P sources are not renewable through such biological means [5, 10]. Therefore, soil P replenishment is mainly through inorganic fertilizer sources from phosphate rocks (PR) with minor sources from manures, guano and human excreta [11]. The main source of P fertilizer is finite and this poses a great danger to world food production, especially in African due to its high human population growth rate compared to other parts of the world.

1.4 Phosphorus Fertilizer Use in Africa Compared to Other Parts of the World

Farmers in Africa are becoming aware of the importance of using fertilizer to increase crop production [12]. As a result the demand for fertilizers such as those containing phosphorus is on the increase. Between the years 1950 and 2000, global use of fertilizers that contain P, N and K increased by 600% [13]. The increase is linked to soil fertility depletion. Average annual fertilizer use in Africa is only about 17 kg per ha, compared, for example to 85 kg/ha in North America, 96 kg/ha in Latin America and 196 kg/ha in Asia. Even this low rate of consumption is restricted to just a few African countries. Sub-Saharan Africa, excluding South Africa, uses about 5 kg per ha per year of fertilizer, of which less than 30 per cent is phosphorus [14]. With this background, it is apparent that on average Africa uses about 5.1 kg P fertilizer per ha/year. The continent looses between 2 and 5 kg P/ha through crop harvest from its farmlands [8]. On African's high potential areas with acid soils crops recover only 10 – 25 % of the applied P fertilizers [15, 16]. Crops therefore recovers only about 0.5 – 1.3 kg P per ha of the applied P fertilizers. As a result, the rates of P fertilizer applied by African farmers are insufficient to balance off the amounts taken up by crops as well as those fixed in acid soils. A combination of high cost and low accessibility to credit prevents many African farmers from acquiring fertilizers. Poor transport, low trade volumes and lack of local production or distribution capacity resulting in farm-gate fertilizer prices two to six times higher than the world average. Nevertheless, fertilizer is needed to achieve adequate and sustainable crop yields. The Africa Fertilizer Summit [17] concluded that a lasting solution requires policies to sustain robust distribution networks; including adequate credit sources, retail outlets and transportation, as well as the transfer of technology and knowledge for efficient fertilizer use.

2. WORLD PHOSPHATE RESERVES

It is not easy to ascertain the quantity of world phosphate reserves. Knowledge of phosphate rock deposits is evolving, along with technology and the economics of production [18]. Compared to fossil fuel, most deposits of PR are found in very few countries. Most reserves are found in Morocco, the USA and China (Table 1). The reserves are estimated to be about 16 billion tons [19]. These reports also suggest that estimates are not comprehensive, as they do not include deposits in all countries. A recent report from the International Fertilizer Development Center (IFDC) on reserves and resources provisionally revised the estimate of phosphate rock reserves from the United States Geological Survey (USGS) estimate of around 16 to 60 billion tonnes [19], which is somehow consistent with the most recent USGS report [20].

The IFDC report estimates world's phosphate reserves to be approximately 290 billion tonnes and potentially as much as 490 billion tonnes [19]. It seems the world phosphate reserves are underestimated given the fact that they are continually being revised upwards as more reserves are discovered. At the same time the deposits with small quantities in Africa such as Minjingu in

Tanzania, Busumbu and Sukulu in Uganda among others are not listed [21]. Since not all the reserves are quantified, it's likely that the deposits are still under-estimated even with these recent upward predictions. Therefore, there is need to accurately estimate the quantity of all the deposits for proper planning for use of this vital resource.

Table 1. World phosphate reserves

Country	Morocco	China	USA	Jordan	Russia	Brazil	Syria	Israel	South Africa	Tunisia	Australia	Egypt	Senegal	Togo	Canada	Other Countries
Billion tons	51000	3700	1800	900	500	400	250	230	230	85	82	51	50	34	50	600

Sources: [19, 20]

3. LIFESPAN OF WORLD PHOSPHATE ROCK RESERVES

There is conflicting information on how long PR reserves would last. However, how long they will last is dependent on their quantity, quality and rate of mining. Knowledge of phosphate rock deposits is evolving, along with technology and the economics of production [18]. It is predicted that peak phosphorus production will occur between the years 2030 and 2040 [11]. The estimate was based on USGS data for global phosphate reserves [20]. It is suggested that world PR reserves depletion would occur in 50-100 years [22] meaning that it will be between the years 2058 and 2108. However, recent upward estimates of the extent of the PR reserves to about 60 – 160 billion metric tonnes have pushed upward when the reserves would be depleted [19, 20]. A report by IFDC indicates that there are sufficient PR reserves to produce P fertilizers for the next 300-400 years at current production rates of 160 to 170 million tonnes per year. This prediction therefore indicates that the PR deposits would be depleted between the years 2311 and 2411. To cater for the increasing demand for P fertilizer due to population increase, the rate of PR mining is likely to increase making the reserves to be depleted sooner than later. This is likely to pose food crisis in Africa given its high population growth rate compared to other parts of the world. This date of depletion is with an assumption that the rate of mining and consumption will remain the same, which is unlikely scenario. Small PR reserves are not included and more discoveries are expected to be reported in future, therefore it is likely that the depletion would take longer than expected. A number of deposits particularly in Africa are not economically viable since they have very low P content [21] and therefore not worth exploiting.

4. OPPORTUNITIES FOR AFRICA TO IMPROVE PHOSPHATE FERTILIZER USE EFFICIENCY

Rock phosphate sources are non-renewable, hence the need for Africa to adopt best practices to help prolong the lifespan of existing PR deposits. Morocco has the highest world PR reserve, however, it has export restrictions to preserve its deposits [19]. A part from Morocco and Egypt, the rest of African countries import phosphate fertilizers. This therefore calls for African as a continent to put in place practices that will minimize P fertilizer losses as well as improving it use efficiency by plants. Such practices include soil erosion control, use of P efficient crop germplasms, P solubilizing organisms and organic materials among others as discussed below. The practices are likely to reduce the amount of P fertilizer required by the continent.

4.1 Soil Erosion Control

Most plant nutrients are found in the topsoil and therefore removal of topsoil through erosion reduces soil fertility. Protecting the topsoil from soil erosion therefore minimizes nutrient losses. Run-off and erosion combined are responsible for 48 and 40 per cent of phosphorus losses in intensively cultivated highland areas and in parts of the Sahel, respectively [8]. Africa looses about 0.47 tons per ha per year of its topsoil [23]. Soil erosion accounts for about 75-90% soil P losses in Africa estimated at 1.0 kg P loss ha per year [8, 25]. A number of soil erosion control techniques exist. Ploughing across rather down the slope and planting of hedgerows on steep lands greatly reduce soil erosion. Soil vegetation cover is one of the best ways to control soil and nutrient losses due to erosion. African farmers need to use mulches, cover crops and fertility enhancing systems on low-fertility soil to minimize soil erosion losses [26].

Given the extent of soil fertility losses through erosion, there is need for African countries to put in place measures to curb these losses. Farmer education on soil erosion control and creation of awareness on the available control measures are important. African countries also need to formulate and put in place policies on soil erosion control measures. These will help maintain high soil fertility levels through minimization of nutrient losses such as P.

4.2 Use P Efficient Crop Germplasms

Most African soils are inherently low in soil available P. This is exacerbated by the fact that a vast majority of this P is not readily available to plants. Traditional systems of farming thus, unknowingly, relied on growing crop species with low P requirements [27]. Large proportion of P in African soils is unavailable for plants uptake due to its fixation particularly in high to medium agricultural areas with acid soils [5]. In modern agriculture, continuous use of P fertilizers over many years has increased the total P levels in the soils but the available P remains low [28]. The unavailable P can represent a reserve which can be exploited by crops that are well adapted to extraction of P from less available soil fractions [29].

Many trees, shrubs and important crop species grown in Africa have the ability to exude organic acids from their roots or have mycorrhizal associations that help dissolve inorganic P that are not otherwise available to plants [5]. Other P acquisition strategies that are used by adapted species include excretion of phosphatases to release the organically bound P and provision of extra carbon as a booster of microorganisms, which in turn, also produce organic acids as well as phosphatase [30]. There is, therefore, a campaign in some quarters to tailor plants to fit the soil through genetic improvement in the belief that it is more economical than changing the soil. There may be reasonably good prospects for improving the efficiency of P use by plants by selecting appropriate genotypes with characteristics for root hair length, organic acids production in the rhizosphere, and mycorrhizal associations for soils with low P [31]. It has been reported that some of the genotypes express a protein kinase gene called phosphorous starvation tolerance gene (Pstol1), which enables acquisition of P and other nutrients [32] even in P deficient soils.

To deal with low soil available P related problems, plant breeding programs have developed germplasms tolerant to low soil P [33, 34]. Studies in Africa have reported maize and sorghum germplasms that are P use efficient [35-37]. These elite materials provide a good foundation for breeding for P use efficiency. Currently, there are no commercial maize, sorghum or other crop varieties available to farmers that are adapted to low P soils [35]. There is need therefore, to develop crop varieties for Africa that are P use efficient to enhanced crop productivity on low P soils. Use of P efficient crop germplasms will make both the native and the applied P fertilizer normally fixed on medium to high potential areas with acid soils available for plants uptake [3, 5]. It is important to note this management option is not sustainable without application of P fertilizers, because the removal of P in the harvested produce will eventually lead to a decline in total soil P levels.

4.3 Use of Phosphorus Solubilizing Organisms

Almost 75–90% of added phosphatic fertilizer is precipitated by metal cation complexes present in soils [38] and has led to accumulation of P in forms that are not available for plants uptake. Further, it has been suggested that the accumulated phosphates in agricultural soils are sufficient to sustain high crop yields worldwide for about 100 years [39]. Thus, the dependence of fertilizer production on a fossil energy source and the prospects of the diminishing availability of costly input of fertilizer production in years to come have obviously brought the subject of mineral phosphate solubilization to the forefront [40]. P-solubilizing activities in agricultural soils are considered to be environmentally friendly alternative to further applications of mineral based P fertilizers [41]. Under diverse soil and agro-climatic conditions, the organisms with phosphate-solubilizing abilities have proved to be an economically sound alternative to the more expensive superphosphates and possess a greater agronomic utility [40]. Use of phosphate solubilizing bacteria as inoculants increases soil P availability, P uptake by plants that reduces external P-fertilizer application rates, reduces environmental pollution and promotes sustainable agriculture. The introduction of mycorrhizae into soils has also been suggested for improving the availability of soil P, but initial enthusiasm for these has waned [5]. Mycorrhizae are important for many plant species when grown in P-deficient soils, but much less effective where soil P status is adequate. Enhancing the availability of soil fixed P through use of P solubilizing organisms is one way farmers in Africa can reduce the use of fertilizers, thus prolonging the lifespan existing PR reserves.

4.4 Use of Organic Materials

With increasing costs of the inorganic fertilizers and the finite nature of PR, it is imperative to explore alternative phosphate sources. Before the advent of inorganic P fertilizers, crop production relied on native soil P and the addition of locally available organic matter, mainly animal manures [11]. The unavailable P could be made available to other subsequent crops after decomposition of the residues of P use efficient plants [42]. Organic P sources vary widely in terms of P concentration, chemical form and state (solid, liquid or sludge). They include animal manures, composts, crop residues, green manures and human excreta. In most cases however, their P content is often too low to meet the crop nutrient demands [43]. Organic materials (OMs) can improves plant P use efficiency of both the native soil P and applied P fertilizers; therefore reducing on the need for fertilizer P inputs [44]. Use of OMs for soil fertility management in Africa face challenges such as inadequate amounts available to farmers and their low nutrient levels. Their low nutrient contents requires application of large volumes which increases the labour costs that cannot be offset by the crop yields obtained [44, 46]. Therefore, OMs suitable for use as P sources should have a high P content and low cost of production to make them economically viable to farmers [47]. A part from using from high quality OMs, the quality of organic materials can be enhanced through pit storage and manure storage under shade [48]

A lot work in Africa on use of OMs has not focused on use of human wastes. Human beings produce large amounts of excreta (faeces and urine), that can provide adequate amount of organic materials for soil fertility management. Human urine has been reported to contain P, N and potassium (K) in the correct ratios, necessary for plant nutrition [49]. Studies in African countries such as Zimbabwe have revealed that nutrients content in one person’s urine are adequate to produce 50-100% of the food requirement for another person [49]. Challenges on human excreta handling has been resolved by development of guidelines that minimize health risks [50]. Many Africans consider food produced from human excreta unfit for human consumption. As a result there is need to create awareness among Africans that food produced using human excreta is safe if the guidelines are properly followed.

5. CONCLUSION

Most African soils have low soil available P and crop responses to its applications are widespread. Use of fertilizers such as P in African as a continent to feed in its human population is on the increase. Future use of P fertilizer faces a major change since its major source, the PR deposits are finite. This is likely to cause food crisis in Africa due to its high population growth rate. It has not been easy to accurately quantify PR reserves, thus making it difficult to predict how long they will last so as to plan for its judicious use. However, with estimates of 290 billion tonnes and a potential of 490 billion tonnes reserves at the current production rate of 160 - 170 million tonnes per year they are likely to be depleted between years 2311 and 2411. With eminent PR reserves depletion, Africa needs to adopt farming practices that will minimize P losses as well as improving its availability to plants to help reduce use of inorganic P fertilizers. Soil erosion control is one of such measures that should be adopted to minimize top soil P losses. Large amounts of soil P in Africa soils particularly in acid soils are fixed. Use of P use efficient crop germplasms and P solubilizing organisms are some of the practices that can help African farmers exploit fixed soil P thereby reducing external P fertilizer use. Unfortunately there are no improved P use efficient crop germplasms in Africa, therefore the need to develop such germplasms. Another practice that can help reduce use of inorganic P fertilizers is application of organic materials since it increases soil P and improves its availability in soils. Use of organic materials in Africa faces challenges such as low quantities available to farmers and low nutrient contents. Human urine as organic source should be exploited since it has right nutrient contents necessary for healthy plant growth.

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