Review Article

Current And The Future Of Phosphate Fertilizer Use In Africa: Challenges And Opportunities (A review)

ABSTRACT

Phosphorus (P) is an essential plant nutrient, however its main source, phosphate rocks (PR) is finite. This poses world food crisis, especially Africa due to its high population growth rate. Most African soils are low in P and farmers are increasingly using more P fertilizer for crop production. The information on the existing PR deposit reserves is conflicting making it difficult to predict how low they would last for properly planning for its use. The most recent information predicts about 290 billion tonnes and potentially 490 billion tonnes PR deposit reserves existing. With the current production of 160-170 million tonnes PR per year, it's predicated that the deposits will be depleted between the years2311 and 2411. Africa will be most affected due to its low crop yields yet it has the world's highest human population growth rate. To prolong the lifespan of the existing PR deposits, soil erosion control, use of P efficient crop germplasms, P solubilizing organisms and organic materials are perceived among best practices suitable for Africa. Human excreta as an organic source, particularly urine has the highest potential since it is rich in plant nutrients necessary for healthy plant growth.

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 its 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 leaves 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]. Therefore, P deficiency in soils interferes with photosynthesis, protein synthesis, respiration and biomass production in plants.

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 sector. 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]. Little attention is given by African governments to rural areas where farming is carried out. As a result most small holder farmers who produce about 90% of food in Africa 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 losing 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, while 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 Soil phosphorus sources

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 rock phosphates 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 African with the highest human population growth rate.

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 of fertilizer such as phosphates is on the increase. Between the years 1950- 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 (Figure 1). 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 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. These levels are insufficient to balance off the amounts taken up by crops. A combination of high cost and low accessibility 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 sustainable crop yields. The Africa Fertilizer Summit [15] 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.

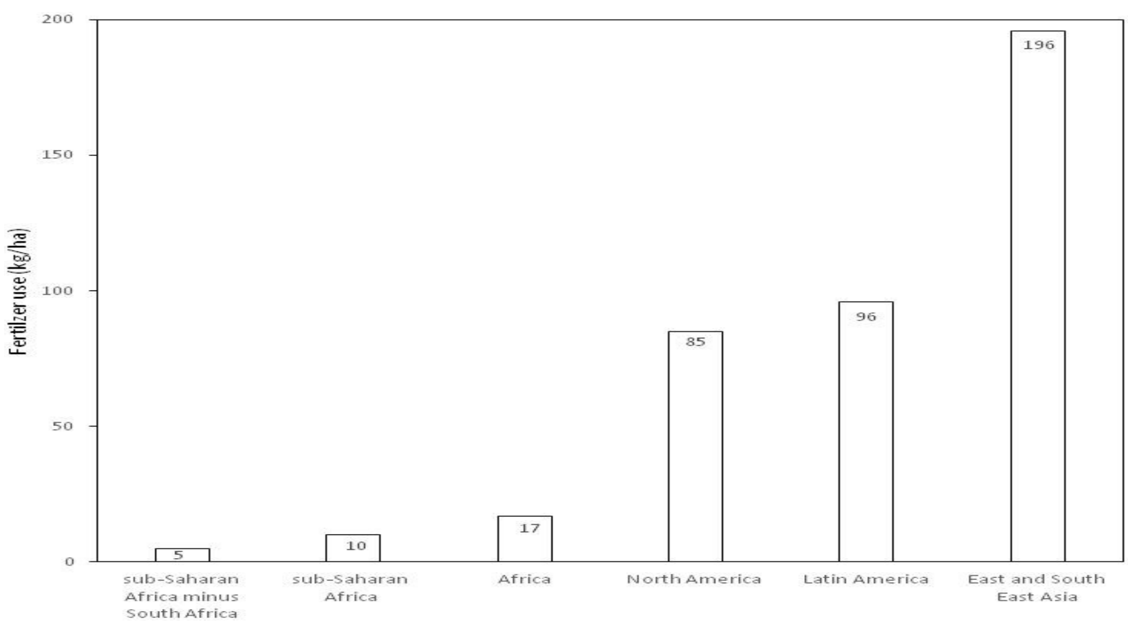

Figure 1. Regional disparities in the application of fertilizers containing nitrogen, phosphorus and potassium. *Source:* [14]

2. WORLD PHOSPHORUS DEPOSITS RESERVES

It is not easy to ascertain the world phosphate reserves. Knowledge of phosphate rock deposits is evolving, along with technology and the economics of production [16]. 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 [17]. These reports also suggest that estimates are not comprehensive, as they do not include deposits in all countries. A recent report from the 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 [17] which is somehow consistent with the most recent USGS report [18].

The International Fertilizer Development Center (IFDC) report estimates world's phosphate reserves to be approximately 290 billion tonnes and potentially as much as 490 billion tonnes [17]. 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 amounts such as Miming in Tanzania, Bujumbura in Uganda among others are not listed as part of the reserves. 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	Africa	Tunisia	Australia	Egypt	Senegal	Togo	Canada	Countries
Tons in	51000	3700	1800	900	500	400	250	230	230	85	82	51	50	34	50	600

Sources: [17, 18]

3. LIFESPAN OF WORLD EXISTING PHOSPHORUS DEPOSITS RESERVES

There is conflicting information on how long PR deposits will 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 [16]. 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 [18]. Early reports under estimated PR deposits reserves (van Kauwenbergh 2010) and therefore the predictions on how long they would last were inaccurate. It is predicted that PR reserves in USA will be depleted in the year 2049 [19]. It is suggested that world PR reserves depletion would occur in 50-100 years [20] meaning that it be between the years 2058 and 2108. However, recent upward estimates of the extent of the PR reserves of about 60 – 160 billion metric tons have pushed upwards when they would be depleted [17, 18]. 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 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 compared to other parts of the world

4. OPPORTUNITIES FOR AFRICA TO HELP PROLONG THE LIFESPAN ROCK PHOSPHATES DEPOSITS

Rock phosphate sources are none renewable, therefore the need for Africa to adopt best practices to help prolong the lifespan of existing PR deposits. Such practices include soil erosion control, use of P efficient crop germplasms, use P solubilizing organisms and use of organic materials among others. Preceding sections discusses some best farming practices than can enhance soil P availability, thus prolonging the lifespan of the existing PR deposits by African countries. The practices are likely to reduce the amount of P fertilizer required in Africa

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 such as phosphorus. Africa looses about 0.47 tons per ha per year of its top soil [20]. Soil erosion accounts for about 75-90% soil P losses in Africa estimated at 1.0 kg P loss ha per year [8, 22]. 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 [23].

Given the extent of soil fertility losses through erosion, there is need for African countries to put in place measures to curb the vice. Farmer education on the importance of soil erosion control and the available control measures is important. African countries also need to formulate and put in place policies on soil erosion control measures. These will help maintain soil fertility level through minimization of nutrient losses.

4.2 Use P efficient crop germplasms

Most tropical 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 [24]. 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 levels remain low [25]. 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 [26]

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 not otherwise available to plants [5]. Other P acquisition strategies that are used by adapted species include excreting 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 [27]. 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 acid production in the rhizosphere, and mycorrhizal associations for soils with low P status [28]. 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 [29] even in P deficient soils.

To deal with low soil available P related problems, plant breeding programs have developed germplasms tolerant to low soil [30, 31]. Studies in Africa have reported maize and sorghum germplasms, P use efficient have been identified [32-34]. 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 [33] Therefore, there is need to develop crop varieties in Africa that are P use efficient to enhanced crop productivity. Use of P efficient crop germplasms will make both the native and the applied P fertilizer normally fixed in acid and alkaline soils available for uptake [3, 5]. It is important to note this management option is not sustainable without application of P inputs, 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 the soils [35] and this as pointed out earlier has led to accumulation of unavailable P in soils. Further, it has been suggested that the accumulated phosphates in agricultural soils are sufficient to sustain maximum crop yields worldwide for about 100 years [36]. 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 [37]. P-solubilizing activities in agricultural soils is considered as an environmental-friendly alternative to further applications of chemical based P fertilizers [38]. 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 [37]. The use of phosphate solubilizing bacteria as inoculants increases the P uptake by plants, increase the available P in soil, P uptake by plants helps to minimize the P-fertilizer application, 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 they are 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 can reduce the use of fertilizers, thus prolonging the lifespan existing PR deposits.

4.4 Use of organic Materials

With increasing costs of fertilizer and the finite nature of rock phosphates, 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 [39]. 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, there P content is often too low to meet the crop nutrient demands [40]. Organic materials 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 [41]. Use of organic material for soil fertility management in Africa faces challenges such due inadequate amounts available to farmers and their low qualities. Their low nutrient contents requires that large amounts are applied which increases the labour costs which cannot be offset by the crop yield obtained [42, 43] 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 [44]. A part from using from high quality OMs, the quality of organic materials can be enhanced through pit storage and manure storage under shade [45]

A lot work Africa on use of organic materials has not focus 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 [46]. 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 [46]. Guidelines on handling of human excreta to minimize health risks have been developed [47]. Therefore, with the existence of the guidelines on proper use of human excreta, there is need to create awareness among the people on its to assure them on its safe for food production since many Africans consider food produced from it is unfit for human consumption. Still one challenge is people's negative attitude on consumption of food produced from human excreta which needs to be challenged.

5. CONCLUSION

Phosphorus is an essential element in plant nutrition while the available forms for plant absorption are in most tropical African farmlands. Farmers in African appreciate importance fertilizer use in crop production however their use still remains low compared to other continents. The main P sources are PR deposits which are not renewable. The information on the quantities of existing PR deposits are inaccurate therefore, making it difficult to predict how long they will last. However, they were recently estimated to be about 290 billion tonnes and potentially as much as 490 billion tonnes. With the current rate of P fertilizer use, PR deposits are expected to be depleted between the years 2311 - 2411. African cultivated lands have low soil available P. The continent looses majority (75-90%) of its soil P through erosion which accounts for losses of about 1.0 kg P/ha per year. These losses can be minimized through erosion control measures such as ploughing across the slope, planting of hedgerows on steep lands, use mulches, cover crops and fertility enhancing systems on low-fertility soils. There is need in Africa to put in place soil erosion control policies and farmer education on the importance of soil erosion to minimize P losses through soil erosion.

Most tropical African soils have large total soil P yet; the available forms are low due to its fixation by Al and Fe oxides found in its high potential areas mainly with acidity soils. Use of P efficient crop germplasms have the capacity to absorb soil fixed P and enhance the recovery the applied inorganic P fertilizers. In addition to P use efficient crop germplasms, P solubilizing organisms, both bacteria and mycorrhiza are capable of solublizing fixable making it available for plant uptake. Use of P efficient crop germplasms and P solubilizing organisms will reduce P fertilizer use in Africa thus, prolonging the lifespan of PR deposits. At the same time application of organic materials improve soil P availability. However, there low volumes of organic materials available to farmers in Africa and the fact that they have low P contents. A few plants such as tithonia with high P contents can increase soil available P, likely reduce the need for external P fertilizer sources. Use of human excreta as organic matter source is unexploited Africa despite the fact large volume are produce that only require proper management. Unlike other organic materials, human urine has right rations of

N, P and K necessary for healthy plant growth. Use of human excreta if well exploited has the potential provide adequate amounts of organic materials required by African farmers

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