



Influence of Elemental Sulphur, Oxalic Acid, and Phosphoric Acid as Acidulating Agents on Phosphorous Dissolution from Rock Phosphate

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Authors' contributions

This work was carried out in collaboration among all authors. Author FWG designed the experiment, corrected data, and developed the first manuscript draft. Author WN analyzed the data and read the manuscript. Author NKK reviewed the experimental design and read the manuscript while author JPGO conceptualized the idea, guided on collection of the study and read the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Phosphorous is a limiting mineral element in crop productivity due to its less availability and fixed form in the soil. Due to its agricultural benefit, most farmers seek for alternative method to supply phosphorous in sufficient amount in the farming systems. Although the soluble P is relatively expensive for the peasant farmers, rock phosphate has proved to be quite efficient due to availability among the small scale holders. However, rock phosphate is faced with insolubility challenges hence is not readily available in the soils to promote crop growth. Therefore, this study sought to establish the influence of various acidulating agents in dissolution of phosphorus in rock phosphate. The study was carried out in a laboratory environment in Completely Randomized Design consisting of the following treatment: control (bare soil); Mijingu Rock Phosphate (MRP) and soil; MRP, soil and oxalic acid; MRP, soil and phosphoric acid; phosphoric acid and soil; MRP, soil

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and elemental sulphur and replicated three times. The incubation period was 90 days and the phosphorous dissolution rate was measured at interval of 30 days. The result revealed that the treatments had significant ($P \leq 0.05$) influence on the dissolution of the phosphorus from both rock phosphate and soil. Elemental sulphur was superior in increasing the rate of phosphorus dissolution from rock phosphate. At 30 days, elemental sulphur had elicited release of a total of 37.5 ppm phosphorus while the control had the least, recording 5.37 ppm. A similar trend was observed in both 60 and 90 days. Regression analysis also exhibited positive relationship between the acidulating agents and the phosphorous dissolution rate from the rock phosphate. Therefore, elemental sulphur can be recommended to be used by in agricultural fields to enhanced solubilisation of rock phosphate and enhance supply of phosphorous.

Keywords: Soil fertility; fixed phosphate; dissolution agent.

1. INTRODUCTION

Low soil fertility in crop land is one of the challenging factors towards achieving maximum agricultural productivity. Phosphorus (P) is one of the critical elements that limit plant production, particularly in humid and acid soils [1]. Phosphorus has been reported to have a tremendous effect on proper root formation, establishment and formation for the absorption of mineral salts and water from the soil [2,3]. The situation is aggravated in smallholder agriculture where use of mineral fertilizers is limited or even non-existent, as peasant farmers, due to their low purchasing capacities, cannot afford high costs of these fertilizers [4]. Rock phosphate (PR) provides an alternative to the expensive soluble P. Unfortunately, use of rock phosphate (PR) to alleviate P deficiency in the soils remains a great challenge due to their low solubility. The PR is water-insoluble but acid-soluble indigenous P source, to be more relevant for these resource-limited farmers, in comparison to the prohibitive expensive soluble P [5]. PR is acid-soluble and activities that increase rhizosphere acidification increase its solubility. Nitrogen fixation is one such aspect that significantly lowers rhizosphere pH [6,7]. In the light of the proceeding, a field experiment is usually important for the purpose of investigating the effect of the acids secreted by cowpeas (*Vigna unguiculata*) into the rhizosphere (during the biologically nitrogen fixation process) on Minjingu PR solubility as well as the subsequent contribution to the plant available P fraction, and on P uptake by the crop. The use of rock phosphate for gardens is a common practice for both flowers as well as vegetables. Flowers and vegetable respond to application of rock phosphate early in the season and give a reward with big, vibrant blooms. Phosphorus deficiency has been identified as one of the major soil fertility constraints in the soils [8]. Many small-scale farmers in the zone

find it increasingly difficult to afford water-soluble commercial P fertilizers because of high cost. Hence, the need to increase crop production with less expensive indigenous phosphate rocks (PRs) merits the attention of local researchers. Large deposits of phosphate rock exist in West Africa [9], and their application to increase crop production has been investigated with varying degree of success [10].

Phosphorus (P) is needed in virtually all metabolic processes such as energy transfer, signal transduction, macro-molecular biosynthesis, photosynthesis and respiration [11]. It is, however, one of the least available and least mobile mineral nutrients to plants in many cropping environments, based on its contribution to the biomass as a macronutrient [12]. Extremely low levels of available phosphorus in the rhizosphere make it one of the major growth-limiting factors in many ecosystems [13]. Phosphate fixation increases significantly in acid soils, which accounts for nearly 26% of the world's soils [14]. As a consequence of organic and inorganic fixation, nearly 80% of applied Pi may be unavailable to plants [15]. This problem is especially acute in tropical regions, particularly Africa, where production of crops without fertilizer application is resulting in continuous mining of essential nutrients by plants. Furthermore, at the current world-wide rate of fertilizer application, the readily available sources of high-grade phosphate rocks may be depleted within the next 60 to 90 years [16]. Increasing population and extension of agriculture to low- and marginal-fertility lands will further increase the demand for the precious supply of phosphate fertilizers. Potential symbiotic nitrogen fixation (SNF) in these heavily weathered acid soils of tropical and semi-humic tropics is limited, since P is generally deficient hence limits the nodulation [17]. Therefore, the objective of this study was to determine the rate of P dissolution from rock

phosphate using elemental sulphur, oxalic acid and phosphoric acid as acidulating agents.

2. MATERIALS AND METHODS

The experiment was carried out at Kenyatta university farm, Kiambu County, Kenya. The site lies at an altitude of 1745 meters above sea level and is within latitude 110 0.012 S and longitude 3649 59.880 E. The average amount of rainfall received is 989 mm per year where 1200 mm rains is recorded during the long rains whereas 780 mm is recorded during the short rains [16]. Temperature ranges between 12.8 degrees Celsius during the cold month and 24.6 degrees Celsius during the hot seasons. The soils are loamy, acidic, well drained and moderately deep [18].

2.1 Experimental Design, Layout and Data Collection

A set of laboratory experiments were conducted to investigate phosphate-dissolution ability from rock phosphate (PR) in soil through application of organic acids (oxalic and phosphoric acid) and elemental sulphur. The soil was collected from Kenyatta university Agricultural farm. An incubation experiment was conducted in an aerobic environment at Kenyatta University, Agricultural Science and Technology laboratory in a completely Randomized Design, with six treatments with four replications. This was a single factor experiment. Treatments applied consisted of the control (bare soil); Rock Phosphate (RP) and soil; RP, soil and oxalic acid; RP, soil and phosphoric acid; phosphoric acid and soil; RP, soil and elemental sulphur. The treatments were thoroughly mixed with 200 g of soil, 400 mg of PR and 60 ml of the desired solvent. A 2 g elemental sulphur was used as described by Ghosal et al. [19]. Three sets of the experiment were incubated for three different periods; 30 days, 60 days and 90 days. This helped to compare the solubility of MPR in different solvents. The solvent with highest solubilising ability was used to grow the vegetables in the field. The mixtures were filled into polythene containers and then irrigation was carried out when necessary to maintain soil moisture content within the soil field capacity using deionised water. Weight of all the filled containers was registered for further reference during readjustment to the initial level of moisture content of the incubated soils. The filled containers were left open at a room temperature (25°C) [20]. The experiment lasted for three

months. Only soil samples were taken at different incubation time namely, 0, 30 60 and 90 from starting experiment, for determination of available P using the method described by (Bray 1). An aliquot of 5 ml was taken per treatment and its phosphate (available P) content determined following the standard procedure [17].

2.2 Data Analysis

Data collected was managed in excel spreadsheet and subjected to Analysis of Variance using SAS software. Significant differences between means were separated using Fischer's Protected Least Significance Difference (L.S.D) test at 5% level of significance. Linear regression on the rate of phosphorous dissolution was also determined.

3. RESULTS AND DISCUSSION

3.1 Rate of Phosphorus Dissolution

The different dissolution agents showed significant differences on the rate of dissolution of phosphorus from the rock phosphate during an incubation period of 30 days. Elemental sulphur treatment had the highest dissolution of phosphorus from the rock phosphate recording 37.5 ppm. This was followed by phosphoric acid and Oxalic acid that had moderate effects on dissolution of phosphorus from rock phosphate each recording 12.42 ppm and 12.03 ppm respectively as illustrated in Fig. 1. The control had the least effect as it recorded a lower rate of phosphorous recording 5.37 ppm.

At sixty and ninety days, sulphur was superior in increasing the rate of phosphorus dissolution from rock phosphate with the highest value being obtained at 90 days with 1822.9 ppm as shown in Table 1. This was more than 50% increase from that observed at day sixty (Table 1) while the other acidulating agents did not differ significantly with lower dissolution rates of phosphorus of lesser than 50 ppm with the control showing only 13.6 ppm.

The trend of P-release by the fertilizers was more pronounced for the treatments with soil. The results on P release thus showed that maximum release of P from the unacidulated and partially acidulated rock phosphates needs some more periods of incubation for thorough acidulation of the fertilizer with the extractant to come into equilibrium with P in solution. Higher solubility of

the PRs in sulphur possibly results from higher reactivity rather than from any difference in surface area presented for dissolution [21]. Such results are in agreement with those of Gholizade et al. [22] who found that P- adsorption occurs rapidly in the first period and followed by a slow adsorption processes, reaching the soil to equilibrium after 50 days. While found that the state of equilibrium in some sedimentary soils occurred during two days only.

3.2 Linear Regression on Influence of Acidulating Agents on Phosphorus Dissolution in Soil

All the acidulating agents used in evaluating their effects on dissolution of phosphorus in soil has a positive correlation as indicated by the high R² values. However, there were no significant

differences observed when compared to the control. Sulphur + Soil had the higher rate of dissolution with a R² value of 0.99, this was followed by rock phosphate +soil with the R² value of 0.96 Fig. 2. Phosphoric acid had the least dissolution rate effect recording R² value of 0.88 during the 90 days incubation period. Phosphate rocks (PRs) are suitable for direct application as a possible alternative to more expensive soluble phosphate fertilizers in agricultural fields. But the ability of the PRs to release phosphates in the plant available forms depends on the particle size and chemical and mineralogical characteristics of the PRs as well as the properties of the soil in which they are applied. The principal mineral in most PR sources is apatite, but it varies widely in physical, chemical, and crystallographic properties.

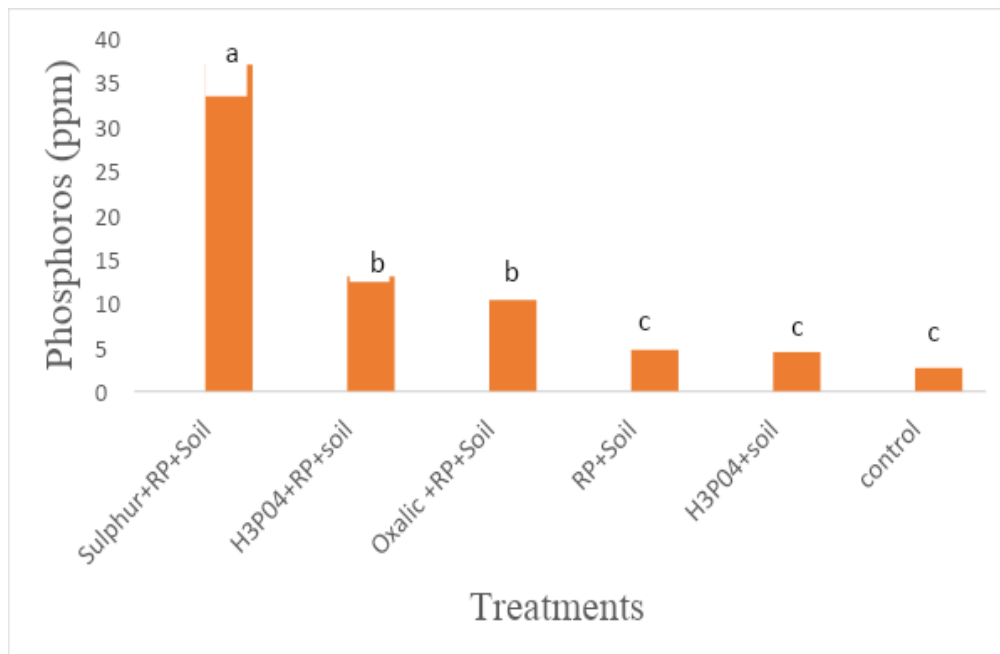


Fig. 1. The phosphorus dissolution rate at 30 days after incubation on the various treatments

Table 1. The influence of acidulating agents on the dissolution rates of phosphorus from rock phosphate

Treatments	30 days ppm	60 days ppm	90 days ppm
Sulphur+P+Soil	37.5 ^a	1175.3 ^a	1822.9 ^a
H ₃ PO ₄ +RP+Soil	12.42 ^b	16.6 ^b	42.9 ^b
Oxalic+RP+Soil	12.03 ^b	14.9 ^b	39.2 ^b
RP+Soil	7.86 ^c	14.0 ^b	35.6 ^b
H ₃ PO ₄ +Soil	6.05 ^{cd}	11.6 ^b	19.9 ^b
Control	5.37 ^d	7.80 ^b	13.6 ^b
L.S.D	1.95	162.0	220.0

Means followed by the same letter within the same column are not significantly different (P≤0.05)

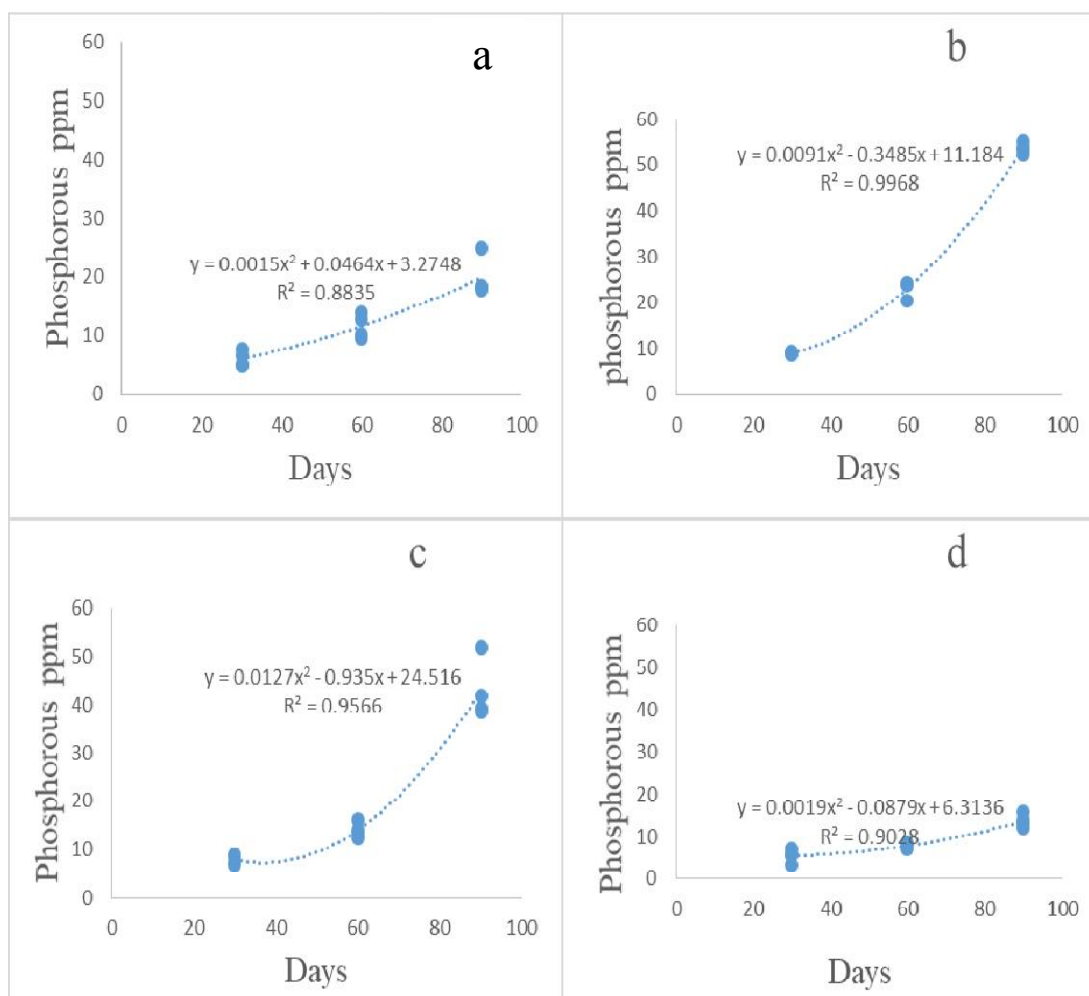


Fig. 2. Regression analysis as a polynomial function of the acidulating agents on phosphorous dissolution from rock phosphate for a period of 90 days. (a) H₃P₀₄+soil, (b) Oxalic+Soil, (c) Sulphur+Soil, (d) Control

3.3 Relationship between Phosphorus Dissolution Rate from Rock Phosphate by Different Acidulating Agents in 90 Days Incubation Period

The acidulating agents exhibited a positive relationship as exhibited by the regression polynomial function in Fig. 3. All the treatment led to an increment in the rock phosphate with the 90 days incubation period. Sulphur + soil + rock phosphate had the highest effect on phosphorus with the R^2 value being 0.92 having obtained 2049.50 ppm of phosphorus concentration in the soil. The phosphoric acid was the second bests with extremely lower levels compared with Sulphur and rock phosphate (Fig. 3). The control had the least dissolution rate of phosphorus but

had a high R^2 value ($R^2 = 0.902$) as shown in Fig. 3.

The solubilization of rock phosphate is an indication of chemical and mineralogical characteristics specific for specific P minerals hence making it available to the crops. Reactivity or solubility is a measure of the rock phosphate ability to release phosphorus (P) for plant uptake. Gholizadeh et al. [19] reported that to avoid time, trouble and cost of doing field trials for determining the reactivity of PRs, solubility of these in different acidulating agents could be a criterion for predicting their reactivity. The 'wet process' for the production of phosphoric acid (H₃PO₄) commonly refers to the dissolution of phosphate rock by sulphuric acid (H₂SO₄) [21].

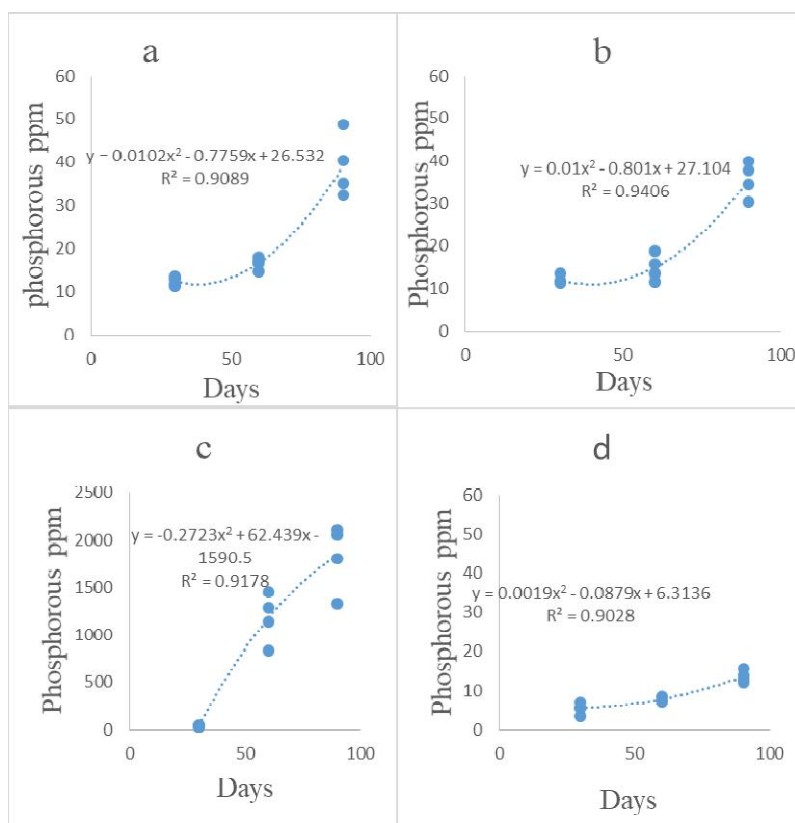


Fig. 3. Regression analysis as a polynomial function of the acidulating agents on phosphorous dissolution from rock phosphate for a period of 90 days. (a) $H_3PO_4+RP+soil$, (b) Oxalic+RP+Soil, (c) Sulphur+RP+Soil, (d) Control

The acidulation solid by product formed as a resultant of this process is phosphogypsum ($CaSO_4 \cdot 2H_2O$). The superphosphate acid concentrate treats further phosphate rocks to form triple superphosphate (TSP) fertilizers (40-48% P_2O_5). The addition of ammonia (NH_3) forms ammonium phosphate (46-48% P_2O_5) [23].

The standard for acidulation has been sulphuric acid because of cost and availability. Phosphogypsum is a by-product waste from this process. For every ton of phosphoric acid produced from sulphuric acid acidulation there are five tons of phosphogypsum produced. Kumari and Phogat [24] reported that plants influence the rate of rock phosphates dissolution by the secretion of acid or alkali, and production of chelating organic acids (citric, malic and 2-ketogluconic acid). Plant species differ in their P uptake, demand and their ability to absorb soil solution P [25]. Additionally, Plant species exhibit differences in their ability to access sparingly forms of P that are unavailable to other plants. According to Bagavathi et al. [25], the

mechanism whereby high rooting density per se stimulates RP dissolution is probable related to the lowering of the concentration of Ca^{2+} and $H_2PO_4^-$ in the solution surrounding the surface of the RP particles. Studies indicated that reactive RPs may have potential applications in alkaline soils when crop such as rapeseed (*Brassica napus*) which is organic-acid secreting is cultivated on it.

The findings of this study also agrees with those of Mnkeni et al. [26] and Weil [27], rapeseed is able to increase the solubilization, even from less reactive RP sources. Partially acidulated rock phosphates (PARP) are rock phosphates which have been acidulated with sulphuric or phosphoric acid with less than the stoichiometric quantity of acid needed for making SSP or TSP. It was reported that that 40-50% acidulation of less reactive rock phosphate with sulphuric acid or 20% acidulation with phosphoric acid is appropriate for increasing efficiency of rock phosphate [27]. Miri, [29] reported that P recovery in the soil was 0.25% for the North

Carolina rock phosphate, whereas it ranged between 1.2-1.6% for the corresponding 50% PARP. The agronomic effectiveness of PARP has been found to be pronounced than rock phosphate. Further, Camenzuli, [30] used rock phosphates acidulation with H_2PO_4^+ HNO_3 in the ratios of 3:1, 1:1 and 1:3 on Vigna mungo. Dry matter yield and P uptake was found highest in PARP which was acidulated in the ratio 3:1. The findings of this study also agree with those of Bagavathi Ammal et al. [25] who reported an increase in the rate of dissolution and efficiency of low grade Udaipur rock phosphate when mixed with elemental sulphur (S) in a ratio of 5:1 and tested on onion-black gram sequence grown on soil having pH of 7.7. The results showed significant increase in available P, due to microbial oxidation of S leading to production of protons (H^+) which dissolved rock phosphate-P and increased available P content.

4. CONCLUSIONS AND RECOMMENDATIONS

The acidulating agents showed significantly increase different dissolution rates of P from rock phosphate with sulphur showing the highest concentration after 90 days. The phosphoric acid and oxalic acid had P dissolution effect on rock phosphate but much lower to that exhibited by sulphur. Therefore, the study highly recommends that sulphur as an acidulating agent is a viable option and can significantly increase the solubility of phosphorus in rock phosphates to benefit agricultural systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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