EFFECTS OF ACIDULATED ROCK PHOSPHATE ON GROWTH AND YIELD PERFORMANCE OF SELECTED LEAFY VEGETABLES IN KIAMBU COUNTY

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October, 2019

DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree or for any other award in any university.

Sign.. Date ………………………………………

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Supervisors

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors

Signature.. Date...

Dr. Joseph P. Onyango Gweyi

Department of Agricultural Science and Technology

Signature………………………………….. Date...

Dr. Nicholas Korir

Department of Agricultural Science and Technology

DEDICATION

To my husband John Githua, my children Nelly, Rose, Karen, and my parents John Karuga and my late mum Rose Wanjiru.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
ALV	African Leafy vegetables
AIDS	Acquired immunodeficiency syndrome
DAP	Di-Ammonium Phosphate
DCPD	Di-Calcium phosphate dehydrate
EDTA	Ethylene-Diamine-Tetraacetic Acid
FAO	Food and Agricultural Organization
HIV	Human Immunodeficiency Virus
IPGRI	International Plant and Genetic Resources Institute
KARI	Kenya Agricultural Research Institute
LSD	Least Significance Difference
MAP	Mono-Ammonium Phosphate
MCP	Mono-Calcium phytate monohydrate
MRP	Mijingu Rock Phosphate
P	Phosphorous
PAPR	Partially Acidulated Phosphate Rocks
PUE	Phosphorus Use Efficiency
RP	Rock phosphate
SNF	Symbiotic Nitrogen Fixation
SSP	Single superphosphate
SSA	Sub-Saharan Africa
TSP	Triple Superphosphate
UNESCO	United Nations Economic, Social and Cultural Organization

ABSTRACT

African leafy vegetables are a good source of vitamin A, vitamin C, and foliate among others. They are also a complementing source of other vitamins such as thiamine, niacin and riboflavin, plus some dietary minerals including calcium, iron, potassium, zinc, copper and manganese. Decline in crop yields is mainly caused by loss of soil fertility. Phosphorus (P) is one of the critical elements that limit vegetable production. 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. 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 current study was therefore conducted to assess growth, yield and quality responses of kales, cowpeas and amaranth to partially solubilised rock phosphate; a cheaper phosphorous source. Laboratory experiments were conducted to investigate phosphate dissolution ability from rock phosphate (RP) in soil as a function of incubation period, through application of organic acids, phosphoric acid and elemental sulphur at different incubation periods (0, 30, 60, and 90 days). Two grams of elemental sulphur and some organic acid solutions containing 0.4 mmolL^{-1} from each of Oxalic acid and phosphoric acid. The field experiment included four treatments: Triple Superphosphate (TSP); Rock phosphate plus Sulphur; Sole Rock Phosphate; and Control under three vegetable crops: Amaranth; Cowpea and Kales. The experiment was set up in a split plot design, where the 3 vegetables constituted the main plots while the rock phosphate, partially acidulated rock phosphate (RP+sulphur), triple super phosphate and control were sub-plots and replicated three times. Data were collected on the growth parameters and fresh weights of edible yield per plant. The soil pH and phosphorus were analysed before and after growing seasons as well as the phosphorus contents in plant tissues. All the growth and biochemical data was subjected to analysis of variance (ANOVA) using SAS. Mean separation was done using LSD at 5% probability level. The fresh root weight, leaf area, root dry weight, root length, shoot dry weight and shoot length were significantly responsive to the different phosphorus sources where the TSP treatment was superior to the other treatments while the control had the lowest growth rate as measured in all of the parameters. In the laboratory experiment, the acidulating agents showed significantly different dissolution rates of P from rock phosphate with sulphur showing the highest at 30, 60 and 90 days after incubation (37.5, 1175.3 and 1822.9 ppm respectively). In the field, the TSP treatment elicited the highest fresh weight, number of leaves and leaf area followed by the RP+sulphur treatment; then the rock phosphate treatment. The RP+sulphur treatment led to the highest reduction of soil pH while the highest pH was observed under the sole rock phosphate treatment. Higher and significant responses of the growth and yield parameters of the three crops to the different forms of P applied compared to the control where TSP had the highest then the RP+ elemental sulphur. The soil pH increased significantly on the rock phosphate treatment under the amaranth and kale crops from 5.7 before planting to above 6.0 while on the cowpea, the treatment showed the least change with a slight drop of pH from 5.7 to around 5.6 with the other treatments dropping to much lower units. Application of acidulated rock phosphate is a viable option to the more expensive soluble phosphate fertilizers among smallholder farmers.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Africa is richly endowed with huge plant genetic resources, with many well -adapted indigenous food crops (Bekele *et al*., 2018). These crops play an important role in the food security of many resource-poor farming families and have potential value as a genetic resource for the global community (Schippers, 2002). There has been a rising demand of Leafy vegetables (LVs) in the recent past in Kenya. The priority species marketed include leafy amaranth (Amaranthus spp), cowpeas (*Vigna unguiculata*), Ethiopian kale (*Brassica carinata*), African black nightshades (*Solanum* spp), pumpkin leaves (*Cucurbita maxima)*(Irungu *et al*., 2011).

Leafy vegetables have gained commercial importance over the past 15 years as a result of the enormous growth in market (Irungu *et al*., 2007). The production of ALVs has its advantages because of the uniqueness, such as short production cycles, are resistant to pests and diseases and are quite acceptable to local tastes (Walingo and Abukutsa- Onyango, 2009). This could be contributed to their perceived nutritional and medicinal values on diseases and alleviation of conditions such as diabetes, high blood pressure, cancer and HIV/AIDS.

There has been increasing ALV consumption trends both in urban centres and rural areas of Kenya, with these vegetables even being traded in the main super markets and hotels in cities. The demand for cowpeas, amaranth and kales has reached the potential of 50 tons per hectare (Irungu *et al*., 2007). This could be attributed to several factors that include environmental and high population particularly in urban areas (Irungu *et al*., 2011). In rural areas of Kenyan, amaranth, cowpeas and kales are largely grown by women, thus providing them with a degree of financial independence and better nutrition (IPGRI, 2003). Low leaf yields of less than 10 tons are normally realised against their agronomic potential. This is compounded by population growth resulting in continuous cultivation of arable land leading to exhaustion of soil nutrients thus reducing production (Bationo *et al*., 2006). Soil fertility depletion on smallholder farms is the major biophysical root-cause of the declining food production in Sub Sahara Africa (Njoloma *et al.*, 2016). The depletion of nutrients is caused by negative balance resulting from losses of nutrients exceeding inputs application, especially the amount removed from the soil in harvests. In Kenya, the annual nutrient mining from the soil averages 42 kg N/ha; 3 kg P/ha; 29 kg K/ha (Margenot *et al*., 2016). The trend clearly indicates that there is an urgent need to increase use of external fertilizing inputs in order to reverse the prevailing negative nutrient balance if food production is to be increased.

Nutrient replenishment may be achieved through use of either mineral fertilizers or organic inputs or a combination of both. Phosphorus (P) is one of the critical elements that limit plant production, particularly in humid and acid soils (Bekele *et al*., 2018). 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 (Marschner, 1995). 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 (Jama and Van Straaten, 2006). 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 (Zapata *et al.*, 2004), PR is acid-soluble and activities that increase rhizosphere acidification increase its solubility. Nitrogen fixation is one such aspect that significantly lowers rhizosphere pH (Maschner, 1995). In the light of the proceeding, a field experiment will therefore be conducted to investigate 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.

Sulphuric acid for the production of superphosphates is usually produced from elemental sulphur, or sulphur-bearing minerals like pyrite (FeS_2) (Venter, 2018). In much of Sub-Saharan Africa, industrial acidulation or even partial acidulation for breaking down the phosphate minerals and making phosphorus more available is constrained by the lack of local sources of sulphur, or inadequate infrastructure to allow for economical transport of sulphur or sulphuric or phosphoric acid, or for lack of capital (Oppong, 2015).

1.2 Problem Statement

The search for alternative ways to enhance the breakdown of PR into plant-available P forms has led to an array of PR modification techniques (Roy, 2017). Over the last few decades, various innovative techniques to enhance PR solubility have been investigated, including modification techniques like partial acidulation, heap leaching, thermal treatment, mechanical activation, as well as modification through biological processes (Karunanithi *et al.,* 2015). Although there are several options open to process PR into a form that is more plant available, the option of partial acidulation using elemental sulphur is viewed as more viable option for local soil conditions (Githua *et al*., 2019) Despite the role of phosphorous in growth of vegetables, very little is reported on the use of PR a cheaper P source to grow vegetables.

There is need to fully exploit ALVs for food, nutrition and economic security in an endeavour to alleviate poverty in Kenya, especially in central region of Kenya where land sizes have reduced and yet these vegetables can be grown throughout the year with minimal supplemental irrigation. Decline in crop yields is mainly caused by loss of soil fertility from nutrient deficiencies caused by factors such as erosions, nutrient imbalance and inherent soil property. Phosphorus (P) is one of the critical elements that limit plant production, particularly in humid and subhumid acid soils (Nziguheba *et al.,* 2016). 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 (Jama and Van Straaten, 2006). 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 a water-insoluble but acid-soluble indigenous P source (FAO, 2004; Gachengo *et al*., 1999). The PR is acid-soluble and activities that increase rhizosphere acidification increase its solubility. Nitrogen fixation is one such aspect that significantly lowers rhizosphere pH (Maschner, 1995). Elemental sulphur seems to play an important role in reducing soil pH values through its transformation to sulphuric acid by sulphur oxidizing bacteria; therefore, it may be helpful in increasing the solubility of P from RP. In this respect, Tibbett and Diaz (2005), reported that the combining phosphate rock RP with elemental sulphur resulted in the production of mineral acids, which creates a localized high acidity in the immediate vicinity of RPs. Moreover, phosphate fertilizers could be increased markedly if they were applied along with organic acids or with organic wastes due to their influences in lowering soil pH values along with chelating Ca and Mg ions and consequently increase the availability of phosphate (Van Straaten, 2002). In addition, protons secreted by cowpeas (*Vigna unguiculata*) into the rhizosphere (during the biologically nitrogen fixation process) assist in Minjingu PR solubility as well as the subsequent contribution to the plant available P fraction, and on P uptake by the ALVs. The practice of utilization of direct application of less soluble phosphate rock as a fertilizer without chemical treatment has proven to be of limited value. The standard for acidulation has been sulphuric acid because of cost and availability. There are specific soil properties that influence the dissolution of apatite minerals in the phosphate rocks and this varies from place to place. The understanding of the variations in such aspect formed the basis for the need to undertake the current research.

1.3 Research Objectives

1.3.1. General objective

The objective of this study was to assess the influence of acidulating rock phosphate to make P available for growth and leaf yield performance of selected indigenous vegetables in Kiambu county.

1.3.2 Specific objectives

The specific objectives of the current work were**:**

1. To determine P dissolution from rock phosphate using elemental sulphur, oxalic acid and phosphoric acid as acidulating agents.
2. To evaluate the effect of different P sources on growth, biomass and yield of cowpeas, kales and amaranth.
3. To determine effect of different P sources on plant rhizosphere chemical properties and P uptake.

1.4 Hypotheses

i. There is differential P dissolution as affected by different acidulating agents applied

ii. There is differential growth, biomass and yield of cowpea, kale and amaranth depending P source supplied

iii. There is differential rhizosphere chemical changes and plant P uptake dependent on P source

1.5 Significance and Justification of the Study

In order to further increase crop yields and improve payback of the activity while lowering the cost of production , there is need to focus on low input approaches. Due to the exorbitant costs of mineral fertilizers, many peasant farmers hardly afford the quantities of fertilizers required for their farms. As a result, farmers resort to either applying insufficient amount of mineral fertilizers or growing crops without fertilizers. These aspects have contributed to poor yields on small holder farms. Partial acidulation of phosphate rocks makes P more available for crop use and it is cheaper for many farmers. Use of crops that have the ability to use P from PR sources mainly because the mobilizing capacity of P from various PRs is important as well as reducing production costs. The information generated in this study will be useful to farmers, agricultural researchers, agriculture-promoting institutions and Non-Governmental Organizations such as the World Bank and Food and Agriculture Organization of the United Nations (FAO), agricultural policy makers (including the ministry of agriculture), extension officers and farmers, especially those in Sub -Saharan Africa (SSA). The information will be of great use in the design of new policies and strategies to increase food production particularly that of annual crops, on acid soils, that have been shown to be deficient in P and highly saturated with Al. It will mainly be utilized to the benefit of smallholder farmers, especially those in SSA who have very limited purchasing power and therefore are unable to afford acquiring the amount of soluble P fertilizers required for their farms due to the high costs of these fertilizers. In SSA, small holder farmers constitute the overwhelming majority of the population.

1.6 Conceptual framework

Independent Variables **Moderating Variables** **Dependent**

Variables

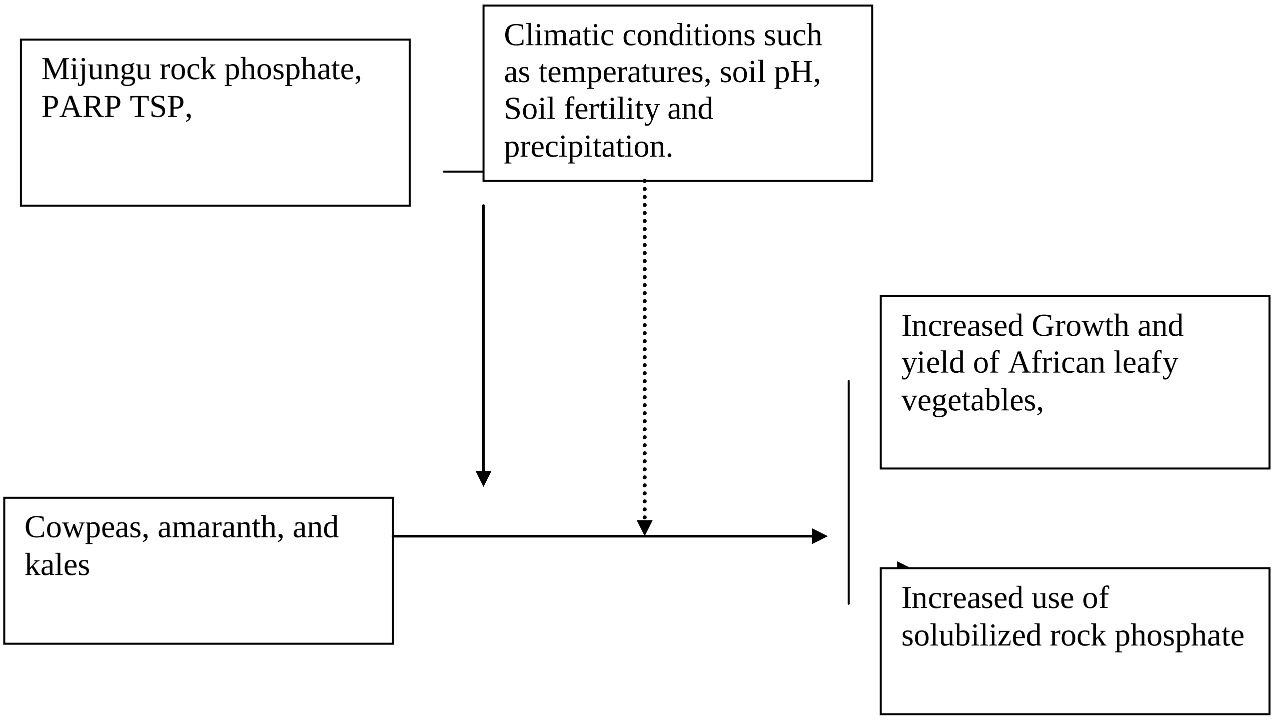

Fig. 1.1 Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction on phosphorous use in crops

Phosphorus (P) is needed in virtually all metabolic processes such as energy transfer, signal transduction, macro-molecular biosynthesis, photosynthesis and respiration (Wan *et al*., 2010). 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 (Githua *et al*., 2019)). Orthophosphate (Pi), the fully oxidized form of P is insoluble in most soils because it forms Ca-salts, is complexed by constituents such as Fe or Al oxides, or fixed into organic forms that render phosphate (Pi) largely inaccessible to plants (Hinsinger 2001). There is a great disparity in distribution of Pi between plant cells and soil solution (µM) (Vance *et al*., 2003). Extremely low levels of available phosphorus in the rhizosphere make it one of the major growth-limiting factors in many ecosystems (Lambers *et al*., 2018). The concentration of available (Pi) in soil seldom exceeds 10 µM (Lambers *et al*., 2018). This problem is further heightened in highly weathered and volcanic soils of the humid tropics and subtropics, and sandy soils of the semi-arid tropics (Wafula *et al*., 2016).

It is estimated that 5.7 billion hectares of land worldwide is deficient in Pi for achieving optimal crop production. Phosphate fixation increases significantly in acid soils, which accounts for nearly 26% of the world’s soils (Herrera-Estrella, and López-Arredondo, 2016). As a consequence of organic and inorganic fixation, nearly 80% of applied Pi may be unavailable to plants (Herrera-Estrella, and López-Arredondo, 2016). 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 (Moharana *et al*., 2018). 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 (Waluyo *et al*., 2004).

2.2 Phosphorous Deficiency in Vegetables

In common bean (*Phaseolus vulgaris*), soybean (*Glycine max (L) Merr*), Lupine (*Lupinus mutabilis*) and alfalfa (*Medicago truncatula*), P deficiency has been reported (i) to reduce number and biomass of nodules as well as their nitrogenase activity (Lazali *et al*., 2017; Kleinert *et al*., 2017; Qiao *et al*., 2007), (ii) to increase the absorption surface and density of roots resulting in more exploration of soil volume (Vance 2001) and (iii) to acidify the rhizosphere by root exudates (Neumann and Römheld 1999) and H+ efflux (Tang *et al*., 2001).

Cowpea (*Vigna unguiculata*) is considered as being more tolerant to phosphorus deficiency than soybean and common bean (Alkama *et al*., 2008). Thus, better tolerance has been related to three main characters; (i) a greater P uses efficiency, (ii) a higher specific nodule activity and (iii) different P distributions between the plant organs (Alkama *et al*., 2008). Cowpea is thus considered as an excellent species in respect to low P tolerance in improvement of symbiotic nitrogen fixation programs. Herrera-Estrella, and López-Arredondo, (2016) reported that the special capacity of P deficiency tolerance in cowpea was related to different abilities to absorb soil P or to differences in P use efficiency to fix N2 from atmosphere, which was in agreement with similar reports for other legume species like common bean, mungbean (*Vigna radiata*) and soybean (Kleinert *et al*., 2017;).

Genotypic variation in P use efficiency (PUE) for symbiotic nitrogen fixation (SNF) and the relation between the H^+ efflux is, however, not well documented. Moreover, one of the options for overcoming the reliance on P-fertilizers for improved crop production in P-deficient soils is the selection of P-tolerant lines that could show a greater growth with a concomitant low proton effect (Mohammed, 2018). Leguminous plants like cowpea form an integral part of African indigenous vegetable with wider acceptance amongst many communities in Kenya. A lot of work regarding its economic value, nutritive and agronomic traits has been undertaken. However, investigation underlying its adaptability to P stress is not an equivocal.

2.2 Properties, solubility and utilization phosphate rocks

Most of the world's phosphate fertilizers are produced from phosphate rock (PR) resources and almost all of these resources contain some form of the mineral apatite (Herrera-Estrella and López-Arredondo, 2016). Phosphate Rock (PR) is a globally accepted but imprecise term describing any naturally occurring geological material that contains one or more phosphate minerals suitable for commercial use (Herrera-Estrella and López-Arredondo, 2016). The term comprises both the unprocessed phosphate ore as well as the concentrated phosphate products (Mohammed, 2018). In agricultural circles, phosphate rocks are also called rock phosphates. The various phosphate minerals present in PR have diverse origins and chemical and physical properties. The phosphorus content or grade of phosphate rocks is commonly reported as phosphorus pentoxide (P_2O_5) (Mohammed, 2018). The principal phosphate minerals in PR are Ca-phosphates, mainly apatites. Pure Fluor-apatite contains 42% P_2O_5, and francolite, the carbonate-substituted form of apatite, may contain up to 34% P_2O_5.

Five major types of naturally occurring phosphate rocks (PRs) differ widely in their mineralogy and chemistry. Marine phosphate deposits, igneous phosphate deposits, metamorphic deposits, biogenic deposits, phosphate deposits as a result of weathering (Hellal *et al.,* 2019). The chemical reactivity or solubility of phosphate rocks is a measure of the PR's ability to release P for plant uptake. The combination of PR properties that determines the rate of dissolution of the PR in a given soil under given field conditions' define reactivity (Nziguheba *et al.*, 2016). The reactivity of sedimentary phosphate rocks is relatively high compared to those of igneous and metamorphic origin. The fundamental difference lies in the crystal chemistry of apatite, specifically the degree of isomorphism substitution of phosphate by carbonate. It has been shown that the solubility of carbonate-substituted phosphate rocks is higher than the solubility of pure fluor-apatite with little or no carbonate-substitution (Hellal *et al.,* 2019). Increasing carbonate substitution in the phosphate rock increases the ease of breakdown of the structure of the apatite thereby releasing P to the soil solution under acidic conditions. The chemical and mineralogical features are key factors in determining the reactivity and subsequent agronomic effectiveness of a given phosphate rock of phosphate resources are being mined in the world (Magallon-Servín *et al*., 2019).

Phosphate rocks with high relative reactivity are best suited for direct application to acid soils with low Ca and P concentrations (Savini *et al.,* 2016). Examples of high to medium ‘reactive’ phosphate rock resources that do not need any further modification, apart from fine grinding, are those of Mali (Tilemsi PR), Tanzania (Minjingu PR), Nigeria (Sokoto) and Niger (Tahoua PR). The dissolution of PR is enhanced in low pH soils following the following equation; Ca_{10} $(PO_4)6F_2$ + 12H+ $\Leftrightarrow$ 10 Ca^{2+} + $6H_2PO^{4-}$ + 2F- . The driving and ‘pushing’ force for the dissolution of appetites is the neutralizing reaction between proton (H+) concentrations and the appetites in PRs. The reaction is driven from left to right by increasing the H+ ion concentrations (protonation/acidulation) in the soil (Agyarko *et al.*, 2016). Many studies have shown that acid soils and acid generating processes, as well as inorganic and organic acids, all contribute to enhanced PR dissolution at low pH. The conditions of low pH, low exchangeable Ca and low P concentrations are common in many tropical, weathered soils. Acid soils are more conducive to PR dissolution than Ca2+-rich alkaline soils (Magallon-Servín *et al.*, 2019).

Roots take up P from the soil solution. Many of the PR resources in the world are inherently low in their reactivity and are not likely to release sufficient P into the soil solution to be agronomically effective, at least not in the short term. Because of inherent chemical and mineralogical properties, many of these PRs are not suitable for direct application for high P-requiring annual crops. These phosphates have to be modified to become more plant available (Al-oud, 2011). The breakdown of apatite can be achieved through various processes. The main industrial process used to solubilise apatite in PR and to get P into a soluble form is through acidulation, for example with sulphuric or phosphoric acid (Fageria and Baligar, 2017). While the resultant products are in general very effective, the production of superphosphates (SSP and TSP) as well as ammonium phosphates (MAP, DAP) require high capital investments, advanced technology and trained personnel (Li *et al*., 2016). These conditions are sensitive to available capital, technology, location and infrastructure**.**

2.3 Role of crop species in rock phosphate utilization

Crops vary in their ability to use P from PR sources mainly because the mobilizing capacity of P from various PRs varies with crop species (Arcand, and Schneider, 2006). The best-known plants with relatively high P-mobilizing capacities are: Buckwheat (*Fagopyrum esculentum*), White sweet clover (*Melilotus albus),* Kale, or rape (*Brassica napus),* White Lupins (*Lupinus albus*), Cabbage (*Brassica oleracea*), Pigeon pea (*Cajanus Cajan*). Other legumes and some crops of the Cruciferae family are also effective in enhancing PR solubilisation (Anand *et al*., 2016). These plants enhance P solubilization from inorganic P sources by the excretion of organic acids from their roots. For example the roots of the leguminous pigeon pea (*Cajanus Cajan*) release piscidic acid that can complex iron to enhance the availability of iron-bound phosphorus (Anand *et al*., 2016).

The application of rock phosphates in arid and semi-arid regions is not common, because of its low availability given the fact that most soils are alkaline under drought stress, high in pH, and low in organic matter (Satyaprakash *et al*., 2017). A number of studies have examined the solution of Rock phosphate (RP) in soils and its subsequent effect on soil availability such as soil pH, particle size of RP, and concentrations of Ca and P in soil solution (Guppy *et al.*, 2005, Park *et al*., 2011; and He *et al*., 2005). On the other hand, calcareous soils are frequently characterized by its low bioavailability of plant nutrients due to high base status and pH between 7.5 and 8.5 and the presences of carbonate minerals (Maschner, 1995). The efficiency of P fertilizers in these soils is generally very low because P applied to the soil reacts with Ca forming minerals such as dicalcium phosphate dehydrate, Octacalcium phosphate, and ultimately hydroxyl-apatite (Leytem and Mikkelsen, 2005). Therefore, Phosphate rock is chemically processed with sulphuric acid or phosphoric acid into soluble phosphate fertilizers (Van Straaten, 2002). Also, rock phosphate application as a phosphate fertilizer along with the activity of soil microorganisms can be effective in solubilising RP (Kang *et al*., 2002). Most soil microorganisms such as bacteria, fungi and actinomycetes have the ability to change insoluble phosphates to soluble forms. Bacillus and Pseudomonas are important genera of phosphate solubilising bacteria (Reyes *et al*., 2006; Valverde*et al*., 2006 ; Vassilev *et al*., 2006; Taalab and Badr 2007; Mittal *et al*., 2008 ; Pandey *et al*., 2008; El– Azouni 2008 and Ogbo, 2010). On the other hand , elemental sulphur seems to play an important role in reducing soil pH values through its transformation to sulphuric acid by sulphur oxidizing bacteria , therefore it may be helpful in increasing the solubility of P from RP. In this respect, Tibbett and Diaz, (2005), reported that the combining phosphate rock RP with elemental sulphur is resulted in the production of mineral acids, which will create a localized high acidity in the immediate vicinity of RPs. Moreover, phosphate fertilizers could be increased markedly if they were applied along with organic acids or with organic wastes due to their influences in lowering soil pH values along with chelating Ca and Mg ions and consequently increase the availability of phosphate (Sinaj *et al*., 2002; Van Straaten, 2002; Savini *et al*., 2006 and Ivanova *et al*., 2006). Therefore, the objective of this study was to improve the solubility and hence the availability of P from rock phosphate as a function of incubation period, addition of elemental sulphur, organic manure, and some organic acids such as Citric, oxalic and EDTA.

Continuous cultivation of diminishing farms to feed the growing population has resulted in soil degradation and consequently rises in use of inorganic fertilizers to increase crop yield. The inorganic fertilizers are expensive and hence out of reach to most rural farmers, majority of which are women (Al-oud, 2011). In addition, they are not always available, especially the subsidized ones which is being blamed for late planting and thus poor yields. The importance of consumption of vegetables as a balanced diet is indisputable. The ALVs which had been neglected in the past by policy makers , researchers, extension workers and farmers, are receiving renewed interest (Ogembo 2015). The cultivation of ALVs in many Kenyan communities has always been done at a subsistence level and their potential as commercial commodities has not been exploited (Abutsa-Onyango, 2005).

2.4 Alternative options for PR utilization

Roots take up P from the soil solution. Many of the PR resources in the world are inherently low in their reactivity and are not likely to release sufficient P into the soil solution to be agronomically effective, at least not in the short term (Syers *et al*., 2008). Because of inherent chemical and mineralogical properties, many of these PRs are not suitable for direct application for high P-requiring annual crops. These phosphates have to be modified to become more plant available (Balemi and Negisho, 2012).

The breakdown of apatite can be achieved through various processes. The main industrial process used to solubilize apatite in PR and to get P into a soluble form is through acidulation, for example with sulphuric or phosphoric acid (Abu-Eishah, and Abu-Jabal, 2001). While the resultant products are in general very effective, the production of superphosphates (SSP and TSP) as well as ammonium phosphates

(MAP, DAP) require high capital investments, advanced technology and trained personnel (Van Straaten, 2002).These conditions are sensitive to available capital, technology, location and infrastructure-Sulphuric acid for the production of superphosphates is usually produced from elemental sulphur, or sulphur-bearing minerals like pyrite (FeS_2) (Oppong, 2015). In much of sub-Saharan Africa industrial acidulation or even partial acidulation for breaking down the phosphate minerals and making phosphorus more available is constrained by the lack of local sources of sulphur, or inadequate infrastructure to allow for economical transport of sulphur or sulphuric or phosphoric acid, or for lack of capital (Oppong, 2015).

The search for alternative ways to enhance the breakdown of PR into plant-available P forms has led to an array of PR modification techniques (van *et al*., 2016). Over the last few decades, various innovative techniques to enhance PR solubility have been investigated, including modification techniques like partial acidulation, heap leaching, thermal treatment, mechanical activation, as well as modification through biological processes (Oppong, 2015). Although there are several options open to process PR into a form that is more plant available, the option for small-scale farmers are limited. Practical alternative methods and technologies of PR modification have to be developed for the farm level. Alternative processing techniques of PR need to be screened for their suitability and acceptance in the local environment. Some of the known modification techniques are presented below (Van Straaten, 2002).

2.4.1 Partial phosphate rock acidulation

The term partially acidulated phosphate rocks - PAPR describes two, but very similar in chemical composition products i.e. P fertilizers produced under two distinct technological processes such as: Partial acidulation, i.e. less than the stoichiometric amount of acid required for complete dissolution of phosphate rock (PR) with H_2SO_4 or H_3PO_4 (Ajiboye *et al*., 2018). 2. Physical mixture of SSP (single superphosphate) and RPRs (reactive phosphate rocks). According to Lal, and Stewart, (2016). processes of phosphoric rock (PR) dissolution can be summarized as follows: $Ca10(PO_4)6F2 + y(6-x)H_2SO_4 + 3xyH_3PO_4 + H2O \rightarrow y(6-x)CaSO_4 + (3 + x)y\ Ca(H_2PO_4)2H2O + (1-y)Ca10(PO_4)6F_2 + yCaF_2$ when $y = 1$, $x = 0$ → single superphosphate (SSP) $y = 1$, $x = 6$ → triple superphosphate (TSP) $0 < y \leq 0{,}75$ → PAPR (Ajiboye *et al*., 2018). The summarized reactions, which take place in the manufactured mixture of SSP- RPR are as follows: $3PR + 18H_2SO_4 \rightarrow 4{,}5MCP + 18CaSO_4 + 2{,}5CaF2 + 6H_3PO_4 + 4RPR \rightarrow 9MCP + 18CaSO4 + 3CaF2 + PR + 3RPR$ The chemical composition and patterns of P release are both affected by the degree of phosphoric rock acidulation and acids used in the fertilizer, i.e. MCP added to the soils undergoes transformation into moderately soluble dicalcium phosphate dehydrate (DCPD) and further to much less soluble P compounds. For ranges from 20% to 50% (Simfukwe, 2016). The first component of the PAPR neutral and no calcareous soils two-step reactions is suggested: The technique of partial acidulation of phosphate rocks (PAPR) requires only a portion of the theoretical (stoichiometric) quantity of acid required for the conversion of insoluble phosphate minerals into water- soluble monocalcium phosphate monohydrate (MCP) (Simfukwe, 2016). In the preparation of PAPR the proportion of acid used to prepare PAPR relative to the quantity of acid required for full acidulation is expressed as ‘percent PAPR.’ When used with sulphuric acid, the resultant product will also provide some sulphur to the soil. The technology provides a portion of the

P in a readily available form and the remainder in a form that should enhance the residual value (Ajiboye *et al.*, 2018).

Partial acidulation has been tested with phosphate rock from Togo, Zimbabwe, Zambia, Uganda, Tanzania, Burkina Faso and Niger. The technology is most effective when using PR material that is low in iron and aluminium oxides. Lal, and Stewart, (2016) showed that the Fe_2O_3 + Al_2O_3 content played a major role in the effectiveness of partially acidulated sedimentary PRs of Niger. They demonstrated that the partially acidulated, Fe+Al-rich Tahoua PR with an initial higher reactivity than Parc West PR was less effective than the Fe+Al-poor, uncreative Parc West PR. Research in many parts of the world has shown that the partial acidulation technique can be successful and effective with relatively unreactive PR materials with low Fe+Al oxide content. An advantage of the method is the robustness of the technology. It can be adapted to local circumstances. Low-tech solutions with the application of appropriate technology have been successfully tested in Zambia, where a local cement mixer was used for the blending and partial acidulation of Chilembwe PR (Borsch, 1993). A major drawback of this technique is the unavailability of inexpensive local sulphuric or phosphoric acid

2.4.2 Acidulation through heap leaching

Another form of acidulation is heap leaching, a technique described by Habashi (1989).This technology requires low-carbonate or carbonate-free phosphate ores piled in heaps with an impermeable liner at the bottom. Nitric acid at 20% or 10% hydrochloric acid is percolated through the heap (Ahmad *et al.*, 2019). The phosphate minerals dissolve during the acid’s passage through the heap. The phosphate-bearing solution is collected at the bottom and can be treated further to remove potentially harmful uranium, radium as well as lanthanides (Calle-Castañeda *et al*., 2018).In Zambia, an initial laboratory leach test (with 1% sulphuric acid) was conducted with phosphate-rich and Fe-rich residual soils from Nkombwa Hill. The leachate was neutralized with dolomite and dried. The resultant extract contained 15% P_2O_5, O.7% Fe, 11% Ca, 6.7% Mg and 7% SO_4 (Habashi, 2015).

2.4.4 Organic solubilisation

The use of organic resources plays an important role in the dissolution of phosphate rocks. There are many factors that influence the transition from inorganic PR to organic P pools and finally to the plants (Zhu and Whelan, 2018). Of special importance is the role of organic materials in enhancing the availability of P from medium to low reactive PRs. The principal processes in biological solubilisation of PRs are acidulation and chelation of Ca^{2+}. Increased solubilization of PR has been reported from exposure to phosphate-solubilizing microorganisms. Research focused on the isolation of PR solubilizing microorganisms most effective in dissolving relatively unreactive PRs are *Aspergillus niger, Penicillium bilaji* and *Pseudomonas cepacia* (Simfukwe, 2016). These microorganisms have been consistently identified as good PR-solubilizing microorganisms. In general, fungi are more effective in producing acids to dissolve PRs than bacteria (Simfukwe, 2016).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

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 (FAO/UNESCO, 1999). The average amount of rainfall received is 989 mm per year (FAO/UNESCO, 1999) where 1200 mm rains is recorded during the long rains whereas 780 mm is recorded during the short rains. 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 (Joel, 2015).

Figure 3.1: The map of Kenyatta University in Kiambu County, Sourced from Google maps

3.2 Soil Incubation experiment

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 replicated four times. This was a single factor experiment. Treatments applied consisted of the control (bare soil); MRP and soil; MRP, soil and oxalic acid; MRP, soil and phosphoric acid; phosphoric acid and soil; MRP, soil and elemental sulphur. The treatments were thoroughly mixed with 200 g of soil, 400 mg of MPR and 60 ml of the desired solvent. A 2 g elemental sulphur was used as described by Ghosal *et al.* (2012). 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. All treatments were arranged in a completely randomized block design with four replicates. 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 (25^0 C) (Ghosal *et al.*, 2012). 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 (Ghosal *et al.,* 2012).

3.3 Field Experimental trials

3.3.1 Experimental Layout and Management

The experiment was arranged in a split-plot arrangement, with three leafy vegetables (cowpeas, kales and amaranth) being the main plots, and various sources of P (TSP, MPR, PARP and control) constituting the subplots with three replicates. Each experimental plot measured 2m x2m. Individual blocks were spaced 1 m apart while the plots within the blocks were separated by a 0.5 m path. The Kale and amaranth seedlings were first raised in a nursery and transplanted at six leaf stage (4 weeks) into a seedbed prepared to a medium tilth at a spacing of 30 cm x 15 cm for amaranth, 45 cm x 15 cm for cowpeas, and 45 cm x 15 cm for kales. The seedlings were subjected to treatment during transplanting to the field. Four treatments used consisted of; control (zero fertilizer input), Mijungu rock phosphate (120 kg P_2O_5 /ha), MRP +S (120 kg P_2O_5 /ha) using 240g of elemental sulphur, and TSP (60 Kg p /ha). The rate of 120 kg P_2O5/ha used in this experiment was adapted from the recommendations of FURP & KARI (1994). MRP, PARP and TSP. Appropriate rates of Calcium Ammonium Nitrate (26%N) at 60 kg N/ha and Muriate of potash (60% $K_2$0) at 30 kg/ha were uniformly administered and incorporated into the soil (Shane *et al.*, 2005) to supply sufficient amounts of N and K to ensure the two nutrients were not limiting factors on plant growth when studying the effects of P. The fields were kept weed free by manual weeding. Pests and diseases were also controlled.

3.4 Data Collection

Data on plant height, fresh weight, dry weight, leaf area and root area were recorded. A well-calibrated ruler in centimetres, electronic weighing balance in grams and physical counting were used. Soil sampling was done before planting and after harvesting for analysis. Plant height was measured from the ground level up to the apex of the youngest leaf. Fresh weight measurement entailed picking all the leaves and tender shoots and weighing them immediately using an electronic weighing balance. Leaf area was calculated using the formula, leaf area= L x W x K, where L is leaf length, W is leaf width and K is a multiplying factor obtained from the ratio of leaf area as traced on a graph paper (Raghothana and Karthikeyan, 2005). Root area was calculated (half width of the longest secondary root by length of the tap root) as recommended by Raghothana and Karthikeyan (2005). The resulting plant was oven dried at 40°C for 72 hours and stored for further analysis. The dry weight was recorded.

3.5 Soil and Plant analysis

Soil pH was determined in water (1:5 soil: water) with a pH meter according to the method of Okalebo *et al*. (2002). Most studies have shown that soils at Kenyatta University are acidic and for this reason, Mehlich 1 method was used to analyse soil P. Mehlich1 extracting solution (0.0125 M H_2SO_4+0.05M HCl) also referred to as dilute double acid. Using a graduated cylinder, 167 ml of concentrated HCl (1.2M) and 28 ml of concentrated H_2SO_4 (1.8M) were added to approximately 35L of de-ionized water in a large polypropylene carboy container. The mixture was made to a final volume of 40L by adding de-ionized water. Bubbling of air through the solution for 3 hours was done to ensure homogenous solution was obtained. 5gms of sieved and air dried soil sample were poured into a 50ml extraction flask. 200mg of charcoal was added to each flask in order to obtain a colourless filtrate followed by the addition of 20ml of the Mehlich1 extracting solution and shaking for five minutes on a reciprocating shaker set at a minimum of 180 rpm at room temperature. The resulting solution was filtered through a medium porosity using Whatman No.2 and analysed for P by colorimetry using a blank and standards prepared in the Mehlich1 extracting solution. To calculate for extractable P the following formula was used; Mehlich1 extractable P (mg P/kg soil) = Concentration of P in Mehlich1 extract (mg/l) x (0.020L extract ÷ 0.005 kg soil) (Mehlich, 1953).

Plant samples were collected from each experimental plot for P analysis. An acidified solution of ammonium molybdate containing ascorbic acid and antimony was added to a powdered plant tissue sample/soil solution. The phosphorus in the plant tissue sample/soil solution reacts with the acidified ammonium molybdate to form an ammonium molydiphosphate/molydi-zinc/molydi-copper complex. A blue coloured solution was generated from the reduction of the ammonium molydiphosphate/molydi-zinc/molydi-copper complex by ascorbic acid. The intensity of the blue colour was proportional to the amount of molybdophosphorus/molydi-zinc/molydi-copper present. Antimony potassium tartrate accelerates the colour development and stabilizes the colour for several hours. The amount of light absorbed by the solution at 660 nm was measured with a visible spectrophotometer (Murphy and Riley, 1962). To determine the concentration of P, 2gms of air dried and ground plant material was weighed and put into 150ml beakers. Two millilitres of 0.1M HCl was added to the mixture in order to digest sample using dry ashing method. The samples were quantitatively transferred into 100ml volumetric flasks and 5ml of distilled water added to dilute. Using a dilutor-dispenser, samples were diluted and the 20, 40, 60 and 80 mg P standards 1:100 with the working solution. Colour was allowed to develop for at least 30 minutes before reading. To calibrate the spectrophotometer for routine analysis, the working solution was used as the blank and develop 0.80 mg P standard to establish the slope of the line. Linearity was checked by reading the developed 0.20, 0.40, and 0.60 mg P standards. When the sample concentration lied above the linear working range, dilution of the samples was done respectively. The concentrations were read at 660 nm with a visible spectrophotometer, the instrument reading were read as percent P in the dried plant tissue (Harborne 1998).

3.6 Data Analysis

Data on P content, plant height, fresh weight, dry weight, leaf area and rhizosphere soil pH was subjected to analyses of variance (ANOVA), using the General Linear Model (GLM) procedure of SAS-computer software (SAS 2002, version 19.0). Mean separation was done using least significant difference (LSD) test at 5% significant level.

CHAPTER FOUR:RESULTS AND DISCUSSION

4.1 Rate of Phosphorus Dissolution

The different dissolution agents elicited 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 form rock phosphate each recording 12.42 ppm and 12.03 ppm respectively as illustrated in Fig.4.1. The control had the least effect as it recorded a lower rate of phosphorous recording 5.37 ppm.

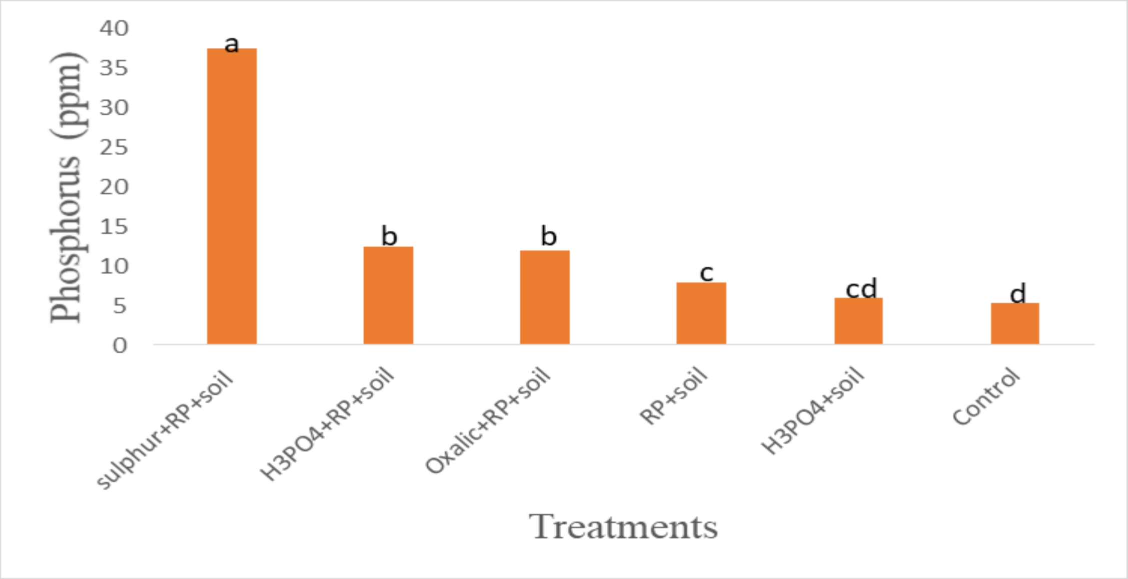

Fig 4.1. The phosphorus dissolution rate at 30 days after incubation on the various treatments

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 4.1. This was more than 50% increase from that observed at day sixty (Table 4.1) 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.

Table 4.1. 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+RP+Soil	37.5^{a}	1175.3^{a}	1822.9^{a}
H_3PO_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_3PO_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 ($P \leq 0.05$)

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. Such results are in agreement with those of Gholizade et *al*. (2001)] 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 R^2 values. However, there were no significant differences observed when compared to the control. Sulphur + Soil had the higher rate of dissolution with a R^2 value of 0.99, this was followed by rock phosphate +soil with the R^2 value of 0.96 Fig.4.2. Phosphoric acid had the least dissolution rate effect recording R^2 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.

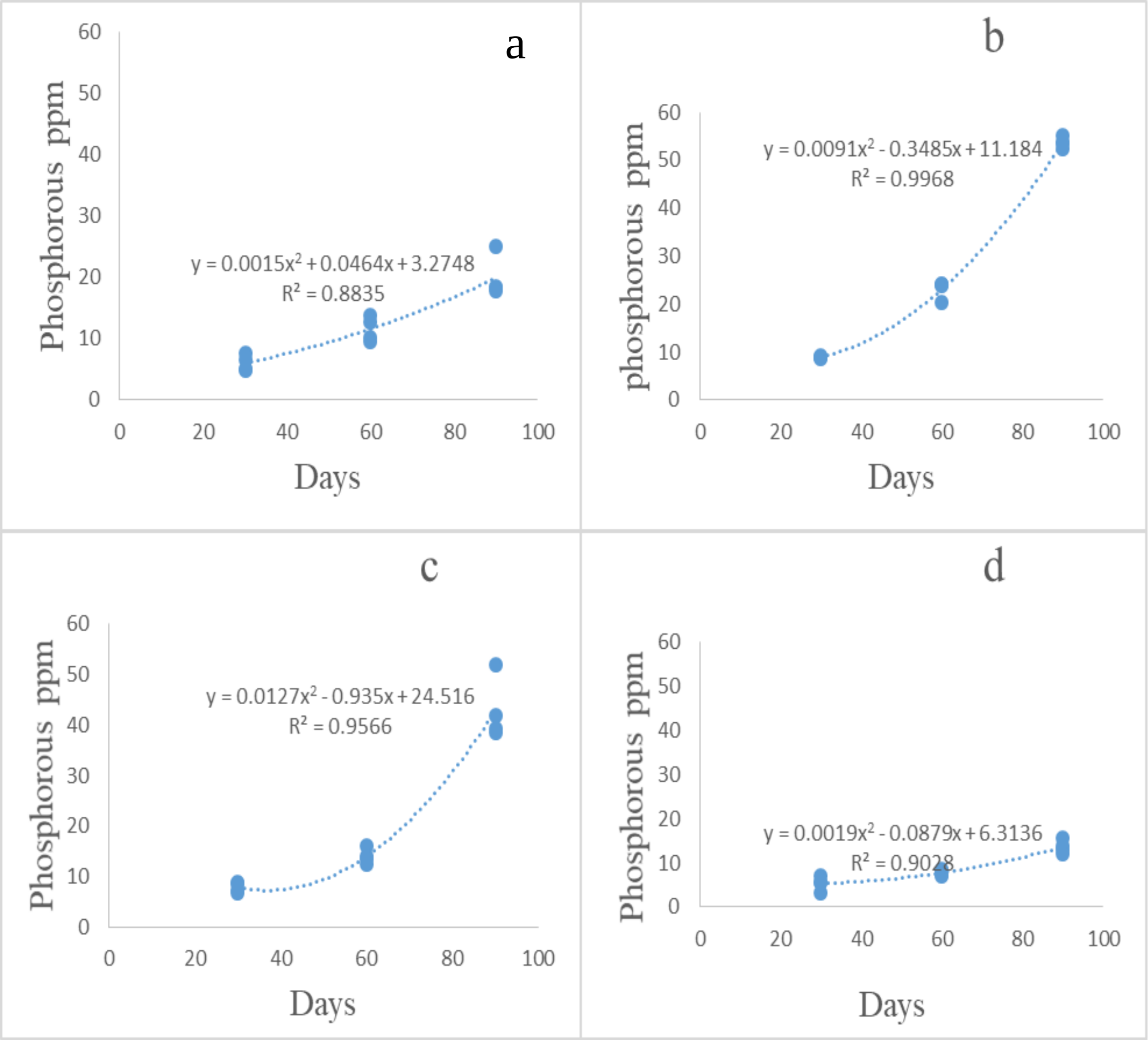

Fig 4.2. Regression analysis as a polynomial function of the acidulating agents on phosphorous dissolution from rock phosphate for a period of 90 days. (a) H_3PO_4+soil, (b) Oxalic+Soil, (c) Sulphur+Soil, (d) Control

The acidulating agents exhibited a positive relationship as exhibited by the regression polynomial function in Fig.4. 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 pmm of phosphorus concentration in the soil. The phosphoric acid was the second bests with extremely lower levels compared with Sulphur and rock phosphate (Fig.4.3). The control had the least dissolution rate of phosphorus but had a high R^2 value (R^2= 0.902) as shown in Fig.4.3.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*. (2012) 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 (H_3PO_4) commonly refers to the dissolution of phosphate rock by sulphuric acid (H_2SO_4) (Gholizadeh *et al*., 2009). The acidulation solid by product formed as a resultant of this process is phosphogypsum ($CaSO_4.2H_2O$). 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) (Jazaeri *et al.*, 2016).

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 (2008) 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 Bagavathi *et al*. (2001). 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*. (2001), 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.

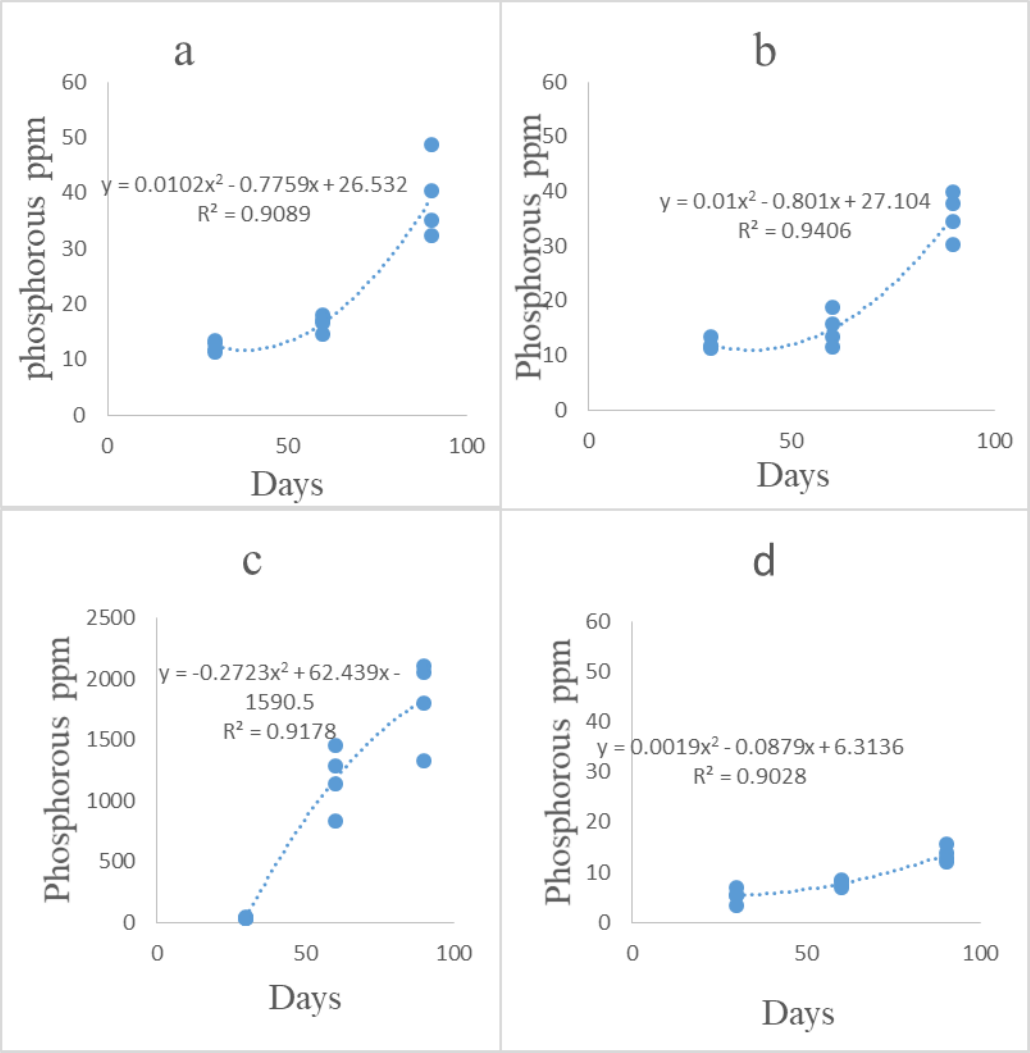

Fig 4. 3. Regression analysis as a polynomial function of the acidulating agents on phosphorous dissolution from rock phosphate for a period of 90 days. (a) H_3P0_4+RP+soil, (b) Oxalic+RP+Soil, (c) Sulphur+RP+Soil, (d) Control

The findings of this study also agrees with those of Mnkeni *et al*. (2000)and Weil (2000), 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 (Weil 2000). Miri, (2015) 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, (2015) 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*. (2001) 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.

4.2 Effect of acidulated rock phosphate on growth and yield of three selected crop species

4.2.1 Effects of P sources and crop species plant height

The plant height was significantly influenced by the phosphorus sources on all the crops at the different sampling stages (Table 4.2). Amaranth was superior in plant height in both season 1 and season 2 recording 19.25 cm in 7 WAP respectively.

Table 4.2: Plant height as affected by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	9.53^{b}	10.82^{b}	13.04^{b}	10.52^{a}	11.92^{b}	13.04^{b}
Amaranth	17.06^{a}	18.04^{a}	19.25^{a}	16.98^{a}	18.04^{a}	19.25^{a}
Cowpea	13.38^{ab}	14.19^{ab}	15.41^{ab}	13.38^{ab}	14.19^{ab}	15.41^{ab}
LSD	**3.61**	**3.64**	**3.53**	**3.46**	**3.56**	**3.53**
Treatments						
Control	8.08^{c}	8.81^{c}	10.54^{b}	9.03^{c}	9.61^{c}	10.54^{b}
TSP	17.50^{a}	18.47^{a}	19.61^{a}	17.50^{a}	18.47^{a}	19.61^{a}
RPS+S	15.72^{ab}	16.64^{ab}	18.11^{a}	15.58^{ab}	17.00^{ab}	18.11^{a}
RP	11.99^{c}	13.47^{bc}	15.33^{a}	12.39^{bc}	13.78^{bc}	15.33^{a}
LSD	**3.74**	**3.61**	**3.36**	**3.57**	**3.38**	**3.36**
SXPF	*	*	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).S-vegetable species, PF-phosphorous sources

Kales had the least growth in plant height with 13.04 cm in 7 WAP in season 1 and season 2 respectively as illustrated in table 4. 2. Phosphorus sources also revealed significant differences on growth of the plant height. RP+S had the highest effect of plant height in the vegetable species across all the weeks with the highest being in 7 WAP 18.11cm as shown in table 4.2. Root and stem development, flower and seed formation, crop maturity and production, N-fixation in legumes, crop quality, and resistance to plant diseases are the attributes associated with phosphorus nutrition (Khan *et al*., 2009). However, the effectiveness of P fertilizers on crop performance depends not only on the characteristics of the P sources, but also on the chemical reactions between the P fertilizers and the soils to which they are applied and their physical factors (Zin *et al*., 2008). Studies by Obigbesan *et al*. (2002) observed inhibited root growth as a result of low P supply.

4.2.2 Effects of P sources and crop species on Leaf area

Vegetable species exhibited significant differences ($P \leq 0.05$) in leaf area in the two study seasons. Kales recorded the largest leaf area in season 1 and season 2 with the greatest values being recorded during the 7 WAP with 2088.0 cm2 in season one and 1905.0 cm2 at 7 WAP in season 2 as illustrated in Table 4.3.

Table 4.3 Leaf Area as affected by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**LA5WAP**	**LA6WAP**	**LA7WAP**	**LA5WAP**	**LA6WAP**	**LA7WAP**
Kales	775.4^{a}	1221.0^{a}	2088.0^{a}	573.7^{a}	1129.3^{a}	1905.0^{a}
Amaranth	263.0^{b}	691.2^{ab}	1141.0^{ab}	263.0^{b}	607.9^{ab}	1149.0^{ab}
Cowpea	189.9^{b}	285.4^{b}	596.0^{b}	189.9^{b}	267.9^{a}	525.0^{a}
LSD	**279.2**	**560.9**	**866.3**	**241.9**	**510.0**	**860.00**
Treatments						
Control	131.3^{b}	187.1^{c}	333.0^{c}	109.1^{b}	176.0^{b}	329.0^{c}
TSP	760.8^{a}	1543.2^{a}	2472.0^{a}	649.7^{a}	1442.1^{a}	2393.0^{a}
RPS+S	553.8^{ab}	910.1^{ab}	1665.0^{ab}	431.6^{ab}	710.1^{b}	1420.0^{ab}
RP	191.9^{b}	289.7^{bc}	630.00^{bc}	178.5^{b}	345.3^{b}	630.0^{bc}
LSD	**329.2**	**518.8**	**810.00**	**246.1**	**485.3**	**815.5**
SXPF				**NS**	**NS**	**NS**

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).S-vegetable species, PF-phosphorous sources

The significant high leaf area in kales could be as a result of proper utilization of the applied phosphorous to match the shoots and root demand. Cowpea had the lowest leaf area in the entire growing season for both season 1 and season 2. The TSP treatment elicited the greatest leaf area followed by the rock phosphate plus sulphur treatment. The control had the least effect on leaf area in vegetable species during the season 1 and season 2. There were significant interactions observed between the vegetable species and phosphorous species. Application of phosphorous promotes growth and differentiation of major organs such as leaf s hence results to increase in leaf area. According to Yan *et al*. (2015), adequate phosphorus nutrition has been reported to lead to an increase in leaf growth and consequently recording a high leaf area in brassica family which also supports the findings of this study. Additionally, phosphorus helps in the conversion of other nutrients into usable building blocks for growth and photosynthesis. It is also indispensable for cell differentiation and for the development of the tissues that form the growing points of the plants (Kunene *et al*., 2017]. This study conforms to the findings of Singh *et al*. (2018) who reported phosphorus that leads to an increase in leaf expansion that's result into high leaf area hence increasing the photosynthetic area of various crops.

4.2.3 Effects of P sources and crop species on number of leaves per plant

There were significant differences on the number of leaves per plant among the treatments in all the crops for both seasons at the different stages of sampling. The number of leaves increased over time and the amaranth crop showed the highest number of leaves at the different stages on the TSP treatment during the long and short rain seasons as illustrated in figure 4.4 The rock phosphate plus sulphur treatment showed significantly higher number of leaves than the rock phosphate alone treatment while the control had the lowest under all the crops at the various stages of sampling. At 5 WAP and 6 WAP on the cowpea crop, there were no significant differences between the number of leaves on the rock phosphate plus sulphur treatment and the sole rock phosphate treatment.

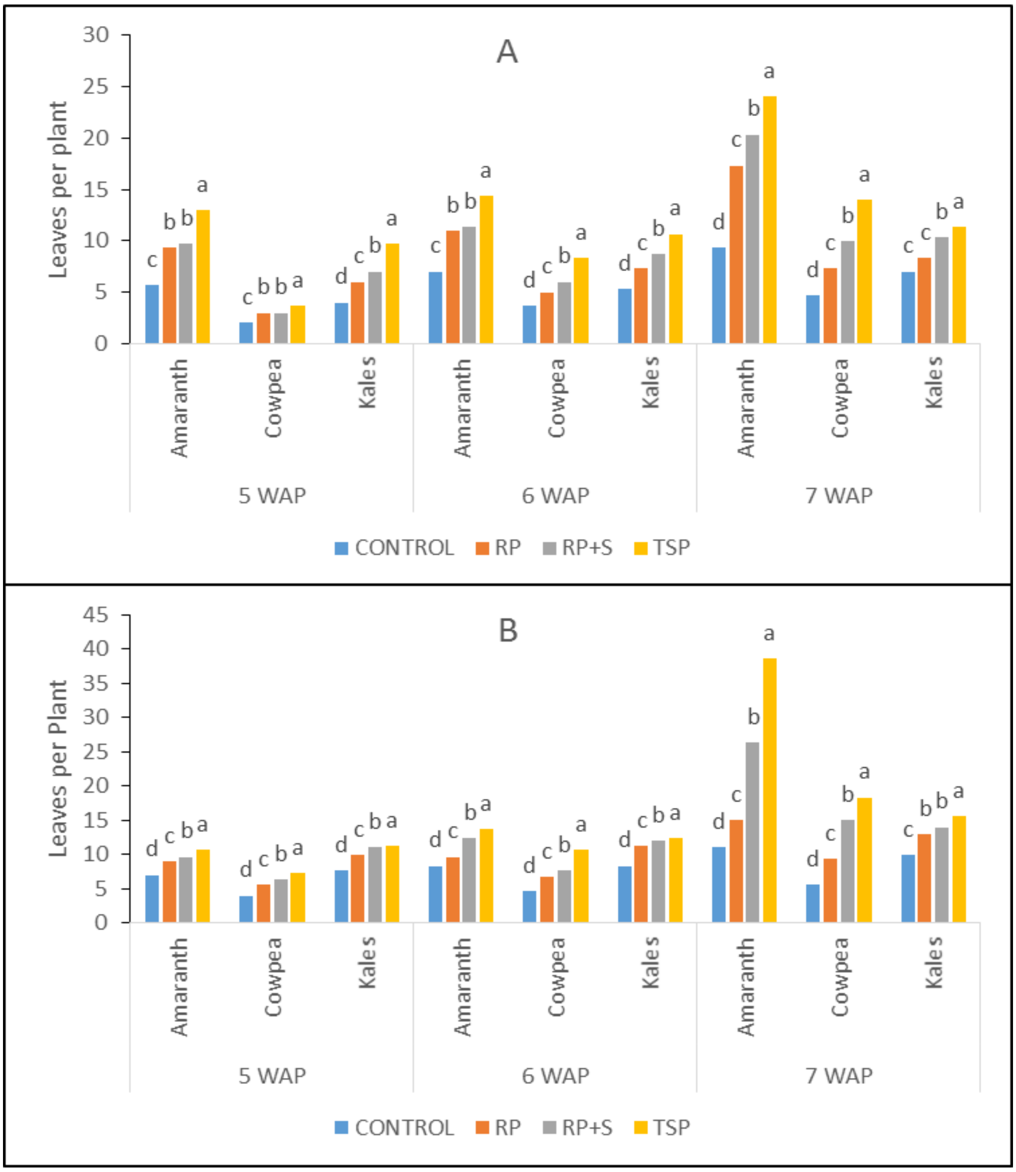

Figure 4.4: The influence of different phosphorus forms on the number of leaves per plant in three crops at 5, 6 and 7 WAP (weeks after planting) during the long (A) and short (B) rains seasons

Adebayo *et al*. (2006) observed that without addition of P, oil palm seedlings exhibited lower number of leaves, butt circumference and leaf nutrient content. Adequate P level has been found to increase plant water and nutrient use efficiency, and help plants to adapt to moisture stress (Nutria-Facts, 2013). Menon and Chien (1990) reported significant increase in leaf nutrient content of oil palm seedlings treated with different P sources, and indicated that doubling the application rate increased the nutrient content of the leaf more than the recommended rate.

4.2.4 Effects of P sources and crop species on number of branches

There were significant differences P ≤ 0.05) on the number of branches between the vegetable species and phosphorus forms treatments in both season 1 and season 2. Amaranthus recorded the highest number of branches in both season with an increment from 5 WAP, 6 WAP and 7 WAP. The highest number of branches was recorded in 7 WAP with 30.88 and 45.58 in season 1and season 2 respectively (Table 4.4). Cowpea had the least number of branches due to the P treatments effect for both seasons. In phosphorous forms the highest number of branches per plant were observed on the TSP treatment for both seasons while the lowest was on the control. The rock phosphate plus sulphur treatment showed higher number of branches than that on the sole rock phosphate treatment.

Table 4.4 Number of branches as affected by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	9.25^{b}	11.75^{a}	14.00^{b}	9.08^{b}	12.12^{b}	14.00^{b}
Amaranth	17.75^{a}	27.50^{a}	30.83^{a}	17.75^{a}	30.00^{a}	45.58^{a}
Cowpea	9.00^{b}	11.50^{b}	13.75^{b}	9.00^{b}	11.35^{b}	13.75^{b}
LSD	**3.48**	**5.98**	**6.94**	**3.51**	**7.64**	**14.46**
Treatments						
Control	7.00^{b}	8.72^{b}	10.33^{b}	7.0^{b}	8.72^{b}	10.44^{b}
TSP	16.44^{a}	23.56^{a}	27.78^{a}	16.44^{a}	26.89^{a}	40.67^{a}
RPS+S	13.56^{a}	19.83^{ab}	22.22^{ab}	13.56^{a}	19.72^{ab}	27.78^{ab}
RP	11.00^{ab}	15.56^{ab}	17.78^{ab}	10.78^{ab}	15.83^{ab}	18.89^{ab}
LSD	**4.67**	**8.82**	**9.60**	**4.71**	**10.75**	**19.95**
SXPF	*	*	*	*	*	*

Means followed by the same letter within the same column are not significantly different (P≤0.05).S-vegetable species, PF-phosphorous sources

Phosphorus sources and vegetable species exhibited an interaction effects on number of branches in the two season as showed in table 4.5. As other parameters Amaranthus treated with TSP was the highest in number of branches in both season 1 and season 2 with the highest being 81.0 branches in 7 WAP.

Table 4.5 Interaction effects on number of branches in season 1 and season 2

Treatments	Season 1			Season 2		
	5WAP	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kale control	7.00^{h}	8.17^{hi}	10.33^{gh}	7.00^{g}	8.17^{g}	10.33^{e}
Amaranth control	9.33^{fg}	11.33^{fg}	13.0^{fg}	9.33^{f}	6.67^{g}	13.33^{de}
Cowpea control	4.67^{i}	6.67^{i}	7.67^{h}	4.67^{h}	6.67^{g}	7.67^{e}
Kales TSP	1.33^{e}	14.67^{e}	17.00^{de}	11.33^{e}	14.67^{de}	17.00^{de}
Amaranth TSP	24.00^{a}	38.00^{a}	42.33^{a}	24.00^{a}	48.00^{a}	81.0^{a}
Cowpea TSP	14.00^{d}	18.00^{d}	24.00^{d}	14.00^{d}	18.00^{d}	24.0^{cd}
Kale RP	8.33^{gh}	10.67^{fgh}	13.33^{fg}	7.67^{g}	11.50^{efg}	13.33^{de}
Amaranth RP	17.33^{c}	26.67^{c}	29.67^{c}	17.33^{c}	26.67^{c}	33.0^{c}
Cowpea RP	7.33^{h}	9.33^{ghi}	10.33^{gh}	7.33^{g}	9.33^{fg}	10.33^{de}
Kale RP+S	10.33^{ef}	13.50^{ef}	15.33^{ef}	10.33^{ef}	14.17^{def}	13.0^{de}
Amaranth RP+S	20.33^{b}	34.00^{b}	38.33^{b}	20.33^{b}	34.0^{b}	55.0^{b}
Cowpea RP+S	10.00^{ef}	12.0^{efg}	13.00^{fg}	10.0^{ef}	11.0^{efg}	13.00^{de}
LSD	1.47	2.89	3.43	1.52	5.32	12.47

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

These results are in conformity with the findings of Shivakumar *et al.* (2004) who reported that the increasing levels of phosphorus in the form of rock phosphate significantly increased the plant height, number of branches per plant, buds per plant, grain and stover yield during both the years indicating that application of higher levels of phosphorus. Similarly Shaktawat *et al.* (2006) reported that, higher phosphorus dose through rock phosphate either alone or in combination with acidulates were better than the control in soybean-mustard cropping system.The positive response of the amaranth, cowpea and kale to applied fertilizer in form of TSP, RP+sulphur and sole RP in the number of leaves per plant was probably due to the initial low fertility status of the soil on which the study was conducted. Similar findings had been reported (Akande *et al.*, 1998; Akintokun *et al*., 2003 and Akande, 2005).

4.2.5 Effects of P sources and crop species on number of buds

The number of buds in the amaranth crop showed significant differences between the treatments in both seasons. The TSP treatment had significantly the highest number of buds per plant than the other treatments during the long rain season while the short rain season showed non-significant difference between the TSP and the rock phosphate plus sulphur treatment. In all the sampling stages, for both seasons, the control showed the lowest number of pods per plant.

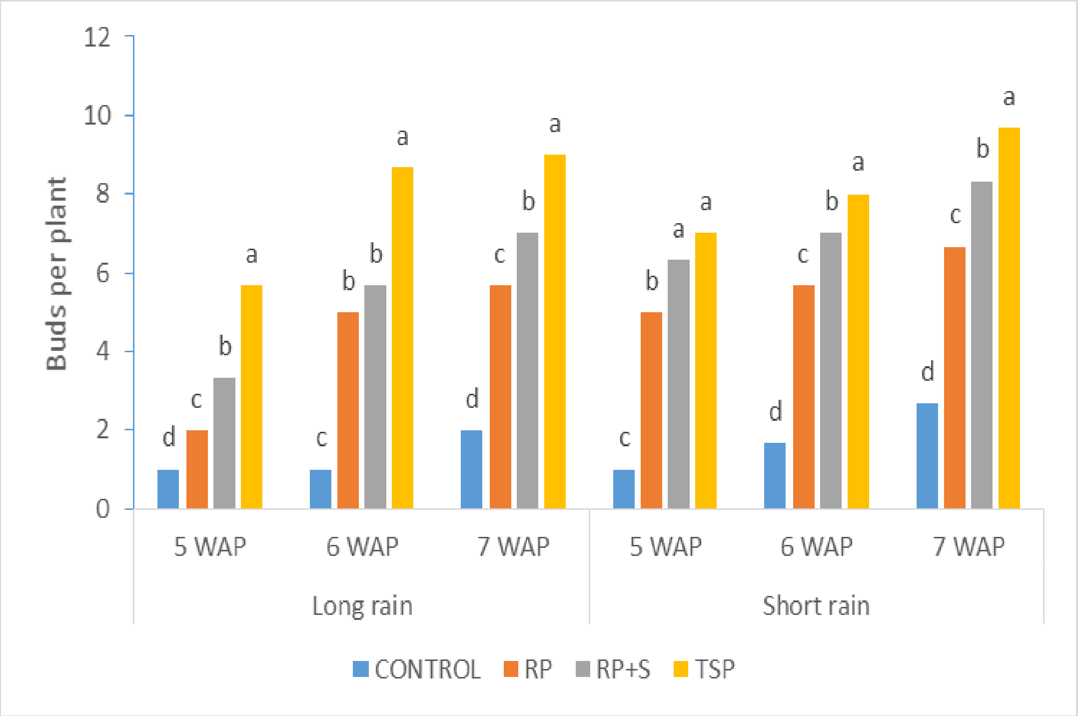

Figure 4.5: The influence of different phosphorus forms on the number of buds per plant in amaranth at 5, 6 and 7 WAP (weeks after planting) during the long and short rain seasons

This better availability and uptake of P by the amaranth crop increased growth parameters notably the buds per plant. It also enhanced plant vigour in terms of increased leaf area and greater accumulation of photosynthates in the plants thereby enhancing bud formation. These results are in conformity with the findings of Shivakumar *et al*. (2004) who reported that the increasing levels of phosphorus in the form of rock phosphate significantly increased the plant height, number of branches per plant, buds per plant, grain and stover yield during both the years indicating that application of higher levels of phosphorus. Similarly Shaktawat *et al*. (2006) reported that, higher phosphorus dose through rock phosphate either alone or in combination with acidulants were better than the control in soybean-mustard cropping systems.

4.2.6 Effects of P sources and crop species on shoot length

The amaranth and kale crop were significantly responsive to the different sources of phosphorus for both seasons on the shoot length but the cowpea showed minimal response during the long rain season. However, TSP only showed significantly higher shoot length on the amaranth compared to the rock phosphate plus sulphur treatment. On the cowpea, there were no significant differences between the TSP, rock phosphate plus sulphur and the sole rock phosphate treatments during the long rain season at all the sampling stages while the short rain season there were significant differences in all the crop species for the different sources of phosphorus. TSP had the longest shoots at all the weeks of sampling then followed by the rock phosphate plus sulphur treatment whereas the control showed the lowest shoot length. Akinrinde *et al*. (2006) reported significant increase in stem girth and leaf area on oil palm seedlings treated with different sources of RP on two different soil types after 6 months of growth under nursery conditions. The authors further stated that, application of P fertilizer, irrespective of source or rates significantly increased the stem thickness in the two soil types studied.

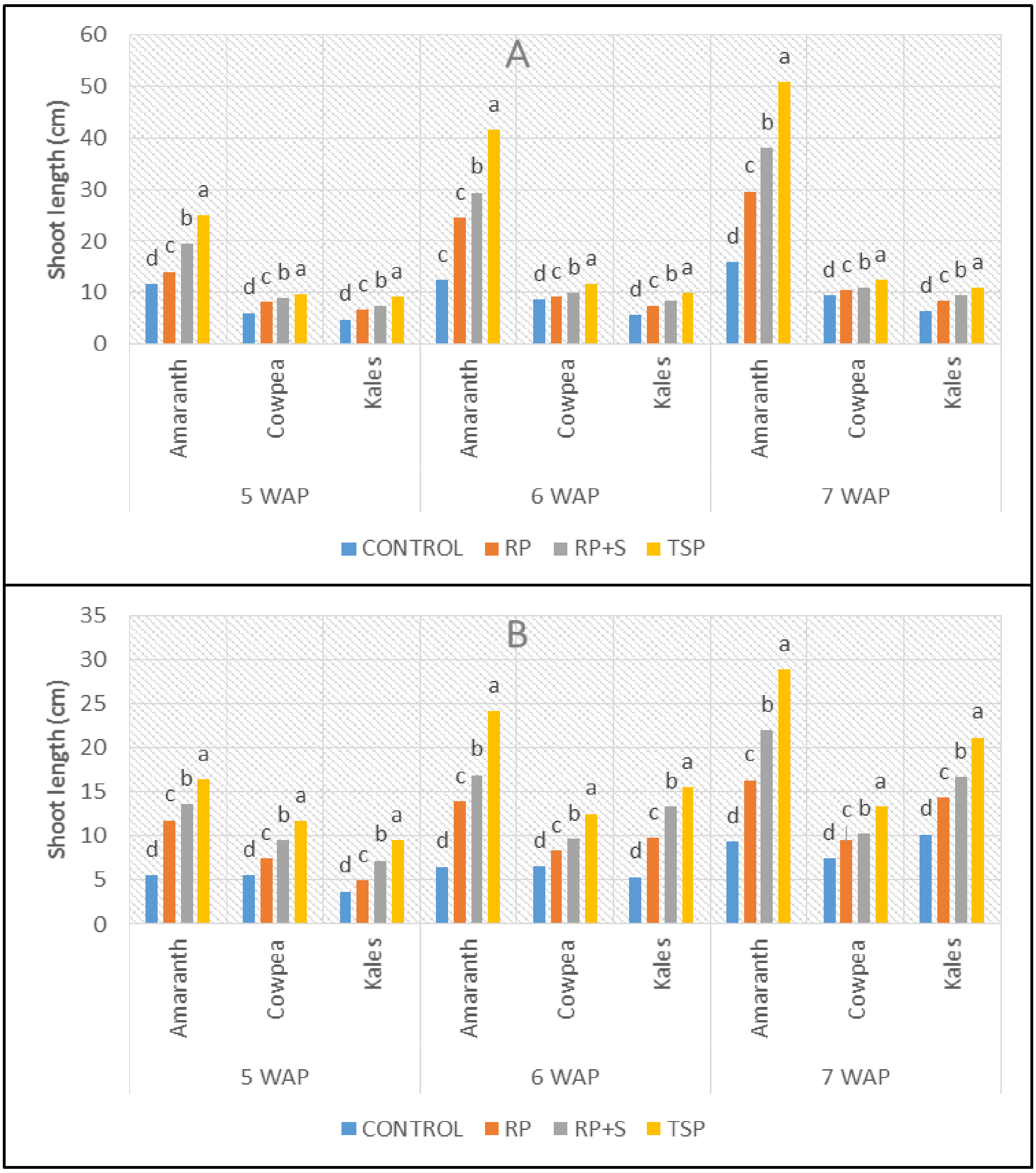

Figure 4.6: The influence of different phosphorus forms on the fresh root weight of Amaranth, Cowpea and kales at 5, 6 and 7 WAP (weeks after planting) during the long (A) short (B) rains season

Application of ground rock phosphate has been proved to be beneficial to crops (Akande *et. al*., 2008a). There are however, a limited range of climatic and soil conditions in which rock phosphates will be sufficiently reactive for use as direct application fertilizers, especially for fast-growing annual crops and that is probably the reason TSP had the highest positive effect because of the fast dissolution of P compared to the rock phosphate plus sulphur and the sole rock phosphate treatments.

4.2.7 Effects of P sources and crop species on shoot fresh weight

Shoot fresh weight had significant differences ($P \leq 0.05$) between the vegetable species and also phosphorus forms in season 1 and season 2. Kales had the highest accumulation of shoot fresh weight in all the sampling stages in both seasons; with 7 WAP having the highest value of 175.03 g and 174.96 g in season 1 and season two respectively as shown in Table 4.6 Cowpea accumulated the least shoot fresh weight in all the growth stages. Phosphorous forms also showed significant ($P \leq 0.05$) increase in shoot fresh weight of vegetable species TSP recorded the highest shoot fresh weigh I in both season 1 and 2 at all the growth stages with the highest in 7 WAP (236.88 g) in season 1 and (228.0 g) in season 2.

Table: 4.6 Shoot Fresh weight as influenced by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	51.48^{a}	107.49^{a}	175.03^{a}	50.80^{a}	107.49^{a}	174.96^{a}
Amaranth	25.25^{ab}	46.42^{ab}	91.54^{ab}	25.25^{ab}	53.09^{ab}	81.54^{ab}
Cowpea	13.32^{b}	22.34^{b}	31.26^{a}	13.66^{b}	23.01^{b}	32.53^{b}
LSD	**23.79**	**49.38**	**93.0**	**24.17**	**48.40**	**92.2**
Treatments						
Control	6.31^{b}	11.87^{b}	17.44^{b}	5.58^{c}	12.76^{b}	18.91^{b}
TSP	60.71^{a}	135.43^{a}	236.88^{a}	61.38^{a}	130.98^{a}	228.0^{a}
RPS+S	37.28^{ab}	64.93^{b}	96.06^{b}	37.39^{ab}	64.93^{b}	96.06^{b}
RP	15.76^{b}	36.12^{b}	46.86^{b}	15.26^{bc}	36.12^{b}	42.41^{b}
LSD	**23.99**	**48.42**	**89.0**	**23.66**	**49.10**	**91.2**
SXPF	*****	*****	**NS**	*****	*****	**NS**

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).S-vegetable species, PF-phosphorous sources

The high shoot fresh weight could be as a result of more available phosphorus that promoted vibrant growth of the vegetative parts. The control had the least shoot fresh weight in all the growth stages.

Interactions effects between the phosphorus forms and vegetable species on the influence of shoot fresh weight during 5 WAP and 6 WAP in season 1 and 2 are illustrated in Fig. 4.7.

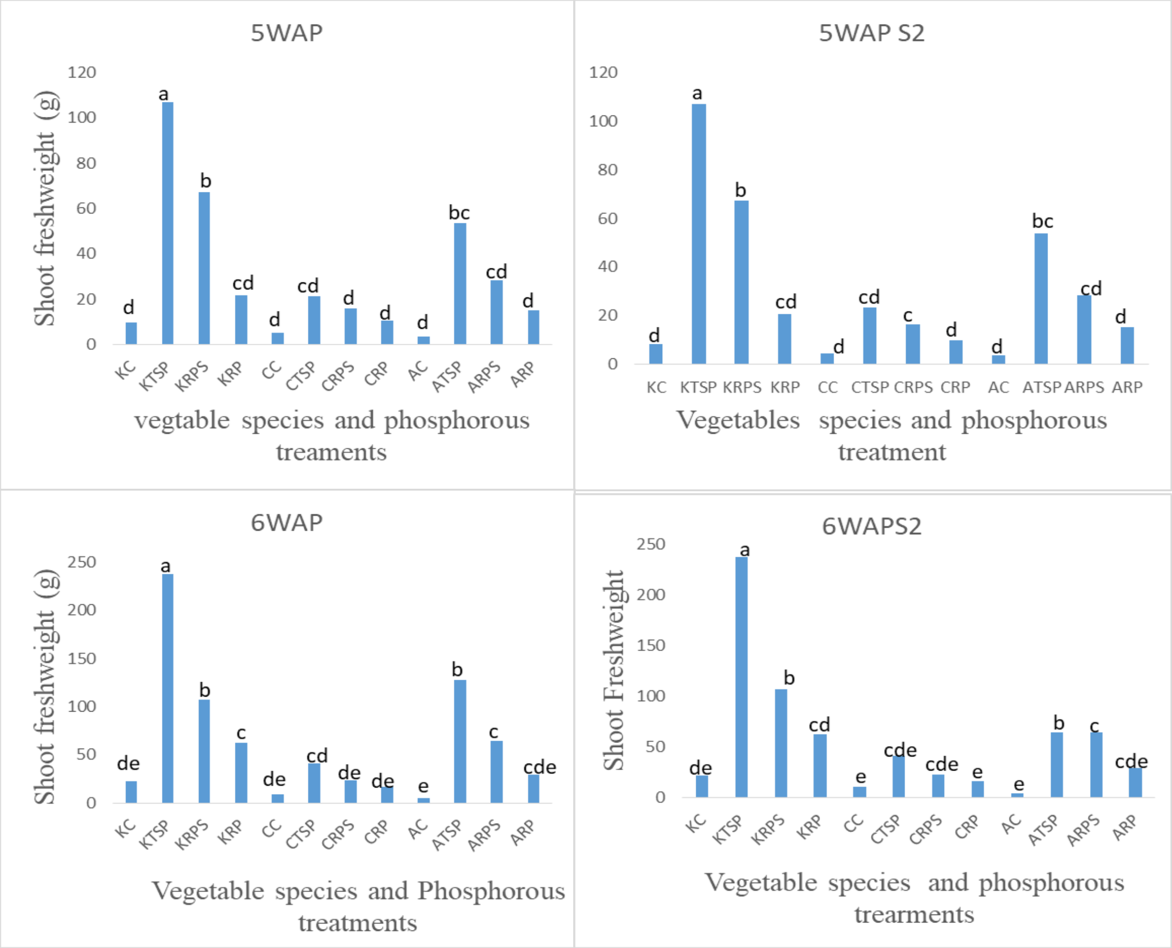

Figure 4.7 Interaction effects of phosphorus forms and vegetable species on shoot fresh weight in season 1 5WAP (a), 6WAP (b) season 2 5WAP (c), 6WAP TSP, KRPS- kales RPS, KRP- Kales RP, CC cowpea RPS, CRP- cowpea RP, AC Amaranth RPS, ARP control, ATSP- Amaranth TSP, ARPS Amaranth RPS, ARP- Amaranth RP

Kales applied with TSP had the highest shoot fresh weight (106.91 g) in season one for both 5 WAP and 6 WAP respectively and 233.91 g in 5 WAP and 6 WAP in season 2. Like other parameters, the control recorded the least shoot fresh weight.

The findings of this study agree with those of Chen *et al*. (2013) who reported an increase in the shoot biomass in Chinese kale upon application of phosphate fertilizers. In another study by Kim *et al*. (2016) application of high phosphorous form led to high growth of the above ground biomass as well as the roots. In soils where P-is deficient in plants, shoot growth was found to be more affected than root growth due to assimilate partitioning towards the roots and this led to a decrease in the shoot: root dry matter ratio (Goh *et al*., 2003). The authors also observed a reduction in trunk diameter, bunch size and a pronounced pyramid shape of the palm due to the progressive depletion of soil P. The superior effect of TSP fertilizer shoot biomass produced could be ascribed to high solubility of phosphate in TSP (Imogie *et al*., 2011).

4.2.8 Effects of P sources and crop species on shoot dry weight

The shoot dry weight of all the crops under the study were significantly influenced by the sources of phosphorus for both seasons. Cowpea had the highest accumulation of shoot biomass in season two during the 6 WAP with a value of 607.9 g while the kales had the least of 18.7 g at 7 WAP.(table 4.7). The TSP treatment showed the highest shoot dry weight then followed by the rock phosphate plus sulphur treatment whereas the control treatment showed the lowest shoot dry weight as showed in table 4.7 There was an increase in all the treatments on the shoot dry weight over time with the TSP treatment showing the highest in all the stages as well as on the crops.

Table 4.7: Shoot dry weight as influenced by vegetable species and phosphorous sources

	Season 1			Season 2		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	5.83^{a}	11.83^{a}	18.29^{a}	5.7^{b}	11.2^{b}	18.7^{b}
Amaranth	3.60^{ab}	7.56^{ab}	10.13^{ab}	263.0^{a}	607.9^{a}	1149.0^{a}
Cowpea	1.95^{b}	2.78^{b}	5.12^{b}	189.9^{a}	267.9^{ab}	525.2^{b}
LSD	2.60	5.32	8.33	115.5	331.9	481.2
Treatments						
Control	0.90^{c}	1.69^{b}	2.57^{b}	47.6^{b}	56.8^{b}	163.0^{b}
TSP	7.40^{a}	15.12^{a}	22.73^{a}	285.3^{a}	716.4^{a}	162.2^{a}
RPS+S	4.60^{ab}	7.79^{b}	12.81^{ab}	200.5^{ab}	277.6^{ab}	719.3^{ab}
RP	2.28^{bc}	4.98^{b}	6.5^{9b}	78.2^{b}	132.0^{b}	312.7^{ab}
LSD	2.31	5.12	8.02	146.1	382.1	647.7
SXPF	*	*	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).S-vegetable species, PF-phosphorous sources

Interaction effects between the phosphorous sources and vegetable species were revealed during different growth stages.

Table 4.8 Interaction effects on shoot dry weight in season 1 and season 2 between vegetable species and phosphorous sources

Treatments	**Season 1**			**Season 2**		
	5WAP	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kale control	0.88^{g}	2.46^{fgh}	4.59^{f}	1.2^{f}	3.1^{d}	4.6^{e}
Amaranth control	0.735^{g}	0.86^{i}	1.06^{h}	50.0^{def}	65.1^{cd}	289.3^{de}
Cowpea control	1.07^{fg}	1.73^{hi}	2.06^{gh}	91.5^{de}	102.1^{cd}	195.2^{de}
Kales TSP	11.79^{a}	24.66^{a}	41.74^{a}	11.8^{ef}	24.7^{d}	$45.1d^{e}$
Amaranth TSP	7.31^{b}	17.04^{b}	18.09^{b}	507.0^{a}	1579.7^{a}	2063.0^{a}
Cowpea TSP	3.09^{cd}	3.66^{f}	8.36^{de}	337.2^{b}	544.8^{b}	1078.5^{bc}
Kale RP	3.16^{cd}	7.20^{d}	7.84^{de}	2.5^{ef}	6.5^{d}	7.8^{e}
Amaranth RP	2.35^{de}	5.32^{e}	8.64^{d}	112.8^{d}	244.0^{cd}	628.7^{cd}
Cowpea RP	1.33^{efg}	2.41^{gh}	3.30^{fg}	119.1^{d}	155.4^{cd}	301.5^{e}
Kale RP+S	7.49^{b}	12.99^{c}	18.97^{b}	7.5^{ef}	10.7^{d}	17.3^{e}
Amaranth RP+S	4.00^{c}	7.06^{d}	12.70^{c}	382.3^{b}	552.7^{b}	1615.0^{a}
Cowpea RP+S	2.30^{def}	3.333^{fg}	6.75^{e}	211.8^{c}	269.3^{c}	525.7^{cde}
LSD	**1.27**	**1.23**	**1.61**	**89.27**	**114.2**	**600.5**

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).

Amaranthus treated with TSP at 7 WAP had the highest interaction effect on shoot dry weight recording 2063.0 g as illustrated in table 4.8. Finely ground RP directly applied to soil in Malaysia for oil palm production was reported to have improved growth and yield (Zaharah *et al*., 1997). Moreover, in Brazil, a single application of RP per ha of land deficient of P gave 100 % yield increase in oil palm over a period of 6 years (Hartley, 1988). This supports the role RP play in increasing oil palm yield (ton / ha) by 58 % in Indonesia in a second year following implementation of best management practices (Griffiths and Fairhust, 2002). Application of RP increased fresh fruit bunch (FFB) and on acid sands, was found to be superior to single super phosphate (Imogie *et al*., 2011). Its incorporation ensured a steady supply of P over a long period and also provided a high rooting density to crops (Bolan *et al*., 1990).

4.2.9 Root dry weight

Significant differences ($P \leq 0.05$) were observed between the phosphorus treatments in the root dry weight of the vegetable species in season 1 and season 2. Kales recorded the highest root biomass in 5 WAP, 6 WAP and 7 WAP in both season 1 and season 2 with the 7 WAP being superior with 9.84 g and 9.83 g in season 1 and 2 respectively. This could be due to high growth rate of the kales as a result of phosphorous nutrition. Cowpea had the least biomass accumulation in root in both seasons as shown in Table 4.9. Phosphorous forms also exhibited significant differences in root biomass with TSP being superior during the whole growth period with the highest being recorded at 7WAP with 11.2 g in the two seasons.

Table: 4.9 Root Dry weight as influenced by vegetable species and phosphorous sources

	Season 1			**Season 2**		
Species	**5WAP**	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kales	2.04^{a}	2.96^{a}	3.99^{a}	2.03^{b}	2.96^{b}	3.99^{a}
Amaranth	1.57^{ab}	2.92^{a}	3.71^{a}	5.62^{a}	5.47^{a}	5.54^{a}
Cowpea	1.11^{b}	2.16^{a}	2.54^{b}	5.26^{a}	5.22^{a}	5.33^{a}
LSD	0.53	0.87	0.94	0.41	0.53	0.53
Treatments						
Control	0.76^{c}	1.41^{a}	2.00^{b}	4.08^{a}	4.23^{a}	4.59^{a}
TSP	2.21^{a}	3.63^{a}	4.40^{a}	4.50^{a}	4.86^{a}	5.21^{a}
RPS+S	1.83^{ab}	3.12^{ab}	3.87^{a}	4.06^{a}	4.26^{a}	4.78^{a}
RP	1.49^{b}	2.56^{b}	3.39^{a}	4.57^{a}	4.86^{a}	5.23^{a}
LSD	**0.49**	**0.67**	**0.88**	**1.74**	**1.30**	**0.91**
SXPF	*	*	*	*	*	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$).S-vegetable species, PF-phosphorous sources

The RP+sulphur was the second best in terms of root growth which is an indication of high availability of phosphorus from this particular source of phosphorous. The control recorded the least root biomass compared to other sources of phosphorous. Interaction effects between the vegetable species and phosphorus source at various growth stages in the two experimental sites. During the first season , amaranth supplied with TSP was superior in root biomass in three sampling stages recording 2.64 g, 4.62 g and 5.50 g in 5 WAP, 6 WAP AND 7 WAP respectively as shown in Table 4.10.

Table 4. 10 Interaction effects on root dry weight in season 1 and season 2

Treatments	Season 1			Season 2		
	5WAP	**6WAP**	**7WAP**	**5WAP**	**6WAP**	**7WAP**
Kale control	1.24^{f}	1.86^{g}	2.69^{f}	1.24^{h}	1.85^{i}	2.69^{h}
Amaranth control	0.24^{i}	0.58^{h}	1.13^{i}	5.86^{ab}	5.83^{b}	5.83^{ab}
Cowpea control	0.81^{h}	1.79^{g}	2.17^{h}	5.12^{d}	4.99^{d}	5.25^{cd}
Kales TSP	2.61^{a}	3.81^{b}	4.87^{b}	2.60^{f}	3.81^{f}	4.87^{e}
Amaranth TSP	2.64^{a}	4.62^{a}	5.50^{a}	5.38^{cd}	5.31^{c}	5.27^{cd}
Cowpea TSP	1.39^{e}	2.46^{e}	2.84^{e}	5.51^{c}	5.48^{c}	5.49^{bc}
Kale RP	1.97^{c}	2.29^{e}	3.89^{d}	1.97^{g}	2.76^{h}	3.89^{g}
Amaranth RP	1.49^{d}	2.83^{d}	3.82^{d}	6.12^{a}	6.14^{a}	6.033^{a}
Cowpea RP	1.01^{g}	2.10^{f}	2.46^{g}	5.63^{bc}	5.69^{b}	5.76^{ab}
Kale RP+S	2.34^{b}	3.43^{c}	4.51^{c}	2.33^{f}	3.43^{g}	4.51^{f}
Amaranth RP+S	1.91^{c}	3.65^{b}	4.40^{c}	5.10^{de}	4.60^{e}	5.02^{de}
Cowpea RP+S	1.24^{f}	2.29^{e}	2.70^{f}	4.77^{e}	4.74^{e}	4.81^{ef}
LSD	0.12	0.17	0.11	0.35	0.18	0.34

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

In the second season, significant differences were observed in the interaction of the vegetable species and phosphorus with amaranth supplied with rock phosphate having the highest root dry weight of 6.12 g, 6.14 g and 6.03 in 5 WAP, 6 WAP and 7 WAP respectively (Table 4.10). RP+S followed in root biomass accumulation which was an indicator of vibrant root growth as influenced by phosphorus from dissolved rock phosphate. There was a significant influence on the all-vegetable species compared to the control which could be as a result of promoted growth of young cells and rapid cell division as a result of phosphorus nutrition. Phosphorous has also been associated with increased root formation which is confirmed from the current study.

The current study agrees with the findings of Ojo *et al.* (2007) who reported an increase in root biomass on grain amaranth when supplied with phosphorus forms. Application of phosphorus sources in cowpea has also reported to increase nodulation which is a sign of vibrant root growth as reported by Kyei-Boahen *et al.*

(2017) particularly for cow pea. On the other hand the effective utilization of rock phosphate in combination with sulphur was obvious where by the S seem to play a role in decreasing soil pH, and consequently helped in transformation of insoluble P to available form for plant uptake (Koch *et al.*, 2018). Moreover, mixing the RP with elemental S caused a significant increase in the available P over those applied without S. As stated by Huang *et al.* (2018), phosphorus is an essential element for plant growth and is particularly important for root growth during the establishment and early growth stages. The current study thus, indicates that growers can embark on rock phosphate utilization in farming as an alternative in provision of phosphorous nutrition in vegetable species.

4.2.10 Effects of P sources and crop species on plant root fresh weight

There were significant differences in the root fresh weight among the P treatments during the long and short rain seasons in all the crops at the different sampling stages (Figure 4.8). As expected, the control treatment resulted in the lowest root weight probably conforming that P was limiting in the soils of the experiment. The TSP treatment showed the highest fresh root weight throughout the sampling weeks for both trials in all the crop species. The rock phosphate plus sulphur amendment had the second highest fresh root weight after the TSP in all the sampling stages on all the crop species and at some stages on the cowpea crop, there were no significant differences between the rock phosphate plus sulphur treatment and the TSP treatment.

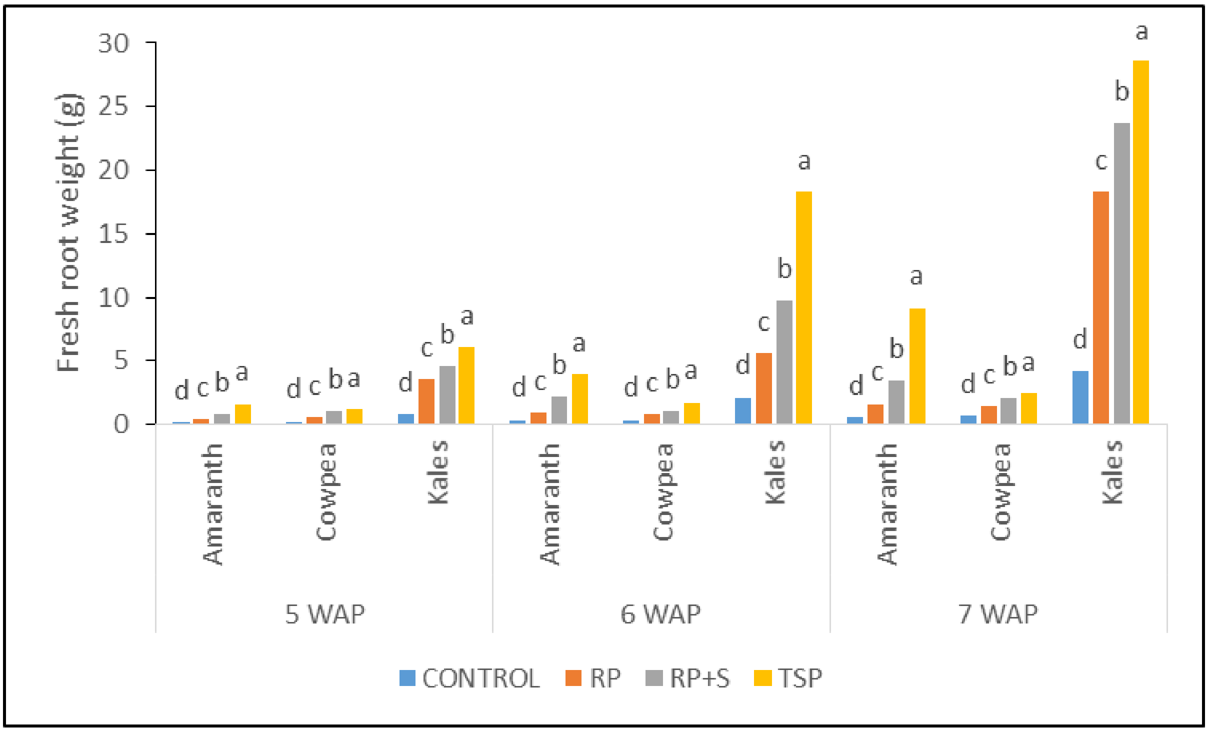

Figure 4.8: The influence of different phosphorus forms on the root fresh weight of Amaranth, Cowpea and kales at 5, 6 and 7 WAP (weeks after planting) during the short rains season

4.3 The influence of phosphorus sources on the rhizosphere and phosphorus uptake

4.3.1 Effect of different P sources and plant species on soil rhizosphere pH

The phosphorus sources showed significant influence in the soil pH with differing effects among them. Under the amaranth, the sole rock phosphate increased the soil pH while the rock phosphate plus sulphur treatment reduced the soil pH significantly. The control showed almost no influence on the amaranth with the pH slightly increasing at later weeks while at 5 WAP almost no change from the one recorded before planting. Under the cowpea, all the treatments showed a decreasing trend on the soil pH compared to the soil pH before planting, however, the least change was observed under rock phosphate treatment while that under the rock phosphate plus sulphur had the highest reduction of soil pH. Under the kales, there was a significant increase in the soil pH due to application of rock phosphate alone while the greatest reduction was in the rock phosphate plus sulphur treatment.

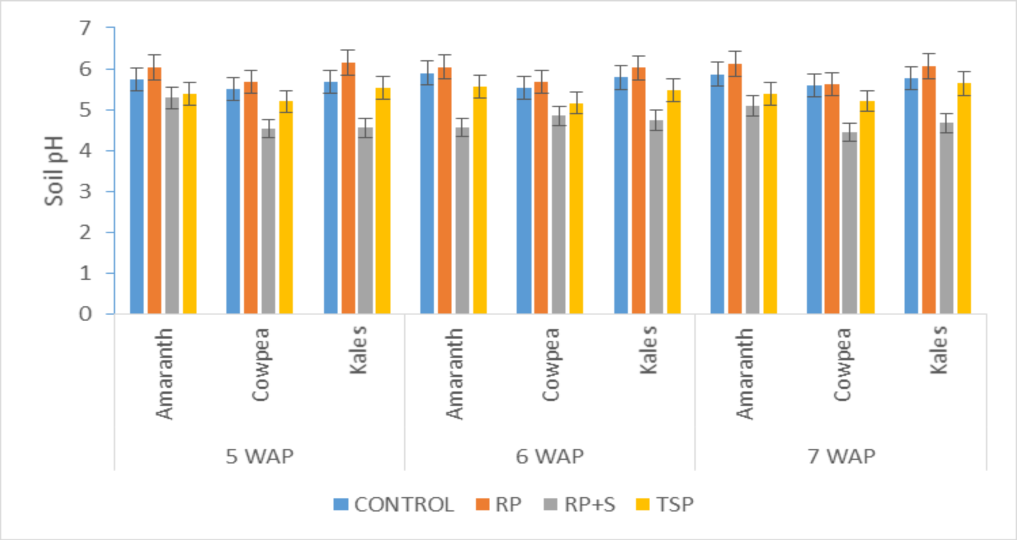

Figure 4.9: The influence of different phosphorus forms on the soil pH at 5, 6 and 7 WAP (weeks after planting) during the long rain season

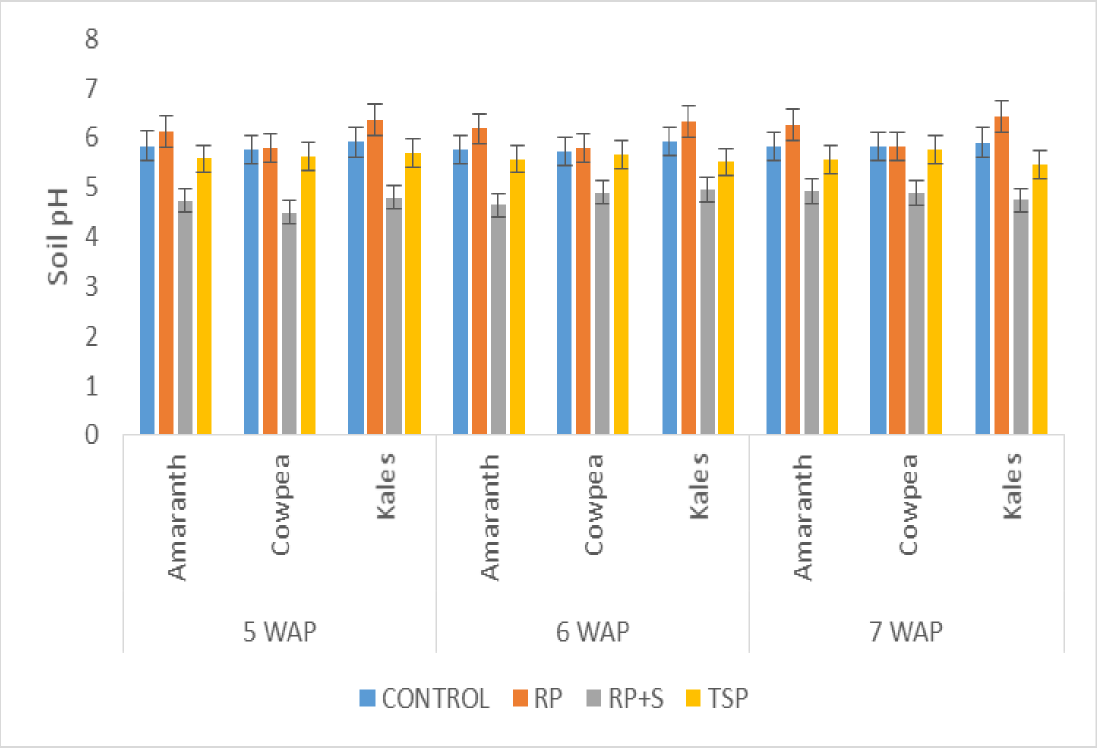

Figure 4.10: The influence of different phosphorus forms on the soil pH at 5, 6and 7 WAP (weeks after planting) during the short rains

The significant variations (increases) in the concentration of available P that occurred mainly in PR or PR-related soil treatment have been likely brought about by the effects of acids released into the rhizosphere of amaranth, cowpea and kale on PR solubility (Troelstra *et al*., 1985; Dakora and Phillips, 2002; Sugiyama and Yazaki, 2012). In a physiologically view point, the reduction of pH in the cowpea crop is probably because the maturation of cowpea plants led to an increase of biological activities in nitrogen fixation and the consequent increase release of acids into the rhizosphere thus reducing the soil pH significantly. Similar findings were reported by AICAR (2008) in bean plants where there was a significant reduction of biological activities led to a diminishing release of acids in the rhizosphere. The applied phosphorites as rock phosphate normally lack any readily soluble phosphate salts and, therefore, rely on the chemical rhizospheric capability of the plant life system to break down and release the available phosphorous from the contained phosphate minerals and develop a calcium sink for the process. Therefore the increased soil pH might be due to the development of calcium as well as the different reactions from the crop species in the two seasons. In selected cases rock phosphates represent a better product for plant recovery, thus allowing the utilization of phosphorites that are normally not desirable in the wet phosphoric acid extraction system and, as a natural system, it avoids not only the potential generation of excessive liquid pollutants but also the production of the solid phosphogypsum tenorm waste. Certainly not all soils and crop systems are suitable for the direct application of phosphate rocks. The commonly used wet process sedimentary phosphorites are very complex due to their variant geologic origins and may contain unacceptable levels of heavy metals such as uranium. The level of knowledge of the environmental impact of rock phosphate and the inherent level of risk involved, if proven significant, will require rigorous future evaluation of the benefits and problems of the application of raw phosphorites versus the more readily soluble processed fertilizers on crop systems.

Phosphate rock is chemically processed with sulphuric acid or phosphoric acid into soluble phosphate fertilizers (Van Straaten, 2002). Also, rock phosphate application as a phosphate fertilizer along with the activity of soil microorganisms can be effective in solubilizing RP (Kang *et al*., 2002). Most soil microorganisms such as bacteria, fungi and actinomycetes have the ability to change insoluble phosphates to soluble forms. Bacillus and Pseudomonas are important genera of phosphate solubilizing bacteria. (Reyes *et al*., 2006; Valverde *et al*.,2006 ; Vassilev *et al*., 2006; Taalab and Badr 2007; Mittal *et al*., 2008 ; Pandey *et al*., 2008; El– Azouni 2008 and Ogbo, 2010). On the other hand , elemental sulphur seems to play an important role in reducing soil pH values through its transformation to sulphuric acid by sulphur oxidizing bacteria , therefore it may have been helpful in increasing the solubility of P from RP. In this respect, Tibbett and Diaz, 2005, reported that the combining phosphate rock RP with elemental sulphur is resulted in the production of mineral acids which will create a localized high acidity in the immediate vicinity of RPs. Moreover, phosphate fertilizers could be increased markedly if they were applied along with organic acids or with organic wastes due to their influences in lowering soil pH values along with chelating Ca and Mg ions and consequently increase the availability of phosphate (Rajan and Ghani, 1997; Sagoe *et al*., 1998; .Sinaj *et al*., 2002; Van Straaten, 2002; Savini *et al*., 2006 and Ivanova *et al*., 2006).

Zin *et al*. (2005) reported that RP fertilizers have a higher content of calcium ranging from 24 – 33 %. This makes RP beneficial in increasing soil pH and cation exchange capacity (CEC) resulting in yield increases of oil palm (Zin *et al*., 2005). Their use has also been shown to have great potentials for liming due to their high content of calcium (Isenmila *et al*., 2006). According to Imogie *et al*. (2011), in the acid soils of the humid tropics, reactive rock phosphate can be substituted profitably for soluble fertilizers; nevertheless, the effect of RP is limited in neutral or alkali soils. Its incorporation ensures a steady supply of P over a long period and also provides a high rooting density to crops (Bolan *et al*., 1990).

4.3.2 Effects of P sources and crop species on soil P concentrations

There were significant differences between the P sources treatments on the amount of phosphorus in the soil in the three crops (Fig. 4.11). In amaranth, TSP had the highest amount of soil phosphorus (23.0 ppm) with RP + Sulphur exhibiting 15.3 ppm which was significantly higher than that of RP alone. The same trend was observed in cowpea but with lower contents than that of amaranth with 19.0 ppm on the TSP treatment while the lowest was on the control with 5.3 ppm.

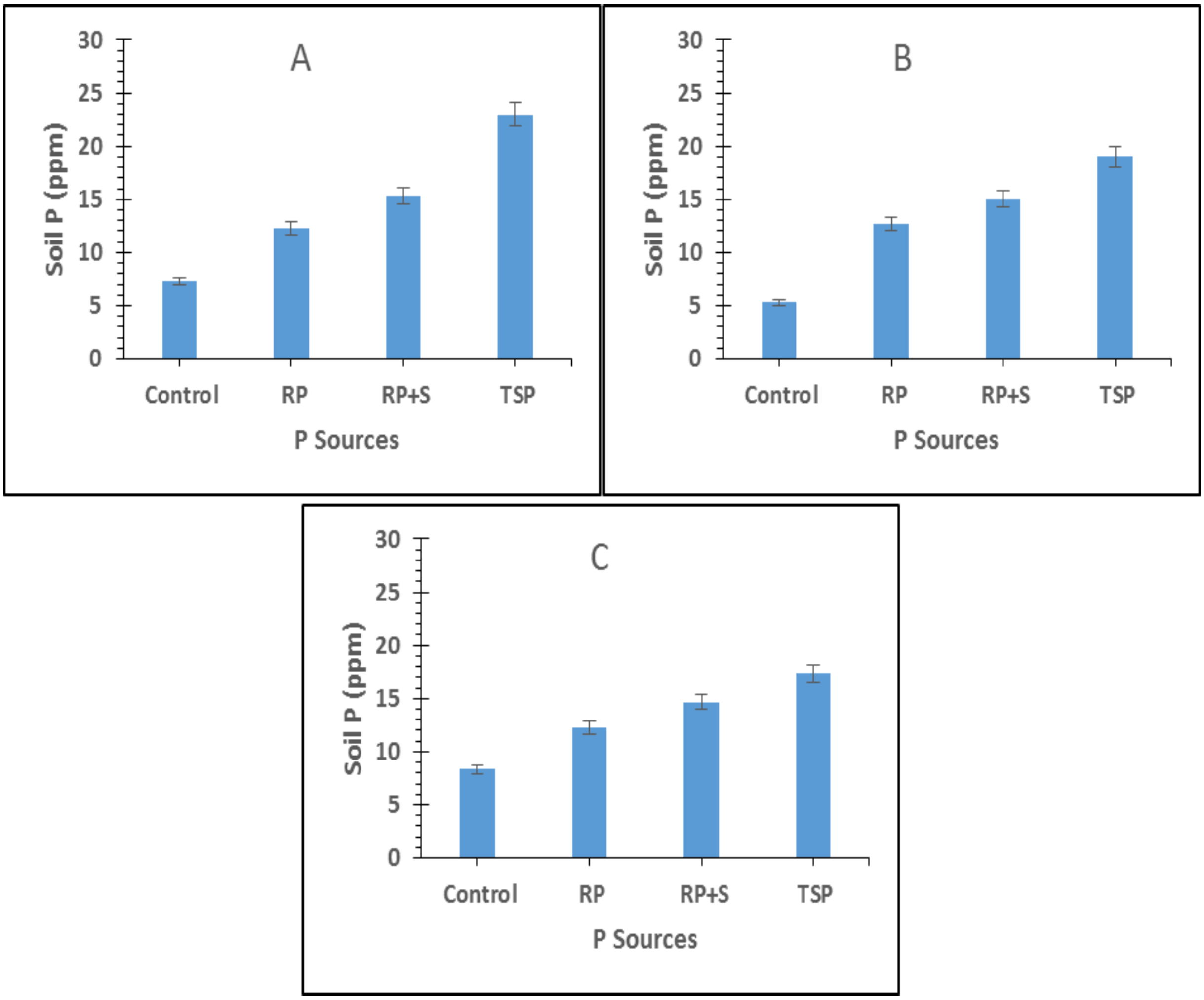

Figure 4.11: Influence of P sources on the soil phosphorus content after the experiment in Amaranth (A), Cowpea (B) and Kale (C)

Available P in TSP amended soils was consistently higher than the available P in the other P fertilizers amended soils because of its solubility. This observation supports the findings of Khasawneh and Doll (1978), that the residual effects of soluble P fertilizers were greater than those of rock phosphates in the first 3 or 4 years after application. The variability in available P recorded was in agreement with the assertion of Roy *et al*. (2006) that available nutrients and their degree of availability and accessibility was not a static condition but an ever-changing and very dynamic process due to the various inorganic and biochemical processes that took place. Studies have shown that decreasing soil pH increases RP effectiveness (Prochnow *et al*., 2010). According to Fankem *et al*. (2006), phosphate solubilization was the result of combined effect of pH decrease and organic acids produced. Moreover, Ghosal and Chakraborty (2012) reported RP dissolution as linearly correlated with the reverse acidity of the soil. This clearly demonstrated the higher soluble nature of TSP and that more P was solubilized and made available in the rhizosphere. Studies have indicated increased P availability from RP with length of incubation period (Sinclair *et al*., 1986; Rajan *et al*., 1987), which contributed to the superior effect of TSP over the RPs in this study. Yet, slow dissolution rates may also be an advantage over soluble fertilizers in soils with very low P-fixing capabilities, as P is less likely to be lost to leaching (Sanyal and De Datta 1991). Roy *et al*. (2006) explained that the amount of nutrients estimated to be available was not a measure of the total available pool of nutrient, but the proportion that correlated significantly to crop response.

4.3.3 Effects of P sources and crop species on plant tissue phosphorus

The plant tissue phosphorus content of the three crops showed significant differences due to the different P sources (Fig. 4.12). The highest tissue phosphorus content (510.7 mg/100 g) was recorded on cowpea under the TSP treatment with observed on amaranth (427.0 mg/100 g) and kale (334.7 mg/100 g). The lowest tissue phosphorus content was exhibited under the control of all the crops with 286.0, 188.3 and 174.7 mg/100 g on amaranth, cowpea and kale, respectively.

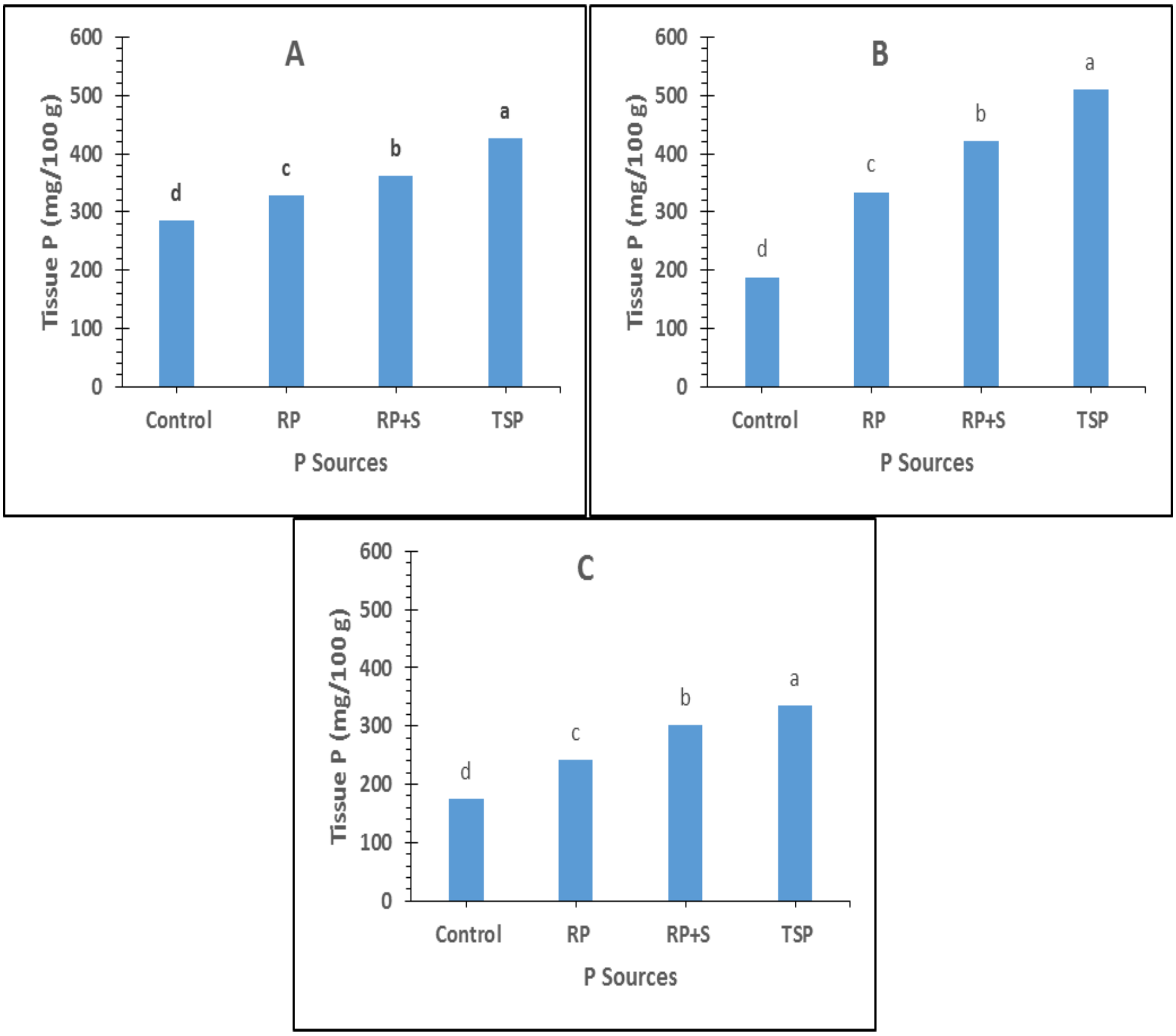

Figure 4.12: Influence of P sources on the tissue phosphorus content after the experiment in Amaranth (A), Cowpea (B) and Kale (C)

Vernieri *et al*. (2005) asserted that fertilizers through rock phosphates worked to increase plant nutrient uptake and improve nutrient use efficiency; and that there were no advantages in the use of sole rock phosphate in the promotion of plant growth (Albregts *et al*., 1988). Studies by Obigbesan *et al*. (2002) showed inhibited root growth as resulted from low P supplied , whereas, Goh and Hadter (2003) reported that in P-deficient plants, shoot growth was found to be more affected than root growth due to assimilate partitioning towards the root which led to a decrease in the shoot: root dry matter ratio. The optimum P contents produced by TSP indicated their positive influence on the uptake of these nutrients and supported the finding of

Lucas *et al*. (1979) and Menon and Chien (1990) when oil palm seedlings and maize plants were treated with different P fertilizers. This could be due to available native soil nutrients in the control medium, whereas, the TSP with its high solubilization ensured high P availability in the vicinity of plant roots which contributed to high P use efficiency and a corresponded higher P content in the tissues.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

- Phosphate rocks (PRs) are suitable for direct application as a possible alternative to more expensive soluble phosphate fertilizers in agricultural fields. In the laboratory experiment, the acidulating agents showed significantly different dissolution rates of P from rock phosphate with sulphur showing the highest at 30 days after incubation with 37.5 ppm, 1175.3 ppm after 60 days and 1822.9 ppm after 90 days. The phosphoric acid and oxalic acid had P dissolution effect on rock phosphate but much lower to that exhibited by sulphur.

- The soil at Kenyatta University was found to be deficient in phosphorus and therefore led to higher and significant responses of the growth and yield parameters of the three crops to the different forms of P applied compared to the control. The triple superphosphate treatment led to the highest fresh root weight, fresh shoot weight, leaf area, number of leaves per plant, root dry weight, root length, shoot dry weight and shoot length especially under the amaranth and kale crop then followed by the rock phosphate plus sulphur treatment which at some instances under the cowpea they were not significantly different with the industrial fertilizer however being superior. Direct application of phosphate rock to soil is a possible alternative to the more expensive soluble phosphate fertilizers in tropical cropping system.

- The soil rhizosphere was significantly influenced by the different forms of phosphorus in different patterns under the different crop species. The soil pH increased significantly on the rock phosphate treatment under the amaranth and kale crops from 5.7 before planting to above 6.0 while on the cowpea, the treatment showed the least change with a slight drop of pH from 5.7 to around 5.6 with the other treatments dropping to much lower units, even the control. The RP+sulphur treatment led to the highest decrease of the soil pH in all the crops with the most observed under the cowpea. The highest uptake of phosphorus was observed on the TSP treatment in all the crops with cowpea showing the highest.

5.2 Recommendations

- The study results recommends the use of sulphur as an acidulating agent is a viable option and can significantly increase the solubility of phosphorus in rock phosphates.
- The acidulated rock phosphate (RP+sulphur) increased the growth parameters of amaranth, cowpea and kale as well as their yield parameters (number of leaves, leaf area and the shoot weight) though lesser than the TSP treatment which was superior. Therefore the use of acidulated rock phosphate is a viable option in the smallholder farmers who may not be able to afford the industrial fertilizer.
- The rock phosphate plus sulphur significantly reduced the soil pH thus showing the acidifying effect which is positive in places where there are higher soil pH or alkaline but can be detrimental in places where the soil acidity is already a problem and rock phosphate alone can be a remedy in such instances due to its ability to increase the soil pH.

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