AGRONOMIC EVALUATION OF PHOSPHATE SOURCES FOR SOYABEAN PRODUCTION IN THE NIGERIAN SAVANNA ALFISOL

BY

ESTHER DABALI PAM
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Faculty of Agriculture
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Nigeria.

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CERTIFICATION

This thesis entitled: "Agronomic Evaluation of Phosphate Sources for Soyabean Production in the Nigerian Savanna Alfisol", by Esther D. Pam, meets the regulations governing the award of the degree of Master of Science (Soil Science) of Ahmadu Bello University for which it is presented. Its form and content is approved for its contribution to scientific knowledge and literary presentation.

Prof. V.O. Chude
Chairman, Supervisory Committee,
Head of Department.

27/2/98
Date

Dr. E.O. Uyovbisere
Member, Supervisory Committee

3/6/98
Date

Dr. T. Kparmwang
Member, Supervisory Committee

3/6/98
Date

Dean, Postgraduate School

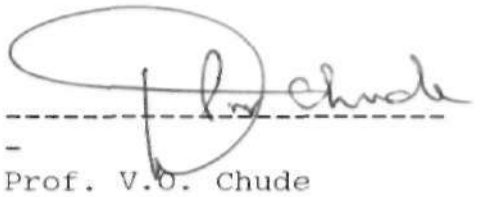
19/8/98
Date

DECLARATION

I hereby declare that this thesis is original in content and that it is a record of my own research work. Where otherwise, the sources of information have been acknowledged by references. It has also not been presented for the award of a higher degree at the Ahmadu Bello University, or any other University.

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Esther D. Pam Date

Confirmed by:



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Prof. V.O. Chude Date
Chairman, Supervisory Committee

DEDICATION

To my late father who would have loved to see me to height of heights in life, and to his wives - Hudung and Hwonji, whose love, care, and devotion are building me in life.

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ABSTRACT

In the Northern Guinea Savanna, phosphorus deficiency has been identified as the most important single element limiting the growth of soyabean. Furthermore, soyabean producers are constrained by the high cost of commercial Single Super-phosphate fertilizers hence the need to identify alternative, cheaper and effective sources of phosphorus that will be within the reach of poor resource farmers. A field trial conducted for two cropping seasons (1994-1995) on two different sites at the Institute for Agriculture Research Farm, Samaru to evaluate the effect of four sources of phosphorus, viz: single superphosphate, partially acidulated phosphate rock (50%), Sokoto phosphate rock and Togo phosphate rock on the performance of soyabean. The phosphorus rates were 0, 30, 60, 120 kg P_20_5 ha"^{1}. Soyabean cultivar Samsoy 2 was used as test crop. All treatments were replicated three times in a randomised complete block design.

Soyabean grain yield and yield components responded significantly (P = 0.01) to P fertilizer application. The number and weight of nodules, number of flowers per plant, shoot dry weight were increased, but reduced root weight with increasing rates. The increased nodulation resulted in increased number of pods and seeds per plant, weight of seeds per plant, 1,000 seed weight and threshing percentage of the crop. The eventual effect was a highly significant grain yield increase, thus indicating a balance requirement of soyabean for P nutrition.

Single Superphosphate was superior to all other sources of phosphorus tested in the trial although the performance of PAPR-50 was also as good as this commercial fertilizer. Grain yields obtained at 120 kg P_20_5 $ha-^1$ application rates of Sokoto phosphate and Togo phosphate rocks were quite appreciable. On the over all performance of the various fertilizers based on their means, SSP > PAPR-50 > SPR > TPR > control. Statistically significant responses were obtained up to 120 kg P_20_5 $ha-^1$. The only fertilizer material that reached its optimum rate of application was the most soluble P fertilizer (SSP) at the rate of 60 - 120 kg P_20_5 ha" ^{1}.

The application of these P sources raised the soil solution P level high enough to benefit the crop. This is shown by increased Nitrogen and phosphorus contents in leaves. The total phosphorus concentration in the leaves were significantly increased (P<0.01) in 1995, with SSP having the highest value (4.47 g $kg"^1$) at 120 kg P_20_5 application rate.

Data obained from chemical analyses of the soil receiving the P treatments and cropped, revealed that the available soil P, ECEC and base saturation were significantly increased (P<0.05); indicating that the application of P significantly maintained the soil P and CEC at optimum level.

The experimental soils had initial low extractable Bray-1 P, low clay content and extractable bases. A positive and significant relationship (r=0.281*) was found

between grain yield and Bray-1 P extractable from the soils at harvest suggesting that plant P uptake and growth could be limited by amounts of soluble P in the soil.

The influence of the P nutrition on plant performance, grain yield and the chemical composition of the soil cropped to soyabean; and particular responses to Sokoto phosphate rock shows that for direct application, the indigenous SPR could be as efficient as the other imported phosphates for soyabean production in this region. These results confirm previous works which show that although widespread phosphorus deficiences occur, moderate amounts of phosphate fertilizers are required to obtain high yields.

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CHAPTER ONE

INTRODUCTION

Phosphorus (P) deficiency is next to that of nitrogen in limiting crop production in the savanna zones of Nigeria. This constraint is common to West Africa and the sub-Saharan Africa at large (Ahn 1970; Lombin, 1979; Mokwunye, 1996). Though the amounts of nutrient elements in soils of the savanna are low, the effects of other nutrients are often limited by the deficiency of P in the soil. The importance of P in the cell nuclei, in energy transfer mechanisms and in root development are well recognised.

Alfisols dominate the soils of the Guinea Savanna region of Nigeria, with ultisols and oxisols in association (Uyobisere and Lombin, 1991). These soils have sustained crop growth for a very long time, and as a consequence, their fertility has become perilously low, and the task of increasing and maintaining the productive capacity of these soils has become a great challenge to scientists in the last half of this century. Alfisols are low in available P, have low P-fixing capacities and show responses to phosphate fertilization. The low P status of the savanna soils has been attributed to low apatite inclusions in the soil forming minerals, and losses are through erosion, leaching (though minimal) and crop harvest. Organically derived P makes only a small contribution to plant uptake in these soils (Ahn, 1970).

While the animal and human populations have steadily grown in Nigeria, the per capita food production has consistently declined over the last three decades (Maduakor, 1991, and Mokwunye, 1995). Population pressures have resulted in continuous and intensive cultivation of these soils, eliminating or reducing fallow periods. This has placed a heavy strain on these soils leading to large decreases in the productive capacity of these soils. Continuous cultivation has been shown to consistently decrease the organic matter content, cation exchange capacity, exchangeable cations and pH (Jones and Wild, 1975). The use of fertilizers and other soil amendments are prerequisites to improve the soil fertility and sustain yields at high enough levels to feed the expanding population in continuously cropped soils.

Inorganic phosphate fertilizer can increase both the amount of total P and the concentration of soluble or labile P. It has been observed that only about 15% of a water-soluble P applied is taken up by the fertilized crop in year of application, with a large part fixed in less soluble forms which provide residual benefits overtime.

Fertilizer use in Nigeria is grossly inadequate in relation to the increasing food needs of the country. It is obvious that increased and efficient fertilizer use is imperative if Nigeria is to produce enough food to feed its rapid increasing population. With the high increase in prices of mineral fertilizer, the need has arisen to find suitable but cheaper alternative to single

superhosphate(SSP). The use of finely ground phosphate rocks, applied directly to tropical soils is an attractive option because they are considerably cheaper P sources than commercially available water-soluble P fertilizers.

With the inherent P deficiency, and low P- fixing capacity of these savanna soils, fertilizing the soil with Phosphate Rock (PR) to build up the soil P reserves is necessary if the annual and long term requirements of P by crops is to be met. Phosphate rocks are able to serve both a productive goal (yield increments required by farmers) and sustainability goal (restoring the P stocks of soils) because of the slow release of P from PR. Though crop yields in year of application are generally lower than that of the soluble P fertilizers; as a basal fertilizer PR would be most effective with adequate moisture and on acid soils that are extremely deficient in P. If PR is used as an annual fertilizer for several years, its cumulative residual effect may be similar to that of a soluble source (Jones and Bromifield, 1974).

A local source of PR in Nigeria is the Sokoto Phosphate Rock (SPR). Laboratory evaluation of SPR under incubation studies have shown it to be as reactive as or slightly more reactive than imported Togo Phosphate Rock (TPR) in P_2O_5 (Phosphoric anhydrate) content and solubility. However, there is no documented information on the agronomic efficiency of SPR in the Nigerian savanna.

Leguminuous crops have been established to be more efficient in using PR compared to cereals. They are

capable of utilizing P from relatively insoluble compounds. This is as a result of their high root densities and more calcium (Ca) requirements.

In view of the importance of P as a major nutrient limiting crop production, especially legumes and soyabean in particular, a study was initiated with the following objectives:

1. to compare the relative effectiveness of the various phosphate sources and
2. to determine the effects of the phosphate sources on some chemical properties of the soil cropped to soyabean.

CHAPTER TWO

REVIEW OF LITERATURE

2.1.1 Features of the Research Environment

The savanna belt of West Africa stretches from approximately 8° to 19° N latitude. There are three ecological zones within the Nigerian savanna region namely: The Sahel savanna, Sudan savanna and Guinea savanna zones. The Guinea savanna lies between 8° and 12° latitude and is further subdivided into the Northern and Southern Guinea. The Northern Guinea receives 900 to 1,300 mm annual rainfall in 4-6 months; with a vegetation that is highly influenced by the rainfall pattern (Mokwunye, 1979). Kowal and Knabe (1972), on the other hand explained that these natural savanna regions of Nigeria ar determined by the duration and intensity of the dry season and not directly related to the total rainfall received. The vegetation consists of grasses with tree and bushes, which are mostly of fire resistant species. They noted that Samaru (Latitude 11° 11'N, and Longitude 7° 38'E) is situated in the Northern Guinea savanna zone with a mean annual rainfall of about 1,100-1,250 mm, falling almost entirely during the period May-October; characterised by the sub-humid climate. Lombin (1979), further characterised Samaru to lie between the Southern limit of the Sudan Savanna and Northern limit of the Guinea savanna zones.

Ahn (1970), reported that in this region evapotranspiration (ET) usually exceeds rainfall, but the reverse is the case in the wet season. When balanced there is a water deficit for all or most of the year. Jones and Wild (1975), on the contrary explained that although, potential ET is greater than rainfall on an annual basis, in most years there is almost every where a period of water surplus, where rainfall temporarily exceeds ET. Depending on the amount of excess rainfall, profiles can recharge and drainage and run off occur. Moreover, the dry season is not too long to allow a continuously high rate of water loss by ET. Hence, the vegetation consists of separate trees or woody plants with grasses which become dominant in the dry season.

In this area, the effect of altitude on climate is small because on a regional scale elevation is generally less than 1,000 metres. The Northern Guinea savanna is covered by unconsolidated or poorly consolidated sands which are undifferentiated. Its geological development is from pre-cambrian basement complex, with stretches of alluvium along river valleys (Jones and Wild, 1975).

2.1.2 Soil of the Nigerian Guinea Savanna (Study Area)

Jones and Wild (1975) reported that much of the material of present-day soil has been subjected to repeated pedogenesis under varying climatic regimes over long periods of geological time.

This area is covered by ferruginous soils of varying parent materials which are highly weathered, markedly

laterised by the loss of silica. The bulk density of the surface soil is seldom less than 1.4-1.5g cm-3, with very unstable or small aggregates. The Water Holding Capacity (WHC) of the soil is good but, primarily depends on its structural composition. The soils are weakly buffered, have a very low cation Exchange Capacity (CEC). The total content of available plant nutrient in these soils is low due to high leaching and erosions. Jones and Wild (1975), further observed that these ferruginous soils are formed on parent materials rich in quartz, the clay has moved down the profile producing a sandy soil low in organic matter, base exchange and a compact subsoil.

Uyovbisere and Lombin (1991), pointed out that soils of the Guinea savanna are predominantly Alfisols with associated Ultisols and oxisols. Nitrogen and Phosphorus are often deficient and the soils are largely coarse in texture. These soils are dominated by the low activity clays such as Kaolinite and the oxides and hydrous oxides of Aluminum and Iron (Lombin 1979).

Esu (1977), observed that the soils are well-drained and deep, but commonly developed plinthic subsoils, soil texture consist of loamy sands to sandy loam topsoils over argillic subsoils. The weak surface aggregates make them susceptable to severe erosion. Soil pH range from moderately acid to acidic soils. The organic matter, CEC, total N, available P content are low, Ca and Mg dominate the exchange· complex of some of the soils. The exchangeable K and percentage base saturation are moderate.

Major pedogenetic process are among other factors that contribute to the inherent fertility of these soils.

Samaru has soils which are well drained and leached luvisols (Lombin, 1979; Mokwunye, 1979; Uyovbisere, 1986) and are formed in drift material. The topsoil is fine sandy loam, which is prone to capping, having a poor structure. These soils have predominantly kaolinitic clay faction with a shallow topsoil and are designated to have low P-fixing capacities because of their relative coarse textured surface horizons.

In consequence, P deficiency is widespread, amounts of organic N, P and S mineralized annually are often well below the requirement for good crop yields; and the soils is poorly buffered against changes induced in it by agricultural activities.

2.1.3 Amount of P in the Soils

For geological and pedological reasons soil phosphate contents are generally low (Jones, 1974) and agronomic studies have shown that P deficiencies occur in nearly all crops in most part of this area. Russel (1988), noted that only few soils in the world are able to provide sufficient P for a sequence of good crop yield.

Bache and Roger (1970); Jones (1974), found the northern Nigerian soils to be inherently deficient in P, and low in P fixing capacities. There are small quantities in the soil, and its tendency to react with soil components or be immobilised is pronounce, therefore, crops respond well to the application of phosphatic fertilizers (Kowal

and Kassan, 1978). Phosphorus deficiency is therefore, a serious limitation to food crop production in these soils especially when continuous cropping practices prevail. One fertility constraints of these soils is the low level of available P (Sale and Mokwunye, 1993).

Udo and Ogunwale (1977), reported that total P was generally low in savanna soils with a large fraction of the inorganic P remaining in non-extractable or residual form and the organic form also low. This is an indication that oxides play a significant role in the reaction and recycling of P in these soils. Agbenin (1996), recently reported that exchangeable calcium in these soils also affects the total and available P. The high level of residual and the low level of active P in these soils in an indication of high degree of weathering and a low available P status of the soil. According to Wong et.al. (991), the low content of both total and labile P may be related to the low content of organically bound P, which is as a consequence of the low content of organic matter; and lack of nutrient recycling due to crop harvest. Also Enwezor and Moore (1966) have shown these soils to have less than 200 mg kg^{-1} total P and Udo (1985) reported an average mean value of 189 mg kg-1 of total P.

Olaitan and Lombin (1984), pointed out that organic P is in the range of 20-25% in Samaru soils and there are no losses due to burning of crop residue; the ash after a burnt contributes only about 10-14 kg P ha-1 to the soil. Other values of the organic P reported in these soils are

17% by Bache and Roger, 1970; 25% by Enwezor and Moore, 1966 and 40% by Udo, 1985, and the importance of this fraction in the tropical soils has been documented.

Mokwunye (1979), showed that active Al-P, Fe-P and Ca-P make up less than 10% of the total P. Water extractable P is less than 0.2 ppm, and most crops will produce only meager yields in the absence of P fertilizers. However, Kowal and Kassan (1978), reported that adequate maintenance of the concentration of P in soil solution largely depend on the pool of readily desorbed P (quantity factor). They observed that sorption is not a serious obstacle to agricultural development in the savanna soils, rather it is the very low content of native P in soils. The P requirements estimated from the sorption capacities are found to be generally low for Alfisols (Udo, 1985). Enwezor and Moore (1966), showed that non-occluded inorganic P shows a dependence on soil pH in these soils. It is associated with Ca and Al in neutral soils, increasing with Al as Ca decreases with declining pH down to 5.5, and probably Fe and organic matter under more acid condition; with Fe coating predominant in ferruginous soils. Losses are through cropping intensity, erosion, slight leaching on sandy soils and gains depend in the amount of P added in manure or commercial fertilizers.

Russel (1988), observed that P differs from N as a plant nutrient for its dependence on the amount provided by the parent material. Phosphorus ions are strongly adsorbed by soil and not lost by leaching except from sand, the

gaseous loss of P (as phosphine-pH3) is rare. Its availability to plants depends on rapid replenishment of the solution by desorption of P from the solid phase, mineralization of soil organic P, and on diffusions through the soils to the root surface

2.2.0 Phosphate Rock as a Source of Phosphate

Phosphate Rocks (PRs) are natural ores containing substantial amounts of P (Young and Davis, 1970). Phosphate rocks deposits differ in physical texture, mineral form in which the P occurs and in nature and abundance of impurities. Phosphote rock forms the first raw material of the world phosphate and phosphate derivatives industry. McClellan and Gremillion (1980), reported that approximately 94 to 96% of phosphoric anhydrate (P_2O_5) produced in the world comes from PR. Phosphate rocks are important because they contain phosphate minerals belonging to the apatite family, which could be found in igneous, sedimentary or metamorphic rocks and show a great variability in chemical composition. Phosphate rock is a non-water-soluble P sources releasing P slowly when it reacts with soil constituents. Phosphate Rocks are classified into three groups (McClellan, 1978): Fe-Al-phosphate, Ca-fe-Al phosphate and Ca-phosphate. The availability of P to the plant is governed by the conversion rate of transformation reactions.

In general, apatites could be in form of carbonate (Francolite) with varying degrees of isomorphic substitution of carbonate for phosphate, fluoride and other

forms. Thermodynamic carbonate substitution of phosphate increase the reactivity of PR (Hammond *et al.* 1986). They noted that PR is not suitable for use in intensive agricultural production because, it cannot maintain a sufficient high P requirement, but that finely ground PR may be a suitable source of P for many tropical agricultural systems where very high yields are not sought and sulphur is not deficient, because it is the cheapest source of P (Khasawneh and Doll, 1978). Sale and Mokwunye (1993), pointed out that the extend to which PRs have a direct role to play as P inputs in management systems for crop production on acid tropical soils depends on their agronomic effectiveness relative to other available P fertilizers and their relative costing of alternative products. Since the Alfisols range from sandy to sandy loam, the absence of large amounts of colloidal materials in these soils create an ideal environment for greater than expected effectiveness of PR even for annual crops (Hanafi *et. al.* 1992)

Work done on PR as a source of P have been erratic and sometimes conflicting (Khasawneh and Doll, 1978). Using the West African indeginous PR (Togo PR) and the typical savanna soils, Jones (1973), reported that in Francophone West Africa, PR increased yield of crops in year of application, though the effect is generally less than that of soluble P fertilizers. As a basal fertilizer, however, PR is most effective. Similar results have been obtained by Lombin (1978), (1979); Jones and Bromfield (1974), in

the savanna soils of Nigeria. Mokwunye (1996), noted that apart from PR satisfying the requirement for P, it improves the efficiency with which crops use other nutrients such as N and K. However, they are of the view that PR showed not be used to provide a complete alternative to annual fertilization. Rather it should be used to build the P stocks of the soil, especially with the limited amounts of rainfall in this area. Jones (1973), further pointed out that crop response to PR is low or irregular where rainfall is less than 700 to 900 mm per annum.

2.3.0 Phosphate Rock for Direct Application

Phosphorus constitute one of the major constraints to crop production and the use of commercial P fertilizers is limited by the high cost of imported fertilizers. Direct application of indigenous PR can be an economic alternative.

Carbonate apatite or Francolite is the common constituent of sedimentary PR which can be used for direct application. The use of PR for direct application is a practice that has been employed with varying degrees of popularity over the years. But, experimental evidence have shows it to be most effective when used on acid soils that are extremely deficient in P. Under suitable conditions, PR applied directly gives nearly as good a result as the manufactured soluble P fertilizers.

The naturally occurring and often mined PR for direct application is examplified by carbonate-apatite (Fracolite) (Ca_{10-x-y} Na_{-x} Mg_{-y} (PO_4) 6.2 (CO_3) $F_{0.42}$ F_2) (McClellan, 1980).

These materials sometimes called soft PR can be used for direct application, depending on P content, solubility in specific organic acids and an extremely fine grinding.

Lombin (1979), observed that the direct effects were significantly superior to the residual effect, though single superphosphate (SSP) performed significantly better than PR. Meaning mineral PR can increase yields in years of application, but, its effect is generally less than that of the soluble P fertilizers . The direct application of PR to the savanna soils of Samaru resulted in a consequent increase in crop yields even in the year of application, especially when the rates of PR were based on the portions of the rock P extractable with anion resin. Mali which is a sub-arid country has reported response of crops due to the direct application of Togo Phosphate Rock (TPR) used in powdery form for annual application or basal dressing (Bello, 1995; Bationo *et. al.*, 1995).

Hammond (1978), has suggested the direct applications of PR to the soil as a possible alternative to the utilization of the more expensive soluble P fertilizer in tropical cropping systems; since these soils are acid, extremely deficient in P and, therefore, present favourable soil conditions for dissolution of relative insoluble apatite. He agrees with the findings of others, that raw phosphates could be used for a better advantage for long-season and perennial crops than for short-season crops.

The use of finely ground PRs, applied directly, as P sources to these soils has been suggested to be attractive

because:

1. it is an economically viable means for fertilization, particularly in view of the nearness, abundance and relative cheapness (Mokwunye; 1983; 1996; Uyovbisere and Lombin, 1991).

2. it can be considered as a calcium fertilizer as well as to improve the soil cation exchange capacity (CEC) status. Some soft PRs are also rich in some micronutrient especially Zinc (Sale and Mokwunye, 1993; Amberger, 1978).

3. more crops can profit from the initial application and yields from the residual P of a PR fertilizations can be higher than yields from the freshly applied rock (Visker et. al., 1995).

4. it can be used to improved the efficiency with which crops use other nutrients such as N and K, apart from satisfying the requirement for the most limiting nutrient (Mokwunye, 1996).

5. it can be used as a liming material in highly acid soils or soils acidification associated with nitrogen fertilization (Hammond, 1978).

6. the rock used may be otherwise unsuitable for other types of processing (Mokwunye and VLek, 1985).

2.4.0 The Agronomic Effectiveness of PR

Agronomic effectiveness is the actual performance of a given PR source as influenced by both agronomic potential and external condition under which it was used. Numerous studies have been conducted to evaluate the agronomic effectiveness of PR as a source of P for plants. The

agronomic effectiveness of PR is found to be highly variable and frequently lower than that of soluble P fertilizers. The general concensus is that the effectiveness of PR can vary from zero to almost equal to that of SSP, depending in the rock, crop species, other soil factors and management practices.

The solubility of PRs, the soil to which they were applied, climate and crop production management system influence PRs effectiveness as a P fertilizer. Phosphate rock's direct role as P fertilizer in tropical soil also depend on their agronomic effectiveness relative to other available P fertilizers and the relative products. Though the use of finely ground PR may be a cheaper alternative to acidulated, water-soluble P product, however, the effectiveness of PRs to the tropics depends on the extend to which the required P uptake rate of the crop (K_2) can be maintained by the rate of PR dissolutions in the soil (K_1) (Sale and Mokwunye, 1993). The factors influencing K_1 and K_2 are discussed:

2.4.1 Factors Influencing Rate of P Release from the PR Particles (K1)

2.4.1.1 PR Characteristics

Phosphate rocks differ widely in their chemical reactivity with soil solution depending on their minerology and chemistry (Khasawneh and Doll, 1978). Though PR exist in igneous, metamorphic and sedimentary setting, the Francolite (Sedimentary-carbonate apatite) are the ores

mined commercially for direct applications. Apatite vary in physical, chemical and crystallographic properties. Chemically the degree of isomorphic substitution of carbonate for phosphate and to a lesser extend of sulphate and silicates for phosphate; Ca^{2+} substituted by mg^{2+} and Na^{+} and to a lesser extend by Sr^{2+}, Mn^{2+}, K^{+} and Fe; and F^{-} is replaced by OH^{-} and Cl^{-} are key factors in determining the reactivity of carbonate apatite (McClellan and Lehr, 1969). Increasing carbonate substitution in PR increases the rate at which the P is released from the PR in the soil as it facilitates the break down of the lattice structure of the apatite crystal. Mokwunye (1995), found that for West African PRs, the most reactive PRs are those having a molar PO_4/CO_3 ratio less than five (5). Methods for measuring this solubility has been by dilute acids and chelating agents. Out of the different methods, the use of neutral ammonium citrate (AOAC) to extract the P in the rock is wide spread but 2% formic acid extraction with a single extraction procedures appeared to be the most useful (Mackay *et. al.*, 1984). Chien (1977) found that the solubility of PR in neutral ammonium acetate (AOAC) was directly related to the level of carbonate substitution for Phosphate.

In addition to mineralogical properties, the physical properties of PR also affect its agronomic effectiveness. Since PR dissolution process is a reaction that occurs at the surface of the PR particles, increasing the particle size by fine grinding will increase surface area of PR

articles exposed to the soil and therefore, increase the rate of P released from the PR. Paauw,(1965); Hammond,(1978); Mokwunye, 1995; found that reducing PR particle size with 80% of the PR to pass through 100 mesh increased solubility. However, grinding less than 100 mesh for direct application is not warranted and is not a substitute for reactivity. Excess dustiness and consequent material loss are frequently encountered when finely ground PR is handled during transportation and application. Wilson and Ellis (1984), indicated that PR dissolution is governed by the amount of reaction surfaces as well as the inherent porosity of the sample. Attempts have been made to produce minigranules with a small reduction in the relative agronomic effectiveness of a particular PR (Livingstone, 1978).

2.4.1.2 Soil Factors (Properties)

The effectiveness of PR in any particular soil is determine largely by pH, the concentration of P and Ca in solution and soil organic matter.

Upon application of P to the soil, both the rate of dissolution and the fate of the P released are determined by the chemical reactions which occur in the soil and the pattern of P uptake by the crop. Hammond *et. al.* (1986), described the simple expression of the dissolution of PR in soil solution using Fluoapatite as an example.

$$Ca_{10}\ (PO_4)_6\ F_2 + 12\ H^+ \ \text{===}\ 10\ Ca^{2+} + 6\ H_2\ PO_{4^-} + 2F^-.$$

They continued by saying that from the law of mass action, any condition that will maintain low concentration

of Ca and P in the soil solution and a low pH, will favour PR dissolution. West African (Tropical soils) with a low inherent level of P, low levels of exchangeable Ca (and low CEC) and low pH provide suitable environment for the dissolutions of PR (Hammond et. al. 1986; Sale and Mokwunye, 1993; Mokwunye, 1995). Hanafi *et. al.* (1992), also showed that PR dissolution increase with increasing P retention capacity of a soil.

The presence of H^+ ions in the soil results in the rapid conversion of the PO_4^- into $H_2PO_4^-$ and HPO_4^{2-} (Khasawneh and Doll, 1978). Barnes and Kamprath (1975), however, showed that although the more acid pH levels increase PR efficiency, the lower pH values are too low for optimum plant growth. For most mineral soils, the pH conducive for efficient acidulation of PR also is favourable for fixation of soluble P by Al and Fe and toxicity of Al. But, many researchers working on non-calcareous weakly acid and acid soils found immediate response to PR application. Bello (1995), reported a response to Togo Phosphate Rock without risk of soil degradation because the soils are low to moderate acidity. In soil dominated by pH dependent surface charges, the extent of dissolution of PRs may increase with decreasing pH but, the proportion of the dissolved P becoming plant available will probably decrease (Boland and Hedley, 1990).

2.4.1.3 Climatic Effect

Rainfall is needed for the dissolution of PR, response to PR application has been found to be more erratic under

low rainfall conditions.

Moisture films surrounding the PR particles are required to provide the H^+ ions needed for the neutralization of the dissolution products and diffusion of Ca-ions from the surface of the PR particles. There has been a linear yield response to crops from mean annual rainfall of 500 to 1,300 (Hammond *et. al.* 1986). High rates of leaching in sandy West African soils would promote the rapid removal of PR dissolution products thus, creating a favourable environment for PR dissolution. IFDC, 1994 found PR dissolution faster in moist then in dry soil (Visker *et. al.* 1995).

Temperature has been found not to have any significant effect on PR dissolution but, a marked effect in the rate of P sorption (Chien *et. al.* 1982; Barrow, 1983). Chien et. al. 1980 reported that the effect of temperature on PR in tropical soils is much less than that of water soluble P fertilizers.

Jones (1973), Jones and Bromfield (1974) and Lombin (1978), have shown that the use of PR in the Northern part of Nigeria is not a substitute to single superphosphate in view of the limited amount of rainfall in these areas; but with 900 mm rainfall or more, responses are expected with PR application.

2.4.1.4 Plant Effect

Crops or plants have different responses to PR application. Actively growing plant roots can stimulate PR dissolution by acidifying the rhizosphere resulting in a

build up of H^+-ions in the surface, with a subsequent increase in the dissolution of PR particles. This they do by taking up N_2 instead of NO_3^-. High root density from plants also result in lowering the mean fraction of Ca-ions and H_2PO_4-ion in the soil solution, increasing dissolution of the PR (Diest *et. al*. 1971; Sale and Mokwunye, 1993; Gerner and Mokwunye, 1995). Legumes also have a high ability to assimilate ammonium -N, leading to excess uptake of cations over anions and the result is the exudation of H^+ ions which further enhance PR dissolution (Bekele *et. al*. 1983).

Khasawneh and Doll 1978, showed that differences of crops on their response to PR application is as a result of their demand patterns of both Ca and P and how the pattern alter the compositions of the soil solution at the root-soil interphase.

2.4.1.5 Management Practices

Crop and soil management practices can influence PR effectiveness. PR dissolution has been enhanced in flooded rice. This has been explained to be the result of the acidification of surrounding soil by rice roots in the cause of its nutrition. This dissolves organic matter will chelate Ca and P in the flooded soil solution, and there will be a lag phase following flooding before the soil pH increases during which time significant amounts of PR, applied pre-flooding might dissolve. However post-flooding application of PR reduces its effectiveness because of post-flooding rise in soil pH (Hammond *et. al*. 1986).

Broadcasting and incorporating in the soil result in greater PR effectiveness than placing the PR in a concentrated band in the soil. Broadcasting exposes the PR articles to larger volumes of soils, while banding results in overlapping diffusion zones around the closely spaced PR particles (Sale and Mokwunye, 1993).

Though liming has been found to improve growth of plants in acid soils, this practice can affect PR dissolution in the soil. Liming reduces the availability of H-ions and increases the concentration of Ca-ion, which are factors that decrease the rate of PR dissolution. One solution is to apply PR in advance of the time in order to reduce the negative PR/lime interaction. This is to allow significant amounts of PR to dissolve before the pH and the Ca status of the soil are raised by lime application (Sale and Mokwunye, 1993). Haynes (1982) observed that adding P fertilizer to a freshly limed acid soil can fail to increase P availability if the soil is not subject to drying cycles. This is because Ca is one active phosphorus adsorbent.

2.4.2 Factors Affecting Uptake of P from Dissolved PR (K2)

The factors describe the P uptake rate required for satisfactory growth of the plant and are external factors to the PR.

2.4.2.1 Soil Properties

For a soil with high P sorption capacity, P in solution from any source is subject to being sorbed. The greater portion of the P thus released from PR is sorbed

strongly on soil particle surfaces and so not available for plant uptake. Hammond *et. al.*(1986), ascribed the poor performance of PRs in such soils to poor root development during the early stages of crop growth due to P deficiency. Though a soil with high sorption capacity may increase PR dissolution, P in solution from any source is subject to being sorbed. Because of the low solubility of PR, P sorbed represent a higher percentage of the soil solution P from PR than from the more soluble P sources. Phosphate Rock would perform better in soils with reduced tendency to immobilize soluble P (Hammond *et. al.* 1986; Mokwunye, 1995).

2.4.2.2 Plant Effect

Phosphate rocks are generally more effective when applied to perennial crop species such as tropical plantation crops than when applied to annual crops. The annual crops require a high rate of P supply during the relatively short vegetation growth phase and can readily be met by water soluble fertilizers. The rapid establishment of a root system by seedling of annual crops is sensitive to P availability while a perennial crop on the other hand, has an established high root density on the surface layer of the soil. For such crops, annual P requirement are taken up over a long period thereby making it most likely that their uptake rates are low and can therefore be met by release characteristics common to PR (Mokwunye, 1995). It has also been observed that plants with high root densities in the surface layer of the soil

and plants that are heavily infected with mycorrhizae acquire dissolved P from PR better (Dieldrids, 1991; Elivazi and Weir, 1989).

2.4.2.3 Management Practices

Management practices such as broadcasting and incorporation instead of localize placement of PR increase the recovery of P from PR. Another practice is to apply the PR to the soil well in a advance of the time of planting the crop (Hanway and Olson, 1980), though this may be unsuccessful on soils with high P sorption characteristics, because the P released from the PR before sowing will be retained by the soil and will not be available for later uptake by the crop roots.

2.5.0 Chemical Methods for Predicting Agronomic Effect/Potential of PR

Although biological techniques are the most reliable methods for assessing the agronomic effectiveness of PR, the resources and facilities required and the time delay in obtaining results preclude their use for rapid assessment. Of the direct method, a chemical extraction procedure offers a simple and rapid alternative. The ability of chemical method to predict the agronomic potential of PRs generally decreases as the residual effect of the PR progresses (Chien and Hammond. 1979; Mackay *et. al*. 1984). This is because of the influence of soil reactions with PR on the residual effect of PR, which is not increased by the initial chemical extraction. Solubility measurements, therefore, cannot be used to predict specific yield

response, but they can serve as a means of predicting the relative performance of one source to another and thus, assist in the selection of the most appropriate source for a given set of conditions (Hammond *et. al.* 1986).

Different extraction procedures have been evaluated in several studies and the conclusions reached as to their suitability for predicting the agronomic effect of PR vary widely. For example, the Ammonium citrate soluble P content of a fertilizer will not give its true value as a P source for plants. The water soluble phosphate content, granule size, soil type, soil pH and crops to be grown are other factors which must be taken into account when determining the actual agronomic value of a phosphate fertilizer (Davies, 1965).

Sani (1995), while assessing the agronomic efficiency of Sokoto Phosphate Rock and other P sources by chemical extraction procedures, found neutral ammonium citrate extraction method to be the best in predicting the agronomic efficiency of the various phosphates sources.

2.6.0 Residual Benefits of PR and P Fertilizers

The existence of a residual phosphate effect means that additional crops profit from the initial P fertilization. An effectiveness rating of PR based on one cropping period is not sufficient because it improves with time. One feature of P fertilizer is that only a small fractions of the applied fertilizer is generally taken up by the crop in the year of application. Part of what is not taken up goes to increase the labile P in the soil.

Part is converted in slow reactions to less soluble P forms. These slowly soluble P forms continue to supply P to crop for several years (Mokwunye, 1995).

Visker *et. al.* (1995), have shown that because P is immobile in the soil, leaching of P is negligible. As a result part of P stays in the soil system. Phosphorus losses, however, can occur through erosion. The P in the soil system that is not taken up by the cultivated crop or lost through erosion is carried over to the subsequent crops, which benefit thereby form what is called residual effect of the applied P.

Since PR dissolves slowly, their agronomic effectiveness relative to that of water-soluble fertilizer improves appreciably with time. This can be attributed to the fact that overtime, the amount of soluble P from PR increases as the PR continues to dissolve in the soil for some time. Yields from the residual P of a PR fertilization can be higher than yields from a freshly applied rock. Because of the low P retention capacity of West African soils the residual P effectiveness is high (Visker *et. al.* 1995).

Soluble P is usually adsorbed by Fe and Al oxides and hydroxides, some become occluded in the soil minerals, while part is transformed into stable organic compounds making it less soluble. The rate at which the soluble P is converted into less soluble soil constituents determines the residual value of the PR.

Other researchers explained that P applied previously

blocked the fixation sites, thus allowing better utilization of current application (Jackson, 1966). Kowal and Kassan (1978), reported the residual effect of P fertilizer in most of the savanna soils of West Africa are as a result of adsorption of P by clay, Fe and Al oxides and hydroxides, holding it against leaching. Jones and Wild (1975), continued that the conversion of adsorbed P into fixed, unavailable form appears to be generally slow. Hence, applied P remains available over several seasons and total recoveries are high. Fertilizer P has shown remarkable residual effect in Nigerian savanna soils (Uyovbisere and Lombin, 1991), especially since these soils are low in P fixing capacity and so most of the applied P is available to crops even not in the same year. Jones (1973), observed that under condition of low farming intensity and high rainfall, PR is agronomically as effective as single superphosphate and a superior residual value has been reported by Lombin (1979).

However, the magnitude and duration of the residual benefit depends on the rate of initial application, crop removal and losses, soil characteristics and P source. It has been observed that residual effectiveness index (RAI) of various P sources including Togo Phosphate Rock, applied to maize in the different regions of Togo remained above 60% after three years (Mokwunye, 1996). The residual benefits of PRs may improve and be comparable with water-soluble P sources over time. This does not however, mean they will necessarily out yield or even yield as well as

water-soluble sources (Sale and Mokwunye, 1993).

2.7.0 Increasing the Solubility of PR

Since a vast portion of the arable land in the Nigerian savanna falls within the 600 mm to 900 mm lsoyet; increasing the solubility of the slowly reactive West African PR is therefore, a prerequisite to their use as an annual P fertilizer source for crops (Uyovbisere, 1986).

2.7.1 Partial Acidulation of PR

Since PRs may not be suitable for direct application because of their low chemical reactivity; it has been shown that some partially acidulated PR (PAPR) can be agronomically and economically effective in crop production as compared with conventional fully acidulated fertilizers.

Partially acidulated phosphate rock refers to an under acidulated product that has been treated with only a fraction of the acid (Usually sulphuric or phosphoric) needed to produce SSP. Partial acidulation of a rock can substantially increase its water - and citrate-soluble P_2O_5 content and this has a greater immediate impact on crop production. Hammond (1978), reported that there is available P_2O_5 per unit of sulphuric acid to unacidulated PR; but partial acidulation does not seem to increase the effectiveness of the unacidulated portion of the PR (Khasawneh and Doll, 1978).

However, varied results have been obtained on the agronomic effectiveness of PAPR compared with water soluble fertilizer. Much of the variation has been caused by differences in sorptivity of the soil. Chien and Hammond

(1989), observed equal or more effectiveness of PAPR to soluble phosphate at certain levels of acidulation in soils with high P-fixing capacity; and inferior to triple superphosphate at soils with relatively low P-fixing capacity (Hammond *et. al.* 1986) and with granulation of the PAPR. Mclean and Logan (1970); Mokwunye and Chien (1980), found that powdered PAPR was more effective than powdered extended superphosphate in providing soil solution concentration in acid soils, suggesting a closer proximity for the interaction between monocalcium phosphate and unacidulated PR in the PAPR material. Togo 50% PAPR in West African soils has been found to be equal in agronomic effectiveness to single superphosphate, where as finely ground PR was inferior (Hammond *et. al.* 1986); however, Bagayoko and Caulibaly (1995), noted that through Togo PAPR-50 generally give results that are agronomically better than those of powdery Togo Phosphate Rock (85% against 80%), the difference does not, however, justify the additional cost of production of PAPR.

Though PAPR may be attractive because it is one means of utilizing unreactive PR, Mokwunye (1995), suggested that a maximum of the phosphate particles should be partially solubilized to create a vast number of starter effect *in situ*, which presupposes good contact between the acid and the rock. When H_2SO_4 is used for acidulation, sulphur is included in quantities appropriate for many nutritional demands.

2.7.2 Ground Phosphate Rock with Elemental Sulphur(s)

Ground PR and sulphur have been mixed in various forms and treated. Sulphur is oxidised in the soil to H_2SO_4 by sulphur oxidizing organisms belonging to the genus *Thiobacillus*. The H_2SO_4 so formed reacts with the PR to increase the availability of its P through dissolution effects. Released acidity encourages the formation of the less soluble Fe-phosphate and Fe in soluble products, while the unacidulated portion of the acidulated rock neutralizes the acidity so produced resulting in improved solubility of the PR (Uyovbisere, 1986). An increase in the availability of P to plants is noticed when the PR-S mixture is inoculated with the sulphur oxidizing bacteria *Thiobacillus Taioxydants* (Khasawneh and Doll, 1978).

Bromfield (1974), found a PR-S powder (Rock-S) mixture as effective as SSP for groundnut in soils deficient in both P and S in Northern Nigeria. While there was no clear advantage of PR-S mixture over the ground PR used in the acid soils of Kenya (Bromfield *et. al.* 1981).

2.7.3 Soil Organic Matter Use

Soil organic matter (O.M) is known to enhance the dissolutions of PR due to the organic acids produced by the manure; and chelating of Ca^{2+}, thus lowering Ca in solution. These organic acids form stable complexes with Fe and Al, and also affect the solubility of Ca-P (Brady, 1984; Hammond *et. al.* 1986).

Ikerra *et.al.* (1994) reported that when P fertilizers were added to soils after pre-mixing with farm yard manure,

the availability of P to plants was markedly better than when these materials were applied separately. Composing of organic refuse with PR may help to solubilize the P. Humic acids are produced during microbial decomposition of organic matter. In that way mineral calcium phosphate can be dissolved upto a certain extend (Amberger, 1978). It has further been observed that humic and fulvic acids and low molecular weight organic acids may block sites on soil materials and thus reduce P adsortion. These simple organic acids may be released by decay of plant, animal and microbial tissues or as root exudates (Kafkafi *et. al.* 1988).

Addition of organic matter particularly to calcareous soils has resulted in an increase in P solubilization with time more than single additions of inorganic P (O'corner *et. al.* 1986). Some breakdown products of organic matter have been found to reduce P retention in soils. Andrews (1985), found P sorption to be strongly inhibited by organic acids. Making PR with organic matter for example in microbially active compost pit, is of increasing use in Mali and Burkina Fasco (Gerner and Mokwunye, 1995).

The application of Minjingu PR with compost increased extractable P but dry matter and P uptake was depressed, possibly as a result of microbial immobilization of the released P. By contrast farm yard manure at higher rates of application (2.5 tons) significantly enhanced P uptake. This was attributed to the effect of FYM to enhance the dissolution of the PR and to minimise subsequent fixation

of the released P (Ikerra *et. al*. 1994).

2.7.4 Effect of particle size on availability of P from PR

Physical condition of PR may have a crucial influence in its P availability to plants. This is to achieve the best result and ensuring that large surface areas, and a good contact with soil particles and root with the PR.

Finely ground Arad PR at high and the same level of application with concentrated superphosphate gave the same yield. This finely ground PR has been found to be effective than granulated PR (Hagin, 1981).

Granulation of PR is often necessary to improve transportability and spreadability, but this process may lower the agronomic effectiveness of PR. Placement, size of granules and the binder used in the granulation process all may influence the effectiveness of granulated materials as P sources to plants. A study carried out with Arad PR in Ireland found yields in treatments with granular materials compared to that obtained with concentrated superphosphate and with finely ground Arad PR (Hagin, 1981). The effectiveness of granular products increase with increase in water-soluble P in various products. It tends to increase the effectiveness of water-soluble P products, but that of the unacidulated PR is greatly reduced. Mini-granules have however been formulated.

Finely ground and minigranules of PR were tested on a corn crop and there was no significant difference in their yields. There were however, significant yield reduction when conventional size granules were used. Minigranulation

of PR is considered therefore, as a potentially effective method to improve the handling characteristics of the PR for use in those tropical environments where unacidulated PR is found to be agronomically effective in a finely ground form (Hammond *et. al*. 1986).

2.7.5 Other Methods

2.7.5.1 Biochemical Processes

Researches have shown that mixtures of PR, sulphur, pyrite and urea known as Biosuper phosphate, give promising results under certain agro-climate condition (Johnson, 1995). PR when granulated with $MgSO_4$ as a binder can influence its effectiveness depending on it placement method and the size of the granule (Hagin 1981).

2.7. 5.2 Heat-Treated PR

Heat-treated PR has been found to be less capital intensive. Thermal modification of P raw materials usually involves the decomposition of PR, both apatite and non-apatitic, with or without added reagents. The purpose of the treatment is to increase the availability of the P to the soil and so make the altered rock useful as a fertilizer (McClellan and Gremillion, 1980).

2.7.5.3 Biological Activity

Both plant roots and micro organisms are active in mobilizing soil P by excreting organic acids. Which in part, produce a chelating effect. Microscopic investigations provide evidence that fungi and other microorganism develop a close net work of mycelia around phosphate particles and are able to decompose them

(Amberger, 1978). Organic matter brought into the root zone will make the phosphate readily available to the microoganims and plants. Inoculating the soil with Vesicular-Arbuscular Mycorrhizal (VAM) fungi and other soil organism with PR additions increased the capability of accessing source of P by plants.

2.8.0 Interaction of P with other Elements in the soil and plant

Phosphate ions are involved in major chemical reactions in soils and in numerous metabolic reactions in plants. Consequently, P influences, or is influenced by the availability or utilization of many other elements, both essential and non essential. Such influences of P on other elements and other elements on P are called interactions.

2.8.1 Interaction with N, K, Mg and Ca

There is increased P absorption by plants as a common consequence of adding N fertilizers. Increased tissue growth requires more N and P. Nitrogen deficiency can result in low P percentages in plants growing on soils with inadequate available P and therefore there is a need for a balance of N-P in the metabolism of different crops.

Potassium has been shown to co-precipitate with P in the soil and there is little evidence to support the concept of interactions with the plant. While P uptake has been increased in the presence of Mg.

Efficiency of P fertilizer has long been associated with chemical reactions involving phosphates and certain

cations which calcium is one. The concentration of solution Ca decreases P solubility (Barrow, 1972), irrespective of reaction mechanism. Inversely, increasing solution P by adding annual-P fertilizer lowers the concentration of soil-solution Ca, Ca stimulates P absorption and it is the Ca absorption that directly affects uptake. Lime treatments commonly results in a decreased P content of the crop.

2.8.2 Interaction with Al, Fe, Zn, Mn and other Nutrients

Normal solution concentrations of cations can assure soil-solution P concentration of less than 1 ppm in most soils (Adams, 1980) Al and Fe interact with soluble P fertilizers into insoluble form which depends in the solution activities of Al and P exceeding a certain solubility product, while Fe and P depend on the soil pH and redox potential. Soil are usually most productive in the absence of measurable Al concentration in the soil solution. There is also the need for balance between P and Fe or else P-induced Fe chlorosis may result (Adam, 1980). The P/Fe ratio of leaves appear to be inversely related.

Excess Zn upsets normal P metabolism, thereby creating a growth response and visual symptoms typical of P deficiency. Phosphorus can ameliorate Zn toxicity by increasing plant growth rather than by decreasing total Zn uptake. There has been a respond by an increased in Mn uptake by plant due to high P rates that result in decreased in soil pH. However P fertilizer may have no effect or decrease Mn uptake by plants. There may be

$Mn_3(PO_4)_2$ precipitation between pH 6-9 but this may not play a significant role in lowering the availability of either Mn or P.

Cu-P interaction has had contrasting views, some researchers found antagonistic, some synergic and other found it a root-to-shoot translocation of Cu rather than with absorption. There appear to be a positive interaction of P on M_o uptake by plants. The interaction of absorbed P and S, B with the plants has received scanty attaintion by scientists.

2.9.0 Phosphorus Needs of Soyabean crop on Savanna Soils

Phosphorus is needed for the proper functioning and growth of the plant. It speeds up the maturity of crops and is found in large quantities in seeds and fruits; it also stimulates root development. Phosphorus is needed in the soyabean crop as a basic constituent of protein, it plays as essential role in energy transfer and is involved in numerous reactions in the plant. Work done by Selles *et. al*. (1995), on some crops showed that P removed annually by the grain increases with P fertilization, which means higher quality grains.

Since leguminous crops have the ability to fix atmospheric nitrogen into forms available for their use, they respond greatly to P application than N. In almost all legume research highlights of IAR, Samaru, Zaria, the soyabean crop and especially Samsoy-2 has been established to respond to P application. Increase in yields differ in percentages for different rates of P application and sites.

Graham (1977), reported that P is taken up by soyabean throughout the growing season and the greatest demand starts when the pods begin to form. However, he stated that soyabeans respond to a fertile soil (fertility) and not fertilizer and, extra high levels of fertilizer may not pay off if the soils is already fertile. Responses have been reported by Manuel *et. al.* (1984); Dickson et. al (1983). deMooy *et.al.* (1973), interestingly found corn to be significantly more responsive than soyabean to direct and residual P fertilizer. They gave an explanation for the small response from applied P to be the limited nutritional requirements of soyabeans. On a corn-soyabean cropping system, the P applied to the corn crop supplied adequate P for the subsequent soyabean crop (Gumes, 1958, 1959, deMooy *et. al.* 1973).

Lombin and Chude, (1988); Uyovbisere and Lombin (1991), reported P to be the most critical nutrient for legumes, but, responses are obtained only at low levels of application. The current recommendation for groundnut and related legumes is 8-8.8 kg P ha^{-1} in the Nigerian savanna. Bullen *et. al.* (1983), showed that though soyabeans respond to P application, however, the method of placement and time of application can affect response by the crops in various ways.

Since the savanna soils have low to moderate P adsortion capacities on well drained sites, P fertilization or manuring increases solution concentration and hence its fertility. Bache and Roger (1970), showed that P

fertilizer raised both the concentration of soluble P and the amounts of labile P; and in general the effect of fertilizers varies with adsorption capacity. Where there is high adsorption capacity, most of the fertilizer P applied goes to increase the labile pool and has a small effect on solution concentration. But, where low, addition of P raises solution concentration very considerably.

Mokwunye *et. al.* (1985), concluded that because of the colloidal systems in tropical soils, P is not only a nutrient but also a soil amendment.

2.10.0 Phosphate Rock (PR) for Soyabean Production in the Nigerian Savanna

The effectiveness and efficiency of the P source used for soyabean production is of prime concern because the crop is now widely grown as a cherished legumuous crop in Nigeria to which fertilizers are applied. Much evidence exist in literature to show that P deficiency are common in the areas where the crop is produced. Ground PR if tried, may be a promising source of P for the crop.

Legumes (dicot plants) can be used to convert PR into more available forms. Deist *et. al* (1971); Jone (1982), have shown that dicots absorb considerably more calcium than the monocots. The amount of Ca absorbed by the former is assumed to be the most important factor determining their ability to utilize PR. Explaining further, they said that in considering plant species from point of view of converting PR to more available form, it is not the total amount of P, but the actual amount of P adsorbed by the

plant that is of importance.

Working with cowpea (a dicot plant) Agboola and Obigbesan (1977), showed that differences in sources and levels of P did not significantly increase yields of this crop; rather it only affected nodulations and P content of the leaf and stem of the crop. A research report by IAR and T, O.A.U. Ibadan (1989) showed a high response of soyabean to Sokoto phosphate Rock (SPR). The PR level of 100 kg P_2O_5 ha^{-1} level 80% efficiency as 25 kg P_2O_5 ha^{-1} of SSP in the year of application and the control was significantly lower in yield.

Khasawneh and Doll (1978); Russel (1988), stated that the differences between crops in their ability to utilize P from PR must be considered especially differences related to their chemical demand pattern for P and Ca; their effect on soil pH and extensiveness of their root system. Amberger (1978), has reported that it is the active proliferation of the rooting system of dicotos that results in the adsorption of P from PR. Their roots serve probably as sinks for calcium ions and thus enhance solubilization of PR (Hagin, 1981).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

An experiment was conducted in two different sites for two years (1994 and 1995) on the Institute for Agricultural Research Farm located at Samaru (Latitude 11° 11′ N, Longitude 7° 38′E) Zaria.

Samaru is situated in the sub-humid Northern Guinea savanna ecological zone with a mean annual rainfall of about 1,100 mm; falling almost entirely within six months (May-October). The area is characterised by distinct wet and dry season and the rainfall distribution pattern is monomodal, with a peak in July/August (Kowal and Knabe, 1972).

The soils are broadly classified as Alfisols following the USDA system and are formed on drift materials overlying basement complex (Klinkenbery and Higgins, 1968). They are well drained and characteristically ferruginous tropical sandy loam (the French System of soil classification equivalent).

3.2.0 Sampling and Land Preparation

3.2.1 Land Preparation and Planting

The land was ploughed, harrowed and ridged at 75 cm width row spacing. Soyabeans (Samsoy-2) was planted in 1994 and 1995 raining seasons. The seeds were drilled into the ridges at the rate of 100 per metre in the rows of 0.75 m apart with a final stand of about 2625 plants per

plot and 200,000 plants per hectare. There were seven rows and five meters long in each plot (26.25m^2). Grain yield and other parameters were taken from the three centre rows (Net plot).

3.2.2 Soil Sampling

The field was sampled at a depth of 0-15 cm (surface soil) at random prior to planting. Ten samples were bulked together to give a composite sample. Three soil core samples were also taken from the surface soil (0-15 cm depth) at 50% flowering from each of the plots receiving the different treatments. The samples were air-dried, ground, sieved through a 2mm mesh sieve and stored in p polythene bags for routine chemical and physical analyses.

3.3 Treatment and Experimental Design

The treatments comprised of four sources of phosphorus viz: single superphosphate (SSP), Sokoto Phosphate Rock (SPR), Partially Acidulated Phosphate Rock at 50% (PAPR-50), and Togo Phosphate Rock (TPR). They were applied at the rates of 0,30, 60 and 120 kg P_2O_5 ha^{-1} on drilled seed lines at planting in each of the years. Potassic (Muriate of Potash) fertilizer was applied to the individual plots at the rate of 30 kg K_20 ha^{-1} at planting.

There were thirteen treatments arranged in a Randomised Block Design and replicated three times. A trial was set up in 1994 and 1995 raining season to determine the agronomic efficiency of four phosphate sources, viz- Sokoto phosphate rock, Togo phosphate rock,

Partially acidulated phosphate rock, and Single superphosphate; for soyabean production in the savanna region of Northern Nigerian. The fields were cropped to soyabean variety Samsoy-2.

3.4 Fertilizer Materials

The single superphosphate (100% acidulation) used for the trials was the commercially available granular material containing 18% P_2O_5. The ground phosphate rocks were obtained from Sokoto State (36.25% P_2O_5) and Togo Republic with an analysis of 36.60% P_2O_5 (Diamond, 1979; Nehikhare, 1987). A 50% partially accidulated TPR was also included as a test material. Particle size distribution of the ground phosphate rock (particularly the second year) showed that not less than 80% of it passed through a 100 mesh sieve. Detailed mineralogy of SPR and TRR are shown on Appendix 3.1 and 3.2.

3.5 Plant Sampling

Ten uppermost fully matured trifoliate (index) leaves were sampled at random per plot when the plants were at 50% flowering for chemical analysis. Also plants were sampled for nodule count and shoot dry weight at this stage.

3.6 Records and Agronomic Measurements

The following observations were made on the crops before and after harvest.

3.6.1 Pre-Harvest Observations

1. Percentage germination at one week after planting (WAP)
2. Number of days to 50% flowering of the crop
3. Number of flowers per plant
4. Number and weight of nodules per plant
5. Weight of dry shoot per plant at 50% flowering
6. Root weight per plant
7. Stand count at harvest

3.6.2 Post-Harvest Observations

1. Number of pods per plant at harvest
2. Number of seeds per pod
3. Weight of seeds per plant
4. Weight of seeds per net plot - seed yield
5. Weight of 1,000 seeds
6. Seed density
7. Threshing percentage

3.7 Laboratory Analysis

3.7.1 Soil Analysis

The soil were subjected to physico-chemical determinations. The particle size distribution was determined using the hydrometer method (Day, 1965). Soil pH was determined in 1:2.5 soil: water and soil : $CaCl_2$ suspensions with a glass-electrode pH-meter. Available phosphorus was determined by the Bray-1 method (Bray and Kurtz, 1945). Organic carbon was determined by the wet-oxidation method of Warkley-Black as described by Allison

(1965). The total N was determined by micro-Kjeldahl's distillation procedure (Bremner, 1965). Exchangeable Acidity was determined by shaking the soil with 1*N*KCl and titrating with 0.5*N* NaOH as described by Juo (1979). Exchangeable based were displaced with 1*N* NH_4OAC buffered at pH 7.0 (Chapman, 1965). Potassium and sodium in solution were determined using the flame photometer, while calcium and magnesium were determined by the atomic absorption spectrophotometer. Effective cation exchange capacity was calculated by the summation of exchangeable bases and exchange acidity. Copper, manganese, iron and zinc were extracted with 0.2*N* HCl and determined by the atomic absorption spectrophotometer.

3.7.2 Plant Tissue Analysis

Plant materials (leave samples) were digested in a triple acid mixture of 20 mls H_2SO_4, 80 mls $HClO_4$ and 650mls HNO_3 (Ratio 1:4:35) to determine the various nutrients. The Flame Photometer was used to determine K and Na in the digest, while Ca, Mg, Fe, Mn, Zn, Cu were determined using the atomic absorption spectrophotometer. Phosphorus concentrations were determined in leaves and grains dried at 60% moisture content calorimetrically by Vanadate-Molybdate yellow method (Juo, 1979). Nitrogen in plant tissues was determine by micro-Kjeldahl distillation method (Bremner, 1965).

3.8 Statistical Analysis

The data collected for each year were subjected to a simple analysis of variance (ANOVA) and other appropriate

statistical analysis techniques. Duncan Multiple Range Test was used to test the significance among the treatment means (Duncan, 1955).

Relative Agronomic Efficiency (RAE) of the phosphate sources was calculated using the method of (Chien and Hammond, 1978) and (Reinhorn *et. al.*, 1978) as follows.

$$RAE = \frac{\text{Yield of PR-C}}{\text{Yield of SSP-C}} \times 100$$

where PR, SSP and C are the different Phosphate Rock sources, single superphosphate and control respectively.

3.9 Meteorological Information

Rainfall data covering the experimental period was obtained from the IAR meteorological station in Samaru. Other relevant weather data are presented on Appendix 3.3.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Properties of the Pre-Planting Soils

Some physico-chemical properties of the soils used in this experiment are presented in Table 4.01. Site one (1994 trial) and site two (1995 trial) soils were slightly acid to acid in nature, with low levels of organic carbon, total nitrogen, available phosphorus, effective cation exchange capacity (ECEC) contents and moderate in base saturation. These characteristics are typical of savanna soils of Nigeria (Jones and Wild, 1975). The values of organic carbon and ECEC of the 1994 soils are slightly higher than those of 1995, but exchange acid contributed more to the ECEC of this soil compared to that of 1995 . The soil used for the 1995 cropping was slightly higher in total nitrogen, available P and exchangeable bases. In the two soils, exchangeable calcium dominated the exchange complex. There is an imbalance between exchangeable Mg and K in the first year soil since the Mg/K ratio was 1.56 which is lower than the critical ratio of 2.00 to 2.50 suggested by Pratt et. al (1957). The texture of the first and second sites were sand loam and silty loam respectively

For the two soils, the clay contents were low, the range being 16 - 18% (typical of savanna Alfisols), therefore, the low content of organic carbon, exchangeable bases and available P may not be accidental because organic carbon content correlated closely with clay content; the

Table 4.01: Selected Physico-Chemical Properties of the Soils Used.

Parameters	Site 1 (1994)	Site 2 (1995)
Sand (g kg^{-1})	720.00	180.00
Silt "	120.00	640.00
Clay "	160.00	180.00
Texture	Sandy loam	Silt loam
pH 1.2.5 w/v H_2O	5.2	5.7
pH 1:2.5 w/v $CaCl_2$	4.4	4.8
Organic carbon (g kg^{-1})	6.0	5.0
Total Nitrogen	0.30	0.80
C:N ratio	20	6.25
Bray-1 P (mg kg^{-1})	4.2	9.5
Exchangeble Ca (C mol+ kg^{-1})	2.00	2.03
" Mg "	0.42	0.45
" K "	0.27	0.14
" Na "	0.17	0.10
Base saturation %	78.1	79.5
Exchange Acid (Cmol$^+$ kg^{-1})	0.80	0.70
ECEC	3.66	3.42
Ca:Mg ratio	4.76	4.51
Mg:K	1.56	3.21
Fe (mg kg^{-1})	65.0	60.0
Mn "	35.0	24.0
Cu "	1.1	3.0
Zn "	11.0	3.5

soil P occurs mainly in the organic and clay fractions and these fractions also provide the exchangeable bases (Jones and Wild, 1975).

The soil properties are very important (particularly pH and Exchangeable Ca), because they largely influence the effectiveness of the PR sources used.

4. 2. Effect of P sources on Agronomic Performance of the Crop

4.2.1 Pre-Harvest Performance

The response of the soyabean crop during the growing period to applied P fertilizers are presented in Tables 4.02 - 4.04.

4.2.1.1 Effect on the Number of Days to 50% Flowering and Number of Flowers per plant

The study shows that the number of days to 50% flowering was increased due to P application compared to without P application (Table 4.02) in 1994 and (Table 4.03) in 1995. The application of P in increasing rates resulted in an increased number of days to flower initiation. This increase by 1-2 days was not statistically significant. There was also a highly significant increase ($P<0.01$) in the number of flowers per plant due to P nutrition especially at higher application rates, in 1995 and the combined two years analysis of the trial (Tables 4.03 and 4.04). This can be seen at 60 and 120 kg P_2O_5 ha^{-1} of applied of SSP and PAPR-50; and 120 kg P_2O_5 ha^{-1} of SPR.

Agboola and Obigbesan (1977), however found that SSP and the converted bone material induced early flowering in

cowpea (Ife-brown) when compared to other treatments. Ham *et. al.* (1973), reported that delayed maturity is one of the commonly observed characteristics of a crop seriously deficient in P. They further said this does not mean, however, that fertilizer P will hasten maturity of any one of the crops already functional at a normal level of P nutrition. After all P has been associated with early maturity of crops, particularly of cereals (Tisdale and Nelson, 1986). It is also important to note that P stimulates nitrogen fixation in legumes, therefore, a better crop growth and development, and this does not lead to undue maturity of the crop. Chiezey (1990) also found an increase in one or two days to 50% flowering, which he attributed to an encouraged vegetative stage; for the accumulation of enough assimilates for grain filling.

4.2.1.2 Effect on Nodulation

Phosphorous enhances the nodulation of legumes. Tables 4.02, 4.03 and 4.04 show that the number and weight of nodules per plant for the two years were improved, especially with PAPR-50, SSP and SPR application. Nodulation was significantly highest ($P<0.05$) at 60, 120 kg P_2O_5 ha^{-1} and 120 kg P_2O_5 ha^{-1} rates of applied PAPR-50 and SPR respectively than other treatments. This is mainly due to ready availaility of phosphorus to the crop with these treatments. Agboola and Obigbesan (1977) using the different sources of P on cowpea did not find any significant increase in yield, rather there was enhanced nodulation. Other researcher have also found increased nodulation and nodule weight per plant and per volume of

Table 4.02: The effect of P sources and rate on Agronomic Pre-harvest Performance of soyabean - 1994

Treatment	P rates KgP_2O_5 ha^{-1}	DHF (Days)	NFP	NNP	WNP (g)	SDWP (g)	RWP (g)
Control	0	55	38	6 bc	0.11	3.7	0.9
SSP	30	55	37	7 abc	0.10	3.9	0.7
	60	56	40	10 ab	0.09	4.0	0.9
	120	57	47	11 ab	0.11	4.1	0.6
PAPR-50	30	55	38	8 bc	0.08	3.7	0.7
	60	56	46	12 a	0.18	4.0	0.7
	120	56	45	12 a	0.14	4.2	0.5
TRP	30	56	41	10 ab	0.11	3.3	0.7
	60	56	37	8 abc	0.11	3.2	0.7
	120	56	39	6 bc	0.14	4.1	0.8
SPR	30	55	42	5 c	0.10	3.7	0.9
	60	55	46	8 abc	0.10	3.8	0.6
	120	56	47	12 a	0.15	4.8	0.6
MEAN		56	42	9	0.12	3.9	0.72
SED		0.64^{NS}	4.75^{NS}	2.24^{*}	0.04^{NS}	0.53^{NS}	0.15^{NS}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.
ABBREVIATIONS: Days to 50% flowering (DHF), No of Flowers/Plant (NFP), No of Nodules/Plant (NNP), Weight of Nodules/Plant (WNP), Shoot Dry Weight/Plant (SDWP) and Root Weight/Plant (RDP)

Table 4.03: The effect of P sources and rate on Agronomic Pre-harvest Performance of soyabean - 1995

Treatment	P rates KgP_2O_5 ha^{-1}	DHF (Day)	NFP	NNP	WNP (g)	SDWP (g)	RWP (g)
Control	0	55	36 bcde	13	0.11	3.6 b	0.65
SSP	30	56	37 abcde	23	0.22	3.4 b	0.82
	60	56	40 abcd	14	0.09	3.3 b	0.31
	120	57	43 ab	12	0.11	3.9 b	0.43
PAPR-50	30	55	39 abcd	13	0.12	3.5 b	0.70
	60	56	42 abc	17	0.08	3.9 b	0.36
	120	57	44 a	25	0.16	5.1 a	0.45
TRP	30	56	31 e	15	0.09	3.6 b	0.36
	60	55	35 cde	18	0.17	3.8 b	0.60
	120	55	31 e	12	0.12	3.7 b	0.46
SPR	30	56	33 de	15	0.11	4.1 b	0.45
	60	56	35 cde	18	0.15	3.8 b	0.83
	120	56	41 abc	21	0.13	3.6 b	0.49
MEAN		56	38	17	0.13	3.8	0.53
SED		0.80^{NS}	3.21^{**}	6.9^{NS}	0.66^{NS}	0.41^{*}	0.22^{NS}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.
ABBREVIATIONS: Days to 50% flowering (DHF), No of Flowers/Plant (NFP), No of Nodules/Plant (NNP), Weight of Nodules/Plant (WNP), Shoot Dry Weight/Plant (SDWP) and Root Weight/Plant (RDP)

Table 4.04: The effect of P sources and rate on Agronomic Pre-harvest Performance of soyabean - Two Years Combined Analysis

Treatment	P rates KgP_2O_5 ha^{-1}	DHF (Days)	NFP	NNP	WNP (g)	SDWP (g)	RWP (g)
Control	0	55	37 d	9	0.11	3.7	0.76
SSP	30	56	37 d	15	0.16	3.7	0.78
	60	56	40 bcd	12	0.09	3.7	0.59
	120	57	49 a	11	0.11	4.0	0.53
PAPR-50	30	55	39 bcd	10	0.10	3.6	0.72
	60	56	45 ab	15	0.13	4.0	0.53
	120	57	44 abc	19	0.15	4.7	0.49
TRP	30	56	36 d	13	0.10	3.4	0.53
	60	55	36 d	13	0.14	3.5	0.65
	120	56	35 d	9	0.13	3.9	0.65
SPR	30	56	38 cd	10	0.11	3.9	0.67
	60	56	41 bcd	13	0.14	3.8	0.73
	120	56	44 abc	16	0.14	4.2	0.55
MEAN		56	40	13	0.12	3.9	0.63
SED		0.51^{NS}	2.87^{**}	0.60^{NS}	0.92^{NS}	1.33^{NS}	1.35^{NS}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.
ABBREVIATIONS: Days to 50% flowering (DHF), No of Flowers/Plant (NFP), No of Nodules/Plant (NNP), Weight of Nodules/Plant (WNP), Shoot Dry Weight/Plant (SDWP) and Root Weight/Plant (RDP)

soil produced by soyabean due to increased P nutrition (Jones et al. 1977).

Since the process of nodule formation has a high calcium requirement (Jones et al., 1977). It may not be surprising therefore that PR sources gave the highest number of nodules per plant. The amount of nitrogen fixed by the associated symbiotic nitrogen fixing bacteria is dependent on nodulation.

4.2.1.3 Effect on Shoot and Root Growth

Tables 4.02 - 4.04 show how shoot and root growth of the soyabean crop are affected by the phosphate fertilizers. There was a consistent increase in shoot dry matter. It was also observed that shoot dry weight was increased at high P application than at lower rates. The 120 kg P_2O_5 ha^{-1} of the various phosphate sources produced the highest dry matter yield than when the two years data were combined and analysed. The reverse was the case with root yield at the highest P fertilizer application rates. The highest root yield was obtained at zero to 30 kg ha^{-1} P_2O_5 rates however, the differences were not significant.

Though it has been reported that P stimulates good root development or proliferation, the addition of P led to a reduction in the actual amount of roots per unit weight of shoots. Indeed the total weight of roots may even be reduced when the weight of the plant shoots show a response to applied P (Ozanne *et. al.* 1969; Christie and Moorby, 1975). The high root density in low available P supply may probably be an evolutionary advantage in survival and growth for having relatively large and extensive root

systems.

The effect of P fertilizers on the root system and shoot growth of a crop depends on the fertility of the soil, but if the soil has a low nutrient status then P fertilizer will increase both shoot and root growth; though generally root growth increases relatively less. The root length per weight of root decreased as the P levels in the soil increased. The plant increases both root length and hair length in order to absorb P when P level in the soil are low (Bhat and Nye, 1974; Powel, 1974). Therefore Ozanne (1980) suggested that measurement of just the root weight present in the fertilized zone is not adequate. Root length assessment is better because it determines the amount of nutrient that is absorbed. Deep rooting also allows a crop to take up additional nutrients if the nutrient supply in the surface soil is inadequate. High plant root density actively absorb Ca ions, thereby lowering the concentration of the nutrient in the soil, which stimulates the dissolution of phosphate rocks (Deist *et. al*. 1971).

4.2.2 Post-harvest performance of the various P sources

The response of the soyabean crop to added phosphate as assessed by its post-harvest agronomic performance can be seen on Tables 4.05 - 4.07. Phosphate application has a significant effect in yield components.

4.2.2.1 Effect on Pod and Seed Formation

Phosphate application generally increased the number of pods per plant as shown on Tables 4.05, 4.06 and 4.07.

When the rates were varied, the higher rates of application resulted in more number of pods per plant. The highest values were obtained by 120 kg P_2O_5 ha^{-1} of SSP in the two years trial. Other phosphate treatments (PAPR-50 and SPR) followed, while the least values were recorded by TPR and zero P application. These results were particularly highly significant in the 1995 trial and when the combined analysis was carried out.

The number of seeds per plant was also influenced by P application. The application of the phosphates increased the number of seeds per plant compared with control plots. In the first trial, the highest values was recorded by SSP at 120 kg P_2O_5 ha^{-1}; though this was not significantly different from the other treatments and levels. Again the second year trial recorded a significant increase with SSP at 120 kg P_2O_5 ha^{-1} having the highest value. While zero and low application rates of TPR recorded the lowest values.

Generally, higher rates of P application resulted in delayed flowering of the plant, giving the plant an advantage of a prolonged vegetative stage for enough pod and seed formations. These high application rates resulted in the retention of more pods and seeds per plant. The overall effect will be a higher grain yield per plant and per unit area because they are very important components of yield.

4.2.2.2 Effect on Seed Weight and Density

Seed weight and density were also influenced by phosphates application and rates. The highest seed weight was recorded with 60 kg P_2O_5 ha^{-1} SPR in the 1995 year trial

Table 4.05: The effect of P sources and rate on Agronomic Post-harvest Performance of soyabean - 1994

Treatment	P rates KgP_2O_5 ha^{-1}	NPP	NSP	WSP	W1,000S	SD	TP
				-------- g ------		(g/cm^3)	(%)
Control	0	30	34 cd	6.9	112.3 e	0.73	62.5 c
SSP	30	32	46 bcd	13.1	121.0 bcd	0.75	68.1 a
	60	34	53 bc	13.9	117.0 d	0.75	66.2 ab
	120	45	79 a	12.7	118.7 cd	0.74	66.6 ab
PAPR-50	30	36	42 cd	13.1	123.0 abc	0.74	67.9 a
	60	39	52 bc	10.1	117.7 cl	0.74	68.1 a
	120	39	53 bc	15.4	120.3 bcd	0.75	66.0 ab
TRP	30	36	33 e	15.5	123.0 abc	0.73	66.2 ab
	60	30	36 cd	10.4	123.7 ab	0.75	65.6 ab
	120	33	47 bcd	8.4	126.0 a	0.75	65.6 abc
SPR	30	30	38 cd	9.8	125.7 a	0.75	64.3 bc
	60	28	46 bcd	12.0	120.0 bcd	0.74	64.3 bc
	120	43	58 b	12.8	123.7 ab	0.74	67.5 a
MEAN		35.5	47.5	11.9	120.9	0.74	66.06
SED		6.49^{NS}	6.86^{**}	2.66^{NS}	1.92^{**}	0.01^{NS}	1.32^{*}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.
ABBREVIATIONS: No of Pods/Plant (NPP), No of Seeds/Plant (NSP), Weight of Seeds/Plant (WSP), Weight of 1,000 Seeds (W1,000S), Seed Density (SD) and Threshing Percentage (TP).

Table 4.06: The effect of P sources and rate on Agronomic Post-harvest Performance of soyabean - 1995

Treatment	P rates KgP_2O_5 ha^{-1}	NPP	NSP	WSP	W1,000S	SD	TP
				-------- g -------		(g/cm^3)	(%)
Control	0	29 de	41 bc	4.9 d	104.7 c	0.733 c	63.0
SSP	30	36 cde	53 abc	7.7 ab	114.7 b	0.743 bc	68.0
	60	40 bcde	60 ab	7.2 abc	115.7 b	0.753 a	67.0
	120	56 a	73 c	7.7 ab	123.0 a	0.753 a	67.0
PAPR-50	30	38 bcde	52 abc	6.7 bcd	114.7 b	0.743 bc	69.0
	60	41 bcd	52 abc	6.6 bcd	115.0 b	0.750 ab	67.0
	120	51 ab	57 ab	7.0abcd	122.3 a	0.753 a	67.0
TRP	30	33 cde	34 c	5.0 cd	115.7 b	0.733 c	66.0
	60	31 cde	39 bc	5.8 bcd	105.3 c	0.743 bc	66.0
	120	27 cde	49 bc	6.0 bcd	113.3 b	0.733 c	67.0
SPR	30	34 cde	57 ab	5.9 bcd	112.7 b	0.740 bc	68.0
	60	26 e	39 bc	8.9 a	113.0 b	0.740 bc	68.0
	120	45 abc	61 ab	6.1 bcd	122.7 a	0.750 ab	67.1
MEAN		38	51	6.5	114.8	0.74	66.9
SED		5.97**	9.58^{*}	0.92*	3.01^{**}	0.05^{**}	77.7^{NS}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.
ABBREVIATIONS: No of Pods/Plant (NPP), No of Seeds/Plant (NSP), Weight of Seeds/Plant (WSP), Weight of 1,000 Seeds (W1,000S), Seed Density (SD) and Threshing Percentage (TP).

Table 4.07: The effect of P sources and rate on Agronomic Post-harvest Performance of soyabean - Combined Analysis of the Two Years

Treatment	P rates KgP_2O_5 ha^{-1}	NPP	NSP	WSP	W1,000S	SD	TP
				-------- g -------		(g/cm^3)	(%)
Control	0	30 ef	38 de	5.9 d	108.5 d	0.73	62.9
SSP	30	34 def	50 bcd	10.4 ab	117.8 abc	0.75	68.2
	60	37 bcde	57 bc	10.6 ab	116.3 bc	0.75	66.7
	120	51 a	77 a	10.2 abc	120.8 abc	0.75	67.1
PAPR-50	30	37 bcde	47 bcde	9.9 abc	118.8 abc	0.75	68.4
	60	40 bcd	52 bc	8.4 abcd	116.3 bc	0.75	67.7
	120	45 ab	55 bc	11.2 a	121.3 ab	0.75	66.5
TRP	30	35 cdef	34 e	10.3 abc	119.3 abc	0.73	66.3
	60	31 dec	38 de	8.1 abcd	114.5 c	0.75	65.9
	120	35 cdef	48 bcd	7.2 bcd	119.6 abc	0.74	66.2
SPR	30	35 cdef	48 bcd	7.8 bcd	119.2 abc	0.74	67.1
	60	27 f	43 de	10.4 ab	116.5 bc	0.74	66.1
	120	44 abc	60 b	9.5 abc	123.2 a	0.74	69.2
MEAN		37	50	9.2	117.9	0.74	66.8
SED		4.41**	5.89**	1.40**	2.80**	0.88NS	1.05NS

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.
ABBREVIATIONS: No of Pods/Plant (NPP), No of Seeds/Plant (NSP), Weight of Seeds/Plant (WSP), Weight of 1,000 Seeds (W1,000S), Seed Density (SD) and Threshing Percentage (TP).

and 120 kg P_2O_5 ha^{-1} PAPR-50 in 1994 trial and combined two years analyses. The difference between the means was statistically significant ($P<0.05$) in the 1994 trial and when the combined analysis was carried out ($P<0.05$). Higher values are also recorded for the various phosphate sources compared to the zero application rates. The difference in the seed weight in the first trial were however not significant.

One thousand seed weight was increased with P application of the various phosphate sources. There was a resultant significant increase in 1,000 seed weight compared with plots without P. Though the trend was not consistent, the highest values were obtained at the 120 kg P_2O_5 ha^{-1} for all sources. This was especially so in the second year (1995).

The second year (1995) of the trial recorded a significant increase in seed density due to P application compared with no P. Highest values were recorded by 60 and 120 kg P_2O_5 ha^{-1} SSP and 120 kg P_2O_5 ha^{-1} PAPR-50. The 1994 trial and combined analysis of the two years trial however, did not show any significant effect among treatments, though P application resulted in an increase in seed densities.

Chiezey (1990), reported similar results where seed weight and densities were increased due to P application and were also identified as important yield attributes. Dickson *et. al.* (1983), however, reported that seed number rather than heavier grain weight per plant resulted from application.

4.2.2.3 Threshing Percentage

This is the ratio of the harvested grains to the total pods per plot. The effect of P application on the harvested grains obtained from the pods are presented on Tables 4.05, 4.06 and 4.07. There was no significant and consistent trend discernable on the threshing percentage of the crop due to the different treatments. However most of the P treatment sources and levels had higher threshing percentages compared with control.

4.2.2.4 Effects on Grain Yields of Soyabeans

The comparative responses of soyabean grain yield to the different P sources and rates of application are shown on Figures 1 - 2 Grain yield responses to direct P application were compared on a yearly bases and over the two years in a combined analysis.

At zero rate of application, grain yied was 1358 kg ha^{-1} in the first year and 1568 kg ha^{-1} in the second year. Yield increases were highly significant with P application ($P<0.01$) compared with the control. There was a progressive increase in grain yield as the rate of applied P increase from 30-120 kg P_2O_5 ha^{-1}, except for the second year where applied P in excess of 60 kg P_2O_5 ha^{-1} of SSP did not increase soyabean grain yield. Grain yields recorded in the second trial were higher than those of the first trial and this may be due to differences in environmental conditions including soil factors. The data (Table 4.12) indicate that available P content of control plot is quite low (6.9 mg kg^{-1}) and available P content in treated plots varied from 6.6 mg kg^{-1} - 30 kg P_2O_5 ha^{-1} rate of TPR to 33.6

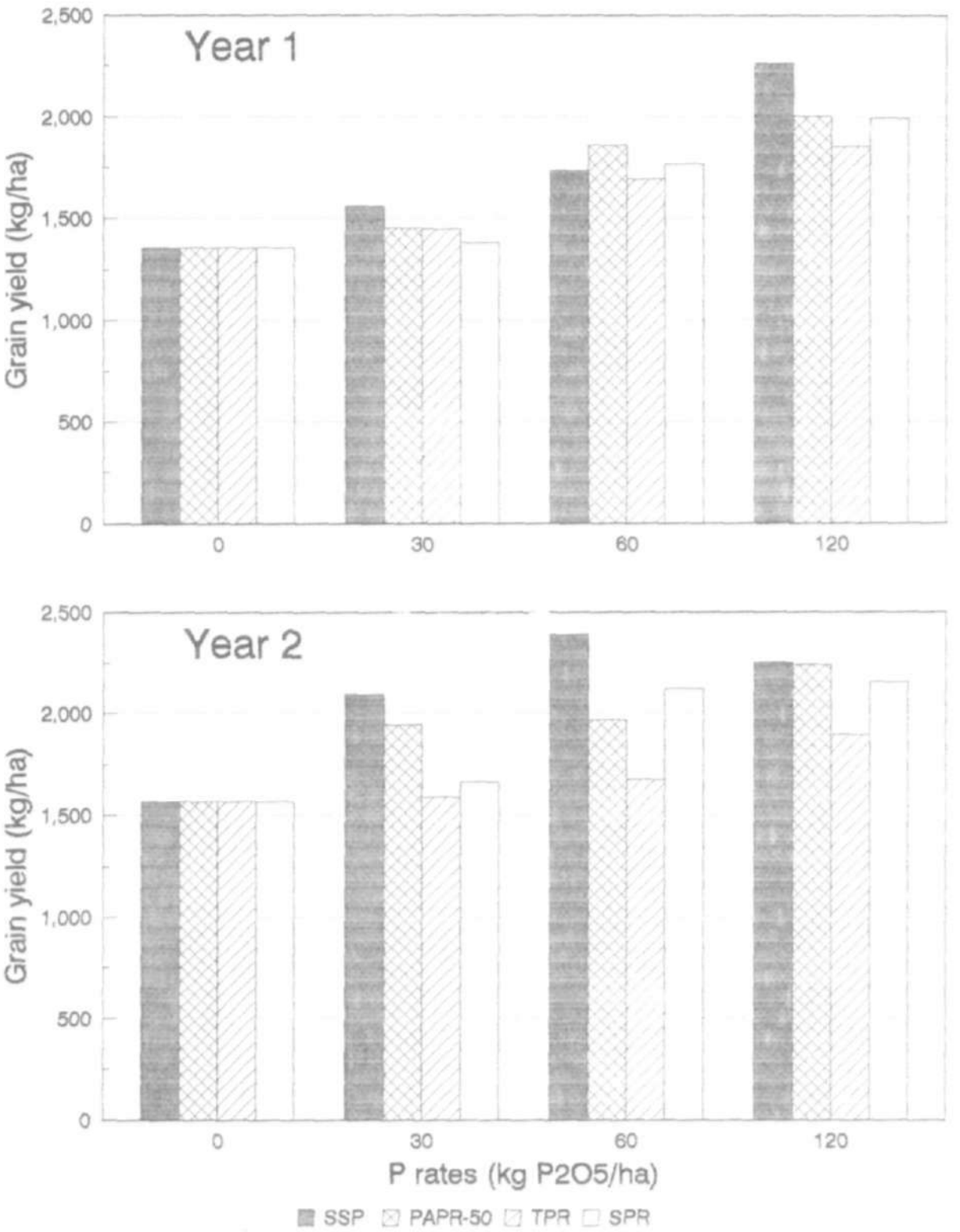


Figure 1. Yield response to P sources and rates

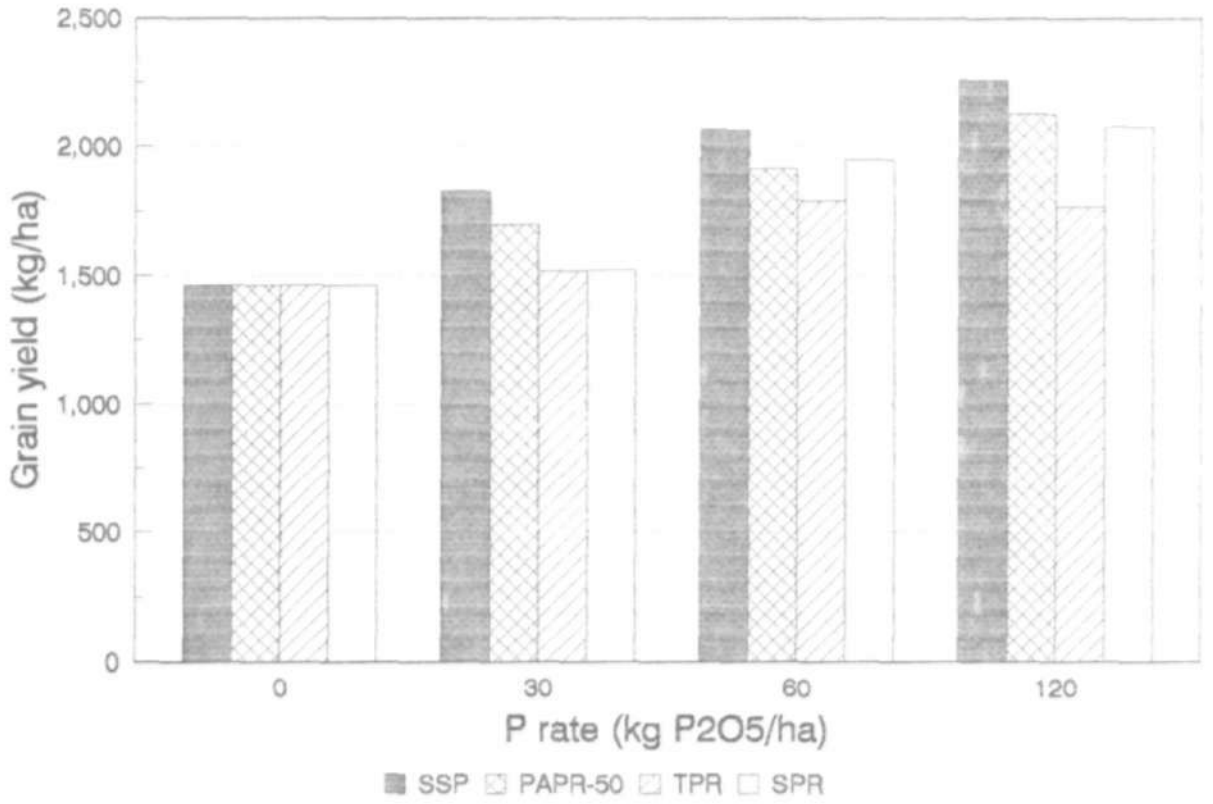


Figure 2. Yield response to P sources and rates (*combined analysis data*)

mg kg^{-1} at 120 kg P_2O_5 of SSP. The significant yield differences is clearly dependent on the P status of the soil.

It is evident from these results that grain yield responses were associated with yield contributing parameters viz; increase nodulation, pod and seed number per plant contributing more to grain weight than heavier grains.

On comparative basis, yield response of this crop to phosphate rock application were quite appreciable as compared with grain yield with the water soluble P source (SSP). The high grain yield recorded in the two years trial by PAPR, SPR and TPR are expected since the soils were acidic, have low ECEC, severe P deficiency, low colloidal system and these conditions increases the solubility of PR. On the over all performance of the various fertilizers based on their grain yield means, SSP was superior to the other sources followed by PAPR-50, SPR and lastly TPR (Figure 3). This shows that the soils are quite low in P fertility (4.2 and 9.5 mg kg^{-1} in 1994 and 1995 respectively) even though the crop has a limited nutrient requirement (deMooy, *et. al*.1973).

On a general note, response to applied P could be said to be appreciable, and this could be attributed to low soil pH, adequate and good distribution of rainfall (909 .2 mm in 1994 and 905.4 mm in 1995) encouraging the dissolution of the PR (Paauw, 1965; Khasawneh and Doll, 1978). Hammond *et. al*. (1986), reported that yield response of crop to applied PR was linearly related to the mean annual rainfall

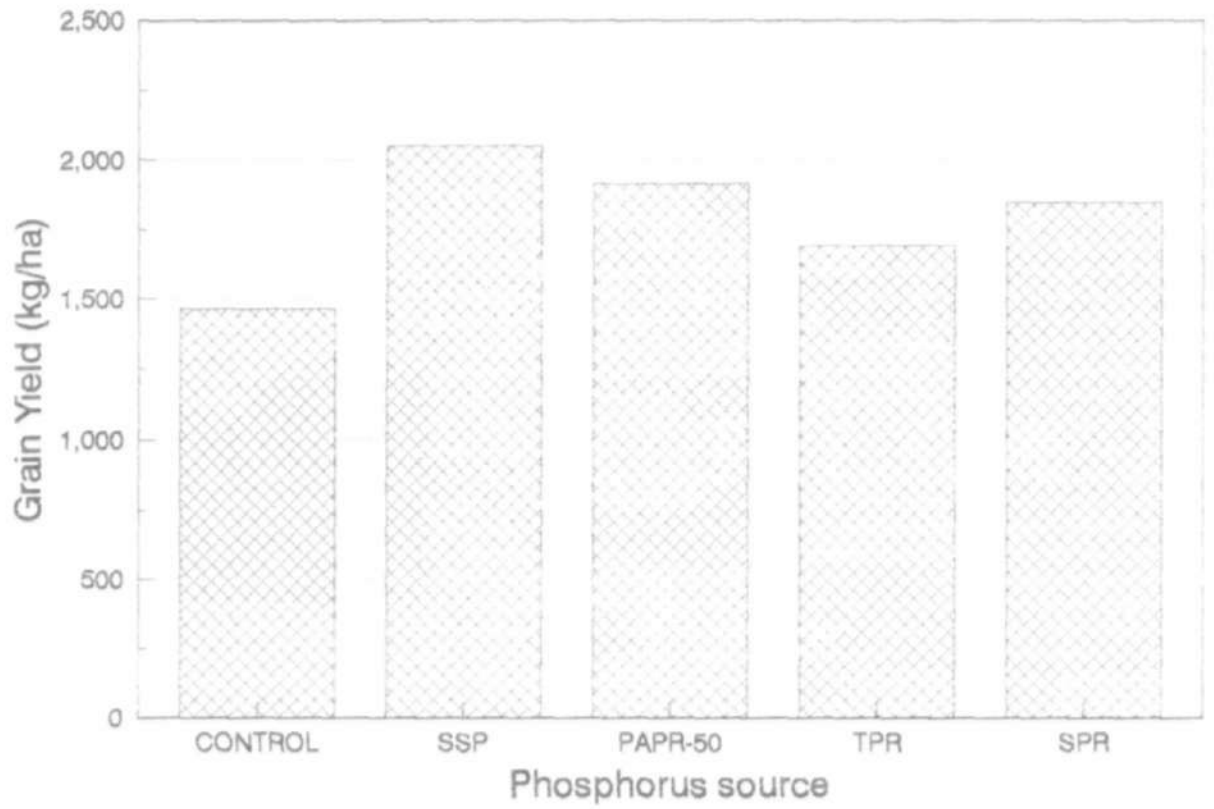


Figure 3. Mean grain yield of soybean

between 500 and 1,300 mm. Lombin (1979) also reported that efficiency of PR increases with increasing rainfall, which is as a result of improved solubilization under water condition; however, responses may be reduced or irregular where rainfall is less than 700-800 mm per annum. Phosphate rocks have also been reported to perform better in soils with reduced tendency to immobilize soluble P (Hammond *et. al.* 1986). Since the rainfall received was greater than above amounts and the soils have low P-fixing capacities, the resultant efficiency of PRS is appropriate.

The result further revealed that dry matter and P uptake are affected by the soil P sources and rates which resulted in considerable grain yield response pattern obtained by the fertilizer treatments. This result corroborate results obtained by other researchers in this crop. Barnes and Kamprath (1975); Hammond (1978); Reinhorn P and Hagin (1979), reported that curves obtained when PRs soluble P of the treated soils were plotted against dry matter yield, the curves indicated that a corn yield obtained with a given Bray-1 P level with PR was higher than that with Triple superphosphate. They however, cautioned that interpretation should be given with care.

4.2.2.5 Relative Agronomic Efficiency (RAE)

The calculated value of RAE as per each P source are presented on Figures 4 and 5. The RAE of the sources indicated that PAPR-50 was 77.4% as effective as commercial SSP increasing the yield of the crop, while SPR was 60% and TPR was 40.9%. Though the untreated SPR and TPR were inferior to SSP and PAPR-50, the values obtained were

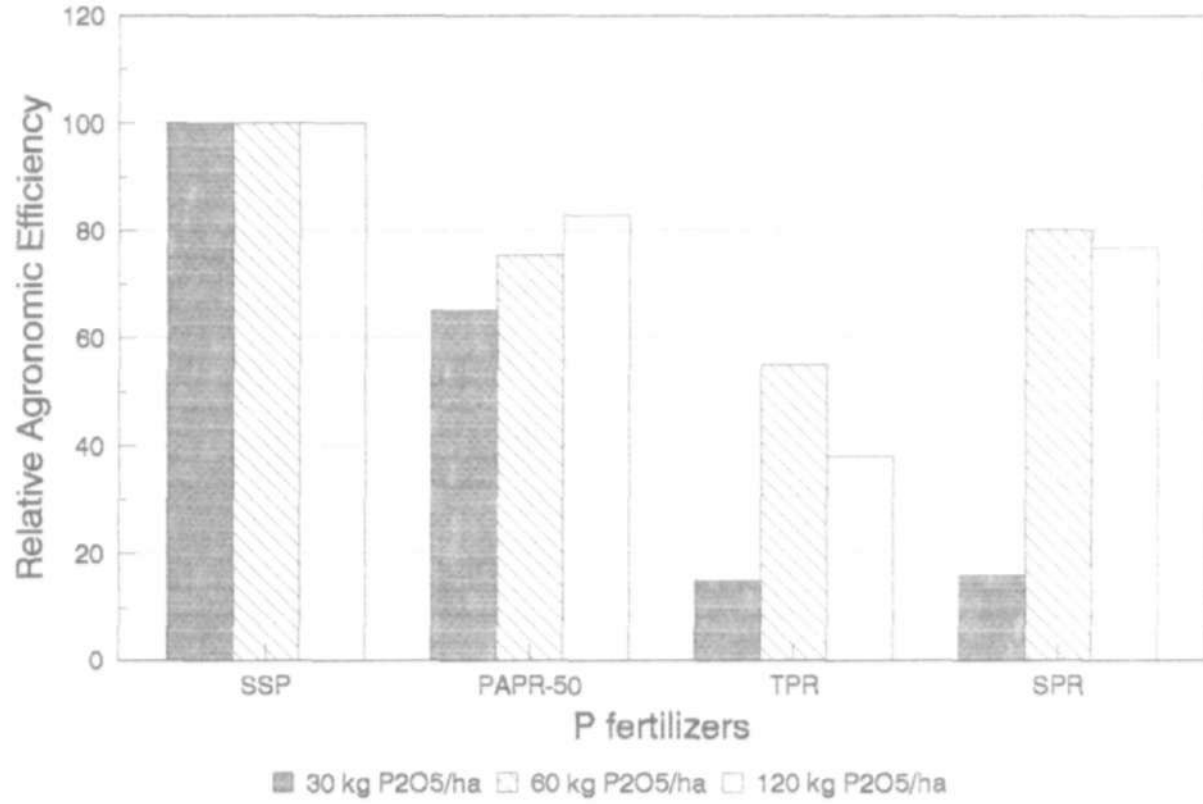


Figure 4. Relative Agronomic Efficiency of P sources and rates

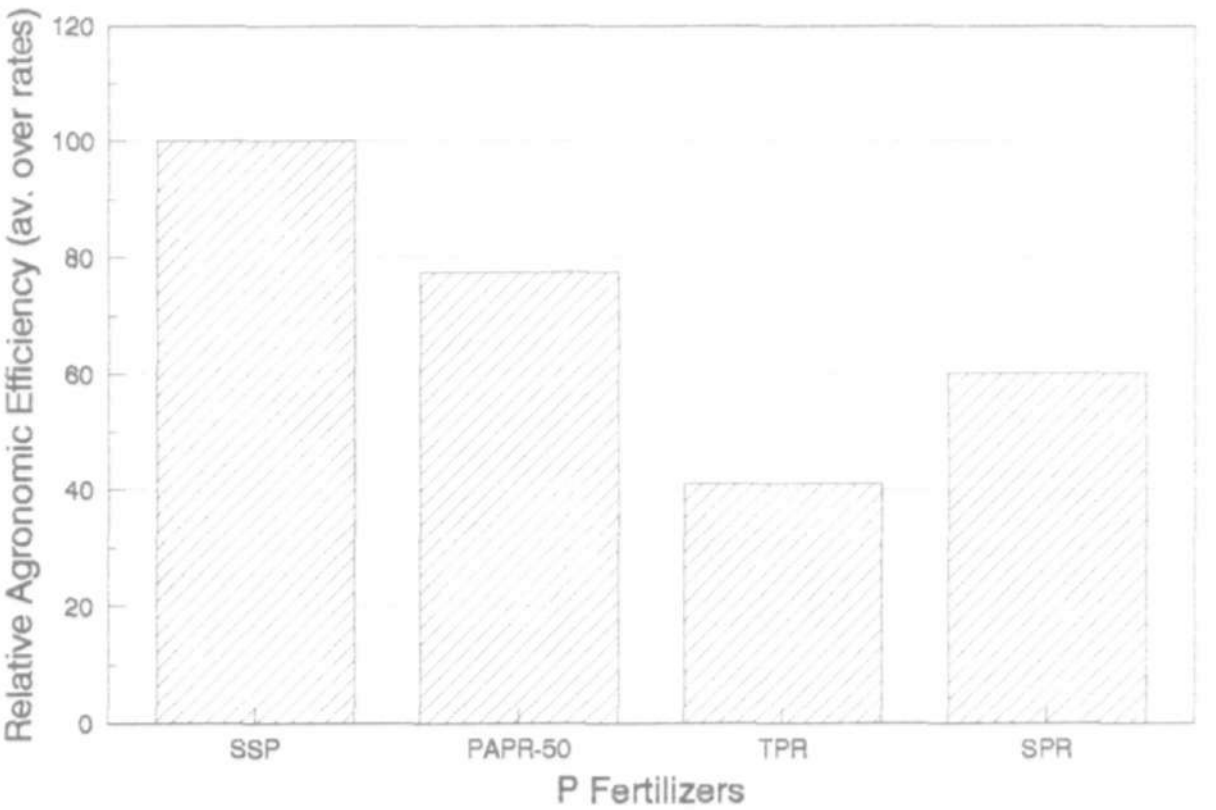


Figure 5. Relative agronomic efficiency of P sources

encouraging. In general there was a decrease in relative agronomic effectiveness with the PR sources. It is possible to infer from the result that grain yield increase was due to P fertilizer was a result of the total soluble P content in the soil, with the variation in yield response due in part of differences in P availibity.

Hammond *et. al.* 1986, conducted a rotational trial involving corn, soyabean and rice to compare the effectiveness of a highly reactive Bayover PR with soluble triple superphosphate (TSP), the result reveals that the PR was equally as effective as TSP and offered a good substitute for the other. Another investigation by Owusu-Bemoad and Acquwaye (1996), showed that relative to SSP, the residues of Togo PAPR-50 and Togo phosphate rock were ineffective for maize production on a sustainable bases in Northern Ghana at pH 6.6. Research has however established that legumes effectively absorb more P from PR than cereals because of their high rooting densities and calcium nutrition with a resultant high RAE.

4.3.0 Effect on Nutrient Concentration of the index Leaf at 50% Flowering of the Crop

Tables 4.08, 4.09 and 4.10 show the effect of rates and P sources on the nutrient concentrations in the leaves.

4.3.1 Effect on Leaf Nitrogen Content

The difference in the nitrogen content of the leaf due to treatments in year one and combined two years data were significant ($P<0.01$); while year two did not show any significant difference in their means. However, in each of the years, the leaf nitrogen contents increased with higher

rates of P application. The highest level was obtained with 120 kg P_2O_5 ha^{-1} SSP, (61.4 g kg^{-1}), while zero P application rate recorded the least value (39.5 g kg^{-1}) when the two years data were combined and analysed. This linear trend is obtained in all the years and ranking the treatment means can be seen in the Tables. The second trial did not show any significant differences in their means probably due to the already moderate N and Bray-1 P in the soil before planting. However, 120 kg P_2O_5 ha^{-1} PAPR-50 recorded the highest level of total N content in the leaf with the least values recorded by zero P application rates.

The concentration of nitrogen in the leaf show the interaction of nitrogen and phosphorus to produce better crop growth. Those treatments with higher levels of total nitrogen in the leaf resulted in higher grain yields. This crop also actively fix nitrogen at slightly low to low pH values, provided they can extract Ca and P from the soil (Jones *et. al.* 1977; Adams, 1980). This Ca is supplied by the various P sources that have been used in these experiments.

Andrew and Robin (1969), working with nine tropical pasture legumes found good positive correlations between the concentrations of P and N. Increasing the level of applied P beyond the rates giving maximum yields gave increasing nitrogen concentrations in the plant leaves. They reported that the concentrations of nitrogen in the plants responded to high levels of applied P than did dry matter. The high P supply, encourages maximum nitrogen

Table 4.08: Nutrient Concentration of the index leaf at 50% Flowering of Soyabean Crop to P sources and rate -1994

Treatment	P rates Kg $P_2O_5ha^{-1}$	Total Nitrogen	Total Phosphorus	Mg	Ca	Fe	Mn	Zn
		----------gkg---------				--------$mgkg^{-1}$----		
Control	0	39.9 c	2.50	4.9	3.4	109	34	21 bc
SSP	30	45.9 bc	3.63	7.8	3.9	181	47	35 a
	60	52.5 bc	3.73	7.3	3.3	145	41	28 ab
	120	74.9 a	4.40	6.5	3.4	153	23	19 c
PAPR-50	30	42.7 c	2.90	7.3	3.3	219	27	31 ab
	60	42.0 c	3.33	5.7	3.2	152	43	25 abc
	120	45.5 bc	3.03	6.1	3.1	293	49	31 ab
TPR	30	44.5 bc	3.33	6.6	3.5	128	33	14 c
	60	43.1 c	3.53	5.8	3.3	89	38	21 bc
	120	40.3 c	2.83	5.7	3.7	251	34	29 ab
SPR	30	49.0 bc	4.17	6.3	3.3	197	39	29 ab
	60	56.7 ab	3.10	5.7	3.1	157	35	29 ab
	120	66.2 ab	4.00	5.5	3.0	273	29	25 abc
MEAN		49.5	3.11	6.3	3.4	181	36	26
SED		0.93^{*}	0.09^{NS}	0.13^{NS}	0.06^{NS}	106.0^{NS}	12.90^{NS}	5.70^{*}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.

Table 4.09: Nutrient Concentration of the index leaf at 50% Flowering of Soyabean Crop to P sources and rate - 1995

Treatment	P rates Kg $P_2O_5 ha^{-1}$	Total Nitrogen	Total Phosphorus	Mg	Ca	Fe	Mn	Zn
		----------gkg---------				--------$mgkg^{-1}$----		
Control	0	39.1	3.23 cd	25	11.1	157 bc	107	36
SSP	30	46.7	3.70 abc	26	10.5	143 c	108	36
	60	40.8	3.50 bcd	27	11.1	186 abc	108	38
	120	47.8	4.47 a	28	12.2	270 a	113	29
PAPR-50	30	43.5	3.70 bcd	24	11.6	290 a	128	41
	60	38.7	4.07 abc	25	10.1	253 ab	113	36
	120	49.5	3.83 abc	26	16.0	227 abc	117	37
TPR	30	43.4	2.63 d	29	12.2	210 abc	105	41
	60	42.0	3.70 abc	27	10.5	243 abc	97	37
	120	41.1	3.70 abc	25	11.1	183 abc	97	38
SPR	30	39.0	3.80 abc	23	11.6	210 abc	110	32
	60	45.0	4.07 abc	29	10.5	213 abc	107	27
	120	48.5	4.30 ab	27	11.1	246 bc	117	43
MEAN		43.5	3.75	36	11.5	218	110	36
SED		0.52^{NS}	0.04^{**}	0.25^{NS}	0.09^{NS}	45.75*	21.03^{NS}	6.13^{NS}

NS = Not Significant at 5% level of probabiity
* Significant at 5% level of probability
** Significant at 1% level of probability
Mean followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.

Table 4.10 Nutrient Concentration of the index leaf at 50% Flowering of Soyabean Crop to P Sources and rate - Combined Two years Analysis

Treatment	P rates Kg $P_2O_5ha^{-1}$	Total Nitrogen	Total Phosphorus	Mg	Ca	Fe	Mn	Zn
		----------gkg---------				--------$mgkg^{-1}$----		
Control	0	39.5 d	2.87	15.0	7.2	133	70	28
SSP	30	46.3 bc	3.67	17.0	7.2	162	78	36
	60	46.7 bc	3.62	17.0	7.2	166	75	33
	120	61.4 a	4.43	17.0	7.8	212	69	24
PAPR-50	30	43.1 c	3.30	16.0	7.4	254	78	36
	60	40.4 c	3.70	15.0	6.6	203	78	30
	120	47.5 bc	3.43	16.0	7.4	260	83	24
TPR	30	43.9 c	2.98	18.0	7.8	219	69	28
	60	42.6 c	3.62	16.0	6.9	166	68	29
	120	40.7 c	3.27	15.0	7.4	217	65	34
SPR	30	44.0 c	3.98	14.0	7.5	204	74	31
	60	50.9 bc	3.58	17.0	6.8	185	71	28
	120	57.3 abc	4.15	16.0	7.1	260	72	34
MEAN		46.5	3.58	16.1	7.3	203	73	30
SED		0.53^{**}	0.47^{NS}	0.14^{NS}	0.05^{ns}	57.7^{NS}	12.34^{NS}	$4,19^{NS}$

NS = Not Significant at 5% level of probability
* Significant at 5% level of probability
** Significant at 1% level of probability
Means followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.

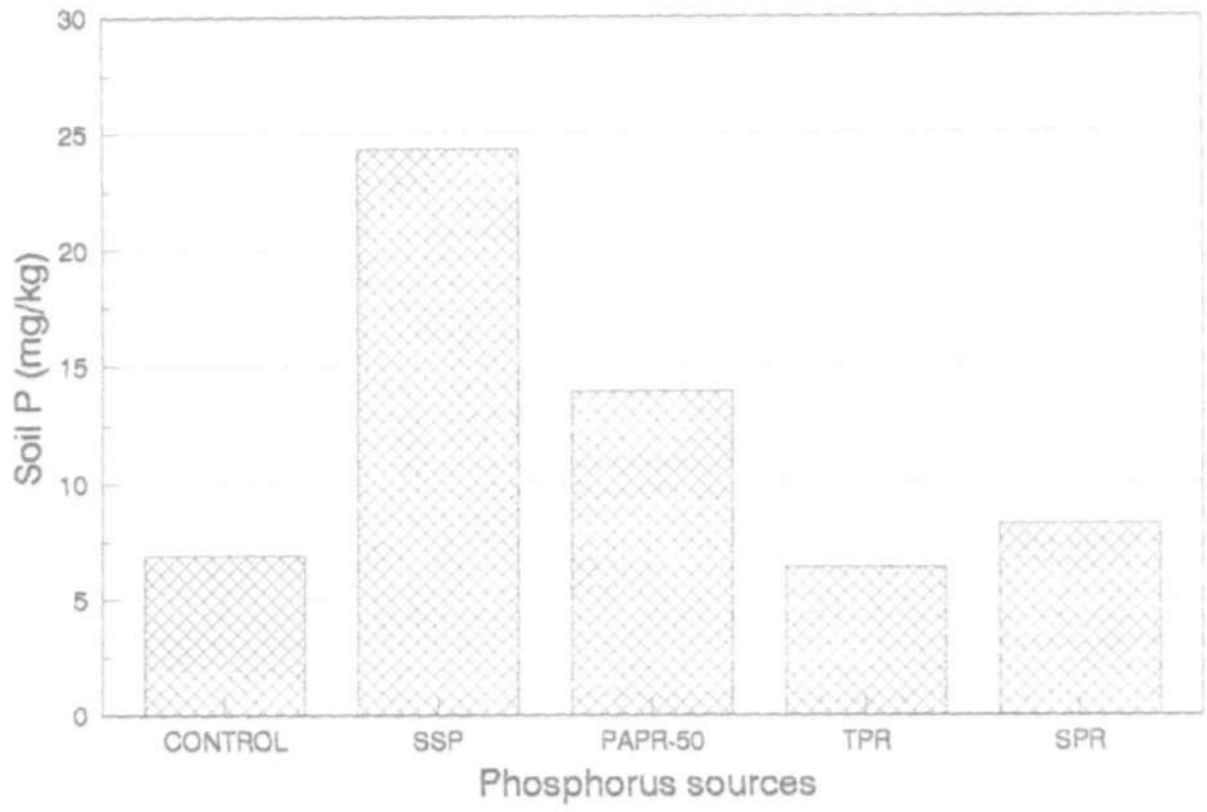


Figure 6. Bray-1 extractable P at harvest

in total P uptake and better utilization. Positive and significant correlation coefficients among P, P uptake and dry matter production at different periods of the growing season indicate that both P uptake and dry matter yield depend on the available P in the soil (Salih et. al., 1989). On the other hand Butegwa et. al. (1996), found that P uptake was affected by the soil P rate, P source and the interaction of source and rate. It has also been reported that increased uptake of Zn and Ca from fertilizers commonly result in decreased P content of the crop (Lagin et. al. 1962).

From the results it is not possible to identify a critical value for P, needed by the crop from the soil from the leave P concentration and the crop dry matter yield. The reason is the insufficiency of data, although I am confident that the P rates used especially for SSP at 60 and 120 kg P_2O_5 ha^{-1} were in adequate amount for early growth.

4.3.3 Other Nutrients Concentrations in the index Leaf

Other nutrient concentration in the leaf were not significantly influenced by P application, except for Zinc in the first trial and Iron in the second year trial (Tables 4.08, 4.09 and 4.10). Adams (1980), reported P/Zn ratio of leaves to be inversely related and this trend was observed in this investigation. The higher values of Zn obtained in the leaves by PR application more than zero P sources rates may not be surprising since PR sources are rich in this micronutrient. Increased uptake of Zn commonly result in decreased P content of the crop.

There was no significant and consistent trend in the different concentration levels of Mg, Ca, Fe and Mn in the leaf

4.4.0 Effects of P sources and Cropping on Soil Properties at Harvest

The influence of phosphate fertilizers and cropping on the soil chemical properties are presented on Tables 4.11, 41.2 and 4.13.

4.4.1 Effect on Soil pH and Exchange Acidity

The use of phosphate materials increased the pH of the soils slightly by 0.1 or 0.2 units compared with the plots with no P application in the two years trials. The trend was however, not significant and consistent. Soils receiving SSP and zero P had the lower pH values. The data from these trials are not sufficient to draw conclusions on the liming effects of phosphate rock and the acidifying effect of SSP in poorly buffered soils

The exchange acidity was not significantly influenced by P applications either. The highest values were however, obtained in zero P application plots particularly in the second year trial. This could possibly explain the low pH of the soil under this treatment. Phosphate rock application has been shown to increase the pH of soils because the rock contains calcium which can modify the pH of acid soils (Mokwunye, 1996), while single superphosphate has acidifying effects (Mokwunye, 1979).

4.4.2 Effect on Organic Carbon (OC), Total Nitrogen (TN) and Bray-1 P in the Soil

As shown in Tables 4.11, 4.12 and 4.13, the organic

carbon contents of the soils were not significantly affected by various phosphate application and rates for the separate years but when the results for the two years were combined, SPR application significantly gave higher organic carbon contents ($P<0.05$) at 30 and 120 kg P_2O_5 ha^{-1} application rates. The organic carbon contents were also low for TPR and zero P applications. It is well recognised that increase in organic carbon content increase P solubilization.

There was no significant difference with the Nitrogen content of the soil due to phosphate application and cropping although higher values of N were obtained with SSP application rate of 120 kg P_2O_5 ha^{-1}.

Data presented in Tables 4.11 - 4.13 show how the P status varied with the P levels applied. Available P as extracted by Bray-1 in the soil was affected or increased by phosphate fertilizer applications. The soil test after the harvest indicated that available P contents were either increased or reduced. In 1994 trial, Bray-1 P mean values were significantly different ($P<0.05$). Single Superphosphate at 120 kg P_2O_5 ha^{-1} recorded the highest value of 27.5 mg kg^{-1} followed by 120 kg P_2O_5 ha^{-1} of PAPR-50 with a value of 6.4 mg kg^{-1} while other treatments such as TPR at 60 kg P_2O_5 ha^{-1} and control recorded 1.8 mg kg_{-1} and 2.4 mg kg-1 values respectively. The second year trial recorded higher level of available P, with SSP application rate of 60 kg P_2O_5 ha^{-1} giving the highest value (44.8 mg kg^{-1}). Results obtained with the amounts of extractable P in the soil show the cummulative effects of the various

Table 4.11: Some Chemical Properties of the Soil at Harvest as influenced by P sources and rates - 1994

Treatment	P rates Kg $P_2O_5 ha^{-1}$	pH(H_2O)	pH($CaCl_2$)	OC	TN	Bray-1 P	Exch Acid (H^+, Al^{3+})	ECEC	BS
		1:2.5	1:2.5	---gkg-------		$mgkg^{-1}$	-----$cmol^+ kg^{-1}$---		%
Control	0	5.5	4.7	5.1	0.8	2.4 b	0.60	3.58	82.8
SSP	30	5.1	4.7	5.0	0.9	3.6 b	0.60	5.93	89.4
	60	5.1	4.8	5.3	0.9	6.3 b	0.67	3.44	81.2
	120	5.4	4.8	5.2	1.0	27.5 a	0.73	4.86	84.6
PAPR-50	30	5.3	4.9	5.8	0.7	3.1 b	0.60	3.53	83.0
	60	5.4	4.7	5.2	0.8	5.1 b	0.67	3.33	79.9
	120	6.0	4.7	4.3	0.7	6.4 b	0.60	4.18	84.5
TPR	30	5.3	4.8	5.9	0.7	2.1 b	0.73	3.21	77.5
	60	5.9	4.7	4.3	0.8	1.8 b	0.73	3.80	80.1
	120	6.1	5.3	4.4	0.8	3.9 b	0.67	5.61	85.2
SPR	30	5.2	4.5	6.0	0.9	2.7 b	0.67	4.02	82.2
	60	5.4	4.7	4.3	0.9	2.2 b	0.67	4.26	82.7
	120	5.6	4.8	6.5	0.8	3.3 b	0.60	3.30	81.8
MEAN		5.5	4.8	5.2	0.8	5.4	0.66	4.08	82.7
SED		0.40^{NS}	0.21^{NS}	0.09^{NS}	0.79^{NS}	5.18^{**}	0.14^{NS}	0.98^{NS}	4.29^{NS}

NS = Not Significant at 5% level of probability
* Significant at 5% level of probability
** Significant at 1% level of probability
Means followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.

Ca	K	Na	Mg	Zn	Fe	Mn
---------$cmol^{+}\ kg^{-1}$---------				--------$mgkg^{-1}$----		
2.23	0.14	0.05	0.55	3.27	78.0abc	40.2
4.17	0.16	0.13	0.87	4.00	77.7abcd	47.3
2.07	0.18	0.05	0.47	0.67	13.7 L	40.3
3.47	0.15	0.06	0.44	2.77	81.3 a	34.5
2.17	0.17	0.08	0.52	2.93	17.0 L	33.3
2.00	0.16	0.06	0.44	4.15	73.0 bcde	39.0
2.90	0.14	0.07	0.47	1.80	53.3 g	34.0
1.73	0.19	0.12	0.43	5.00	46.9 hijk	40.2
2.22	0.14	0.05	0.55	3.97	51.3 ghi	36.2
2.73	0.14	0.09	1.97	6.03	69.7 ef	40.7
2.53	0.18	0.05	0.59	2.17	50.7 ghij	35.3
2.73	0.15	0.10	0.61	5.80	53.0 gh	37.0
2.00	0.16	0.06	0.48	3.47	79.3 ab	33.3
2.53	0.18	0.08	0.65	3.69	57.3	37.8
0.72^{NS}	0.03^{NS}	0.05^{NS}	0.54^{NS}	1.96^{NS}	3.48**	5.24^{NS}

Table 4.12: Some Chemical Properties of the Soil at Harvest as influenced by P sources and rates - 1995

Treatment	P rates Kg $P_2O_5 ha^{-1}$	pH(H_2O)	pH($CaCl_2$)	OC	TN	Bray-1 P	Exch Acid (H^+, Al^{3+})	ECEC	BS
		1:2.5	1:2.5	---gkg-------		$mgkg^{-1}$	-----$cmol^+ kg^{-1}$---		%
Control	0	4.9	4.3	4.5	0.7	11.4	0.86	3.14	72.5 cd
SSP	30	5.5	4.5	4.8	0.9	24.2	9.67	3.35	80.0 abcde
	60	5.1	4.5	5.3	0.9	44.8	0.73	2.63	71.6 d
	120	5.0	4.6	4.3	0.9	39.7	0.49	3.50	86.7 a
PAPR-50	30	5.1	4.4	5.2	0.9	14.3	0.60	3.09	80.4 abcde
	60	5.0	4.5	4.1	0.8	22.7	0.60	3.22	80.5 abcd
	120	5.1	4.4	4.2	0.8	32.0	0.67	3.23	79.0 abcde
TPR	30	5.0	4.5	4.4	0.9	12.2	0.67	2.36	70.9 d
	60	5.4	4.6	2.9	1.0	9.0	0.60	2.90	78.9 abcde
	120	5.3	4.5	3.3	0.8	9.3	0.67	3.53	81.0 abc
SPR	30	5.3	4.4	5.5	0.8	12.3	0.67	3.15	78.8 abcde
	60	5.3	4.6	4.6	0.9	14.9	0.60	2.97	79.6 abcde
	120	5.2	4.4	4.8	0.8	13.4	0.60	3.33	81.9 ab
MEAN		5.2	4.5	4.5	0.9	20.0	0.55	3.11	78.6
SED		0.29^{NS}	0.14^{NS}	0.08^{NS}	0.01^{NS}	11.68^{NS}	0.12^{NS}	0.50^{NS}	4.01^{*}

NS = Not Significant at 5% level of probability
* Significant at 5% level of probability
** Significant at 1% level of probability
Means followed by a common letter within a column are not significant different at 5% or 1% level probability using DMRT.

Ca	K	Na	Mg	Zn	Fe	Mn
---------cmol^{+} kg^{-1}----------				--------mgkg^{-1}----		
1.67	0.12	0.14	0.35	5.03 bc	53.00	18.8
2.13	0.15	0.10	0.30	2.47 cd	92.00	23.00
1.50	0.12	0.10	0.17	3.27 bcd	45.20	18.30
2.20	0.26	0.20	0.34	2.93 bcd	76.70	14.70
1.80	0.17	0.16	0.35	4.43 bcd	50.30	18.30
1.90	0.24	0.14	0.33	10.10 a	81.30	21.70
2.07	0.11	0.11	0.28	3.23 bcd	34.80	13.80
1.12	0.11	0.21	0.21	4.47 bcd	57.70	19.20
1.73	0.14	0.10	0.33	3.97 bcd	69.00	18.20
1.87	0.11	0.10	0.79	2.13 d	56.30	14.50
1.80	0.19	0.14	0.36	5.30 b	60.10	24.70
1.73	0.19	0.15	0.30	3.27 bcd	64.70	17.30
1.93	0.23	0.18	0.39	3.50 bcd	59.70	24.70
1.80	0.16	0.14	0.35	4.16	61.63	
0.28^{NS}	0.09^{NS}	0.06^{NS}	0.20^{NS}	1.09**	27.54^{NS}	6.18^{NS}

Table 4.13: Some Chemical Properties of the Soil at Harvest as influenced by P sources and rates - Combined Two Years Analysis

Treatment	P rates Kg $P_2O_5 ha^{-1}$	pH(H_2O)	pH($CaCl_2$)	OC	TN	Bray-1 P	Exch Acid (H^+, Al^{3+})	ECEC	BS
		1:2.5	1:2.5	---gkg-------		$mgkg^{-1}$	-----$cmol^+ kg^{-1}$------		%
Control	0	5.2	4.5	4.8 d	0.8	6.9 c	0.73	3.36 bcd	77.6 cd
SSP	30	5.3	4.6	4.8 d	0.9	13.9 bc	0.63	4.64 a	84.7 ab
	60	5.1	4.7	5.3 c	0.9	25.5 ab	0.70	3.04 cd	76.4 cd
	120	5.2	4.7	4.8 d	1.0	33.6 a	0.61	4.18 abc	85.6 a
PAPR-50	30	5.2	4.6	5.5 b	0.8	8.7 c	0.60	3.31 cd	81.7 abc
	60	5.2	4.6	4.6 e	0.8	13.9 bc	0.63	3.27 cd	80.2 bcd
	120	5.6	4.5	4.2 g	0.8	19.2 bc	0.63	3.71 abcd	81.8 abc
TPR	30	5.1	4.6	5.2 c	0.8	7.2 c	0.70	2.78 d	74.2 d
	60	5.7	4.6	3.6 i	0.9	5.4 c	0.67	3.35 bcd	79.5 bcd
	120	5.7	4.9	3.8 h	0.8	6.6 c	0.67	4.47 ab	83.1 abc
SPR	30	5.3	4.5	5.7 a	0.9	7.5 c	0.67	3.59 abcd	80.5 bcd
	60	5.4	4.7	4.4 f	0.9	8.6 c	0.63	3.61 abcd	81.2 abc
	120	5.4	4.6	5.7 a	0.8	8.4 c	0.63	3.32 bcd	81.9 abc
MEAN		5.3	4.6	4.8	0.9	12.7	0.65	3.59	80.6
SED		0.24^{NS}	0.13^{NS}	0.06^{*}	0.39^{NS}	6.39^{*}	0.09^{NS}	0.55^{*}	2.93^{*}

NS = Not Significant at 5% level of probability
* Significant at 5% level of probability
** Significant at 1% level of probability
Means followed by a common letter within a column are not significant different at 5% or 1% level of probability using DMRT.

Ca	K	Na	Mg	Zn	Fe	Mn
---------$cmol^{+}\ kg^{-1}$----------				--------$mgkg^{-1}$----------		
1.95	0.13	0.10	0.45	4.15	65.5	29.50
3.15	0.16	0.11	0.59	3.23	84.80	35.20
1.78	0.15	0.08	0.32	1.92	29.50	29.40
2.83	0.21	0.13	0.39	2.87	79.00	24.60
1.98	0.17	0.12	0.44	3.68	33.7	25.80
1.95	0.20	0.10	0.39	7.13	77.3	30.30
2.48	0.13	0.09	0.37	2.52	46.1	23.90
1.45	0.15	0.17	0.32	4.73	52.3	29.70
2.03	0.14	0.07	0.44	3.97	60.2	27.30
2.03	0.12	0.10	1.38	4.08	63.0	27.60
2.18	0.19	0.10	0.47	3.73	55.4	30.30
2.23	0.17	0.13	0.45	4.53	58.8	27.20
1.97	0.20	0.12	0.44	3.48	69.5	29.00
2.16						
0.38^{NS}	0.05^{NS}	0.04^{NS}	0.29^{NS}	1.12^{NS}	16.18^{NS}	4.05^{NS}

fertilizers. Figure 6 shows how the available P status varied with the P sources.

On the whole and from the combined analysis of the two- year data, the application of P fertilizers significantly affected the soil Bray-1 P after cropping. Initially both soils had low extractable P and extractable bases but, the higher rates of application of SSP and PAPR resulted in significantly higher Bray-1 P contents in the soil. The water soluble contents of these P sources are important factors for the P values in solution. It has also been shown that available P extracted with Bray-1 correlate well with chemical reactivity of a PR (Chien, 1979; Hammond, 1979). The solubilities of Togo and Sokoto phosphate Rocks are shown in Appendix 3.2. The agronomic potential and neutral ammonium citrate solubility of SPR has been shown to be higher than that of TPR (Mokwunye, 1995). Since the soil pH was acid to slightly acid in reaction, phosphate dissolution must have been enhanced as similar reactions are enhanced at low pH conditions as reported by Paauw, (1965); Chien, (1977); Hammond *et. al.* (1986), Boland and Hedley, (1989). The amounts of rainfall received (Appendix 3.3) were adequate enough to influence the dissolution of the phosphate sources bringing P in solution. Selles *et. al.* (1995), reported that the rate of P accumulation in soils was highest in P fertilized systems that produced low-yielding crops as indicated by the P balance. Bationo et.al (1995), observed that the build up of soil available P follows the same trend as the agronomic performance of the different P sources.

4.4.3 Effect on Exchangeable Basic Cations

The effect of the P sources and rates on exchangeable basic cations are also shown in Tables 4.11 - 4.13. Phosphorus fertilizers were found not be have any significant effect on the soil mean exchangeable basic cations. Though higher values were recorded for exchangeable Ca due to SSP application at 120 kg P_2O_5 ha^{-1} in the second year trial, these values were not significant different ($P<0.05$) from the other treatments. TPR at the rate of 120 kg P_2O_5 ha^{-1} gave the highest values for Mg in the two trials, though, they were also not significantly different from the other P sources and rates.

Phosphate materials contain some quantity of calcium in them, which when released in solution, can modify the pH of acid soils (Hellum *et. al.* 1989). The soils also served as a sink for Ca dissolved from the PR because of their low exchangeable Ca (Chien *et. al.* 1980).

4.4.4 Effect on ECEC and Percentage Base Saturation (PBS)

As furnished in Tables 4.11 - 4.13, the mean effect of the different P fertilizers did not significantly affect the ECEC of the soils cropped to soyabean in the two trials. The combined analysis of these trials however, gave a significant difference among the treatment of ECEC by the various P fertilizers. The highest values was recorded by 30 kg P_2O_5 ha^{-1} SSP and the lowest by 30 kg P_2O_5 ha^{-1} TPR. Mokwunye (1995), reported that soils with low level of cation exchange capacity provide suitable environments for the dissolution of phosphate rocks.

There was no significant difference in the PBS in the first year of the trial but in the second year trial, the highest and significant values were recorded by SSP; the lowest significant value was recorded by TPR at application rate of 30 kg P_2O_5 ha^{-1}. The combined analysis of the two trails also produced a significant and highest value at 120 kg P_2O_5 ha^{-1} SSP; the lowest significant value was recorded by 30 kg P_2O_5 TPR. Soils with high base saturation have been reported to limit the dissolution of PR (Hammond *et. al*. 1980, Junge and Werne, 1989 and Mokwunye, 1995). The soils used for the trial maintained low levels of Ca and P in the soil solution.

4.4.5 Effect on Micronutrient in the Soil

Statistical significant differences in the means of Fe and Zn were produced by the treatments. The highest significant level of Fe in solutions was observed on the plot receiving 120 kg $P_2O_{5\ ha}^{-1}$ SSP application and lowest by those receiving 60 kg P_2O_5 SSP and 30 kg PAPR P_2O_5 ha^{-1} application rates in the first year trial. The second year trial recorded the highest significant difference for Zn due to the treatments, with PAPR-50 at 60 kg P_2O_5 ha^{-1} recording the highest value and the lowest value at 60 kg P_2O_5 ha^{-1} TPR.

Except for the above micronutrients which showed significant differences in means due to treatments, the remaining micronutrients (Mn and Cu) did not show any significant differences in their means. It must be noted that there has to be a balance between Fe, Zn and P in the soil or an antagonistic effect result. Excess of any of

them may results in induced Fe chlorosis or excess Zn upsets normal P metabolism creating visual symptoms typical of P deficiency (Adams, 1980). Amberger (1978), reported that PRs may be rich in micronutrient like Zn, but Zn uptake is critical in soils with high P levels especially in case of high P application.

4.5.0 Correlation Matrix

The correlation matrix are shown in Tables 4.14 - 4.17. The correlation between grain yield and plant performance were positive and significant for most of the parameters. The results showed a significant and positive correlation between the number of flowers, pods and seeds, the weight of 1,000 seeds and seed densities with the grain yield. This shows that these yield components significantly influence the eventual grain yield; with a resultant higher grain yields. The study shows that the availability of P applied to crops depends markedly on the fertilizer type and rates of addition. The root weight was however significantly negatively correlated (-0.3420^{*} in 1994 and -0.3408^{*} in 1995).

The results indicate that there was a positive and significant correlation between grain yield and with Ca and Mg concentrations in the plant leaves in year one, while the second year recorded a significant negative relationship between Zn concentration in the leaves and the grain yields. The results also showed P concentrations in the leaves which results in a positive but not significant P uptake in the leaves related to the grain yield.

Table 4.14: Correlation matrix of soyabeans grain yield with agronomic performance of the crop to P sources and rate

Agron. Performance	Year-1 (1994)	Year-2 (1995)	Combined Two Years
DHF	0.2196^{NS}	0.1663^{NS}	0.1042^{NS}
NFP	0.826^{NS}	0.3279^{*}	0.3569^{**}
SDWT	-0.1446^{NS}	0.3082^{NS}	0.0244^{NS}
NPP	0.2017^{NS}	0.1947^{NS}	0.0284^{NS}
NNP	0.4589^{**}	0.2127^{NS}	-0.2199^{NS}
WNP	0.2449^{NS}	0.2595^{NS}	0.0666^{NS}
RWP	-0.3420^{*}	-0.3408^{*}	0.2062^{NS}
NSP	0.3466^{*}	0.4970^{*}	0.0861^{NS}
WSP	1.000^{**}	0.9998^{**}	1.000^{**}
1,000SWT	0.0544^{NS}	0.2195^{**}	0.1386ns
SD	0.4163^{**}	-0.0500^{NS}	-0.0898^{NS}

ABBREVIATIONS: Days to 50% flowering (DHF), No of Flowers/Plant (NFP), No of Nodules/Plant (NNP), Weight of Nodules/Plant (WNP), Shoot Dry Weight/Plant (SDWP) and Root Weight/Plant (RDP)

Table 4.15: Correlation matrix of soyabeans grain yield with nutrient concentration to P sources and rates

Nutrient in Plant	Year-1 (1994)	Year-2 (1995)	Combined Two Years
TN	0.0079^{NS}	0.0315^{NS}	0.2055^{NS}
TP	0.1630^{NS}	0.2481^{NS}	$- 0.0009^{NS}$
Ca	0.5143^{**}	0.2099^{NS}	0.6143^{**}
Mg	0.3337^{*}	-0.2293^{NS}	$- 0.6482^{**}$
Fe	0.2291^{NS}	-0.1604^{NS}	$- 0.0277^{NS}$
Zn	-0.0307^{NS}	-0.3892^{*}	$- 0.4296^{**}$
Mn	0.0441	0.0214^{NS}	$- 0.6005^{**}$

Table 4.16: Correlation matrix of Bray-1 P with chemical soil properties at harvest to P sources and rates

Soil Property	Year-1 (1994)	Year-2 (1995)	Combined Two Years
pH (H_2O)	-0.1629^{NS}	-0.1270^{NS}	-0.2569^{*}
pH ($CaCl_2$	-0.1295^{NS}	0.0246^{NS}	-0.2635^{*}
Ex. Acid	0.2345^{NS}	-0.2404^{NS}	-0.0739^{NS}
OC	0.1263^{NS}	0.1058^{NS}	-0.0690^{NS}
TN	0.0343^{NS}	0.1170^{NS}	0.0678^{NS}
Ca	0.4336^{**}	0.2645^{NS}	-0.0095^{NS}
K	0.0373^{NS}	-0.1803^{NS}	0.1845^{NS}
Na	-0.0020^{NS}	0.1235^{NS}	-0.2279^{*}
Mg	-0.0381^{NS}	-0.2919^{NS}	0.1376^{NS}
Fe	0.2406^{NS}	0.0704^{NS}	-0.0109^{NS}
Zn	-0.1130^{NS}	-0.0681^{NS}	-0.4562^{**}
Mn	-0.0785^{NS}	-0.1642^{NS}	-0.0996^{NS}
Cu	-0.0530^{NS}	0.1120^{NS}	-0.1316^{NS}

Table 4.17: Correlation matrix of soyabeans grain yield with soil properties at harvest to P sources and rates

Pre-Planting Soil Property	Year-1 (1994)	Year-2 (1995)	Combined Two Years
pH (H_2O)	-0.1152^{NS}	0.0957^{NS}	0.1631^{NS}
pH ($CaCl_2$	0.2162^{NS}	0.2260^{NS}	0.4646^{**}
Ex. Acid	-0.0885^{NS}	-0.0327^{NS}	-0.0489^{NS}
OC	-0.3272^{*}	0.1693^{NS}	0.0939^{NS}
TN	-0.0168^{NS}	0.0972^{NS}	0.0667^{NS}
Bray-1 P	0.0058^{NS}	0.2500^{NS}	0.2841^{*}
Ca	0.0156^{NS}	0.3494^{*}	0.3433^{*}
K	-0.1082^{NS}	0.2867^{NS}	0.0281^{NS}
Na	0.1553^{NS}	-0.0376^{NS}	-0.3076^{**}
Mg	-0.1154^{NS}	-0.1526^{NS}	0.1145^{NS}
Fe	-0.3325^{*}	0.0284^{NS}	-0.1919^{NN}
Zn	-0.2985^{NS}	-0.1587^{NS}	-0.2447^{*}
Mn	0.1123^{NS}	-0.0124^{NS}	0.5603^{**}
Cu	-0.0642^{NS}	-0.0141^{NS}	-0.0906^{NS}

There were significant and positive correlation of the soyabean grain yield with the Bray-1 extractable P, Mn and Calcium content in the soils at harvest. It clearly indicates that significant yield differences in soyabean grains are dependent on the P status of the soil. As already discussed, Bray-1 P is needed for seed formation and Ca is needed for root nodulation. Fe concentration in the soils at harvest was however significant and negatively correlated with the grain yields of soyabean. This shows the interaction of Fe and P for crop growth.

When Bray-1 extractable P was correlated with other soil properties at harvest, it was significant and positive for exchangeable Ca but negative for exchangeable Na and extractable Zn.

The results show that there was a good relationship between grain yield, P concentration in leaves and Bray-1 P in the soil (r = 0.2841*). The work corroborates the work of Chien (1979); Hammond, (1978); who showed that available P as extracted by Bray-1 in the soil correlates well with chemical reactivity of PR and with plant yield and P uptake (Hammond, 1978; Syers and MaCkay, 1986; Salih *et. al.* 1989). Butegwa (1996) also reported that both Bray-1 and plant uptake P were suitable for measuring the availability of P and estimating expected yields in the soils treated with PR and their derivatives.

CHAPTER FIVE

5.1 SUMMARY AND CONCLUSIONS

An experiment was conducted in two fields for two years (1994 and 1995) at the research farm of IAR, Samaru, Zaria using four sources of phosphorus which were: single superphosphate, partially acidulated phosphate rock (50%), Togo phosphate rock and Sokoto phosphate rock. The treatments were applied at the rates of 0, 30,60 and 120 kg P_2O_5 ha^{-1} with a basal application of 30 kg ha^{-1} K_2O. The experimental design was a randomized complete block design.

The physical and chemical properties of the soils used for the experiment were sandy and silty loam texture with an acid pH, low organic carbon, total Nitrogen, available phosphorous, effective cation exchange capacity and medium base saturation. The investigations were conducted on soil with pH levels of 4.4 and 4.8 in $Cacl_2$ (in 1994 and 1995) and relatively moderate exchangeable calcium levels.

The results showed that P treatments had a significant effect on soyabean crop performance. Responses of soyabean to the applied P in each of the years was shown by the plant performance, yield components and final grain yield. Nodulation of soyabeans was increased by the P treatments, most especially at higher rates of application. The mean difference in nodule number was significant ($P<0.05$) in 1994. The shoot dry weights were increased, but reduced root weights were obtained at increasing P application rates. The components of yield that were significantly

influenced were the number of flowers per plant (1995) at P<0.01; the number of pods per plant, the number of seeds per plant (1994 and 1995) at P<0.01, weight of seeds per plant in 1995 at P<0.05, weight of a thousand seeds and seed density in 1995 at 1% level of probability. It is the above yield component that determine the final grain yield.

The grain yield response to direct phosphates application and rates were significant (P<0.01) in both years. The highest grain yields were obtained by SSP at 120 kg P_2O_5 ha^{-1} application rates in both years (2262 kg ha^{-1} in 1994 and 2388 kg ha^{-1} in 1995); while at zero kg P_2O_5 ha application rates, grain yields were 1358 kg ha^{-1} in 1994 and 1568 kg ha^{-1} in 1995. Looking at the over all mean soyabean grain yields, SSP was superior to all other sources of P tested in the trial. The performance of PAPR-50 was however, as good as this commercial fertiler, though there were yield differences. Grain yields obtained at 120 kg P_2O_5 ha^{-1} application rates of TPR and SPR were also quite appreciable and significantly different from control. On the over all performance of the various fertilizers based on their means, SSP > PAPR-50 > SPR > TPR > Control on grain yields were obtained. Calculated values of relative agronomic effectiveness of the P sources for soyabean grain yields showed that PAPR-50 was 77.4% as effective as SSP; while SPR and TPR were 60% and 40.9% respectively,as effective as this commercial water soluble P source. The better performance of SSP compared to PR in increasing grain yields can be ascribed to the fact that

SSP had more citrate and water-soluble P than PR. Despite the differences obtained in the yields, the PR performance is encouraging for the production of this crop in these poorly buffered soils.

The application of these P sources raised the soil solution P level high enough to benefit the crop. This is shown by increased nitrogen and phosphorus contents in the leaves. The total phosphorus concentrations in the leaves were significantly increased ($P<0.01$) in 1995, with SSP having the highest value (4.47 g kg^{-1}) at 120 kg P_2O_5 application rate.

Results obtained by the application of these materials and cropping soyabean on these soils indicate that there were no significant differences in the values of pH, exchange acidity, organic carbon, and concentration of N, Ca, K, Na, Mg, Fe, and Mn. The differences in the soil mean values of Zn were only significant in 1995 but the values were not high enough to affect the crop. However, the available P in the soil extracted by Bray-1 was significantly increased by P sources and application rates with SSP at 120 kg P_2O_5 ha^{-1} having the highest value (27.5 mg kg^{-1}) in 1994. The data indicated that available P extracted varied with the P levels and rates. The available P extracted in the PR treated plots decreased in 1994 compared to the original value in the soil which indicates that the soil P gets depleted with crop removal and maintenance dose of P is necessary. The differences in ECEC and base saturation were found to be significantly

increased ($P<0.05$) in 1995 due to the phosphates applied. This indicate that the application of P significantly maintain the soil P and CEC in an optimum level. The available P as extracted by Bray-1 in the soil at harvest was found to correlate well with plant yield ($r = 0.2841^*$) and to some extent,with P concentration in the leaves. This suggests that plant P uptake and growth could be limited by amounts of soluble P in the soil.

From the results presented, the following conclusions can be derived at:

1. Soyabeans showed an appreciable response to P fertilization as evidenced by increased grain yield with P application. The yield response to direct application of the phosphates is significantly higher than zero application ($P<0.01$).
2. The yield response pattern was considerably influenced by the fertilizer treatments, with higher rates of P application having the highest crop grain yields.
3. The variation in yields response were due in part to differences in P availability, of which solubility of the P fertilizers were major factors controlling its availability to the crop. This solubility can be measured by Bray-1 extracted in the P treated soils.
4. Though the PR sources produced inferior yields as compared to SSP and PAPR-50 at the same rate of P_2O_5 applied, the yields obtained with these other PR materials were quite appreciable and significantly higher ($P<0.01$) than control. This infers therefore

that PRs and most especially the indeginous PR (Sokoto Phosphate Rock) may offer a substitude to SSP for soyabean production in this area with a mean rainfall of 1040 mm per year where P deficiency may be severe. This is because response to the use of PR for groundnut production in Nigeria (an area of mean rainfall of 600 mm per annum) has been obtained.

5. The absence of large amounts of colloidal materials in these soils create an ideal environment for greater than expected efficiency of the phosphate rocks even for annual crops. The soyabean crop also helped to maintain low ions of Ca and P in the soil thereby favouring further dissolution.
6. The PRs is a promising source of P in the present system of farming, particularly in view of its nearness to source and relative cheapness.

5.2. FUTURE RESEARCH NEEDS

The present study shows how soyabean grain yield and yield related parameters are affected by the various phosphate sources and rates. Further research should place more emphasis more on:

1. finding the economic alternate sources of phosphorus for the crop
2. determining the residual effectiveness of these P sources for this crop production in this ecological zone.
3. studying the effect of the different methods of applications and how they can affect its Relative Agronomic Efficiency in this study area.

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Appendix 3.1: Elemental Composition of Sokoto and Togo Phosphate Rocks

Constitutent (Weight) (%)	Sokoto Phosphate Rock	Togo Phosphate Rock
P_2O_5	34.20	36.60
CaO	47.90	52.20
F	3.40	3.61
SiO_2	4.20	3.25
Al_2O_3	1.70	2.10
Fe_2O_3	3.00	120
Na_2O	0.24	Note available
MgO	0.10	(N.A)
K_2	0.08	(N.A)
Free H_2O	0.77	(N.A)

Analyst: Steven J. Van Kauwenbey, Minerologist IFDC, Alabama USA (Original source not seen, no correlation was found between trace elements content and either soil pH or organic matter-By Obiji (1987).

Constitutent (Weight) (%)	Sokoto Phosphate Rock	Togo Phosphate Rock
P_2O_5	36.25	36.60
SiO_2	3.44	3.25
Fe_2O_3	1.30	1.20
Al_2O_3	1.50	2.10
F	3.84	3.61
CaO	52.30	52.20
Free H_2O	0.76	0.84

The result in the table is an average value of five determinations in each rock sample with a standard deviation of 0.04.

Source: Adeguke et. al. (1994).

Appendix 3.2: **Agronomic Potential of the PRs**

PR	Molar PO_4/CO_3 ratio less than 5
Sokoto	11.5
Togo	12.3

* The most reactive PRs are those having a molar PO_4/CO_3 ratio less than 5.

Solubility of the PRs

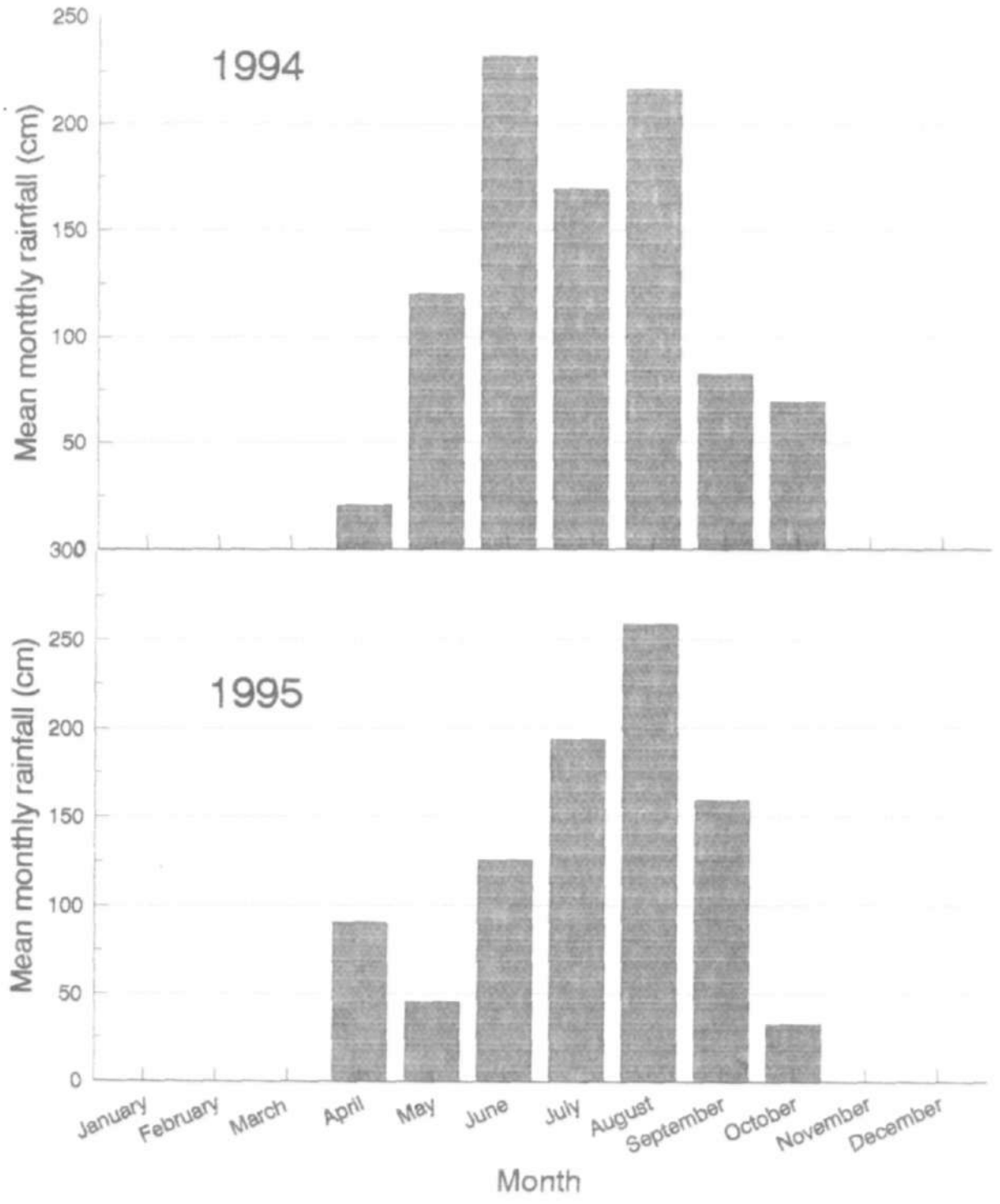
PR	Measured Neutral Ammonium Citrate (NAC) Solubility $\%P_2O_5$
Sokoto	3.2 - 3.7
Togo	2.5 - 3.2

* The higher the value, the more reactive the rock.

Source: Mokwunye, 1995.

The empirical Formula for Sokoto and Togo PRs are:

PR	Length of an axis (A)	Empirical Formula
Sokoto	9.353	$Ca_{9.84}\ Na_{0.14}\ Mg_{0.05}\ (PO_4)_{5.52}\ (CO_3)_{0.48}\ F_{2.19}$
Togo	9.354	$Ca_{9.85}\ Na_{0.11}\ Mg_{0.04}\ (PO_4)_{5.55}\ (CO_3)_{0.45}\ F_{2.18}$



Appendix 3.3 Rainfall distribution in years of study