EFFECT OF PHOSPHATE ROCKS IN COMBINATION WITH ORGANIC AMENDMENTS ON MAIZE (Zea mays L.) IN THE NORTHERN GUINEA SAVANNA

BY

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A Thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfillment of the requirements for the award of MSc Degree in Soil Science.

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DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All sources of information have been specifically acknowledged by means of references.

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CERTIFICATION

This thesis entitled "**Effect of Phosphate Rocks in Combination with Organic Amendments on Maize (Zea Mays L.) in the Northern Guinea Savanna**" by J.M. Jibrin meets the regulations governing the award of degree of Master of Science (Soil Science) of Ahmadu Bello University, Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

To

My Father, Alhaji M.B. Jibrin

and

Monsieur François Akle

ACKNOWLEDGEMENT

My sincere gratitude goes to my major supervisor, Dr. V.O. Chude for his guidance throughout the course of this work. His interest in my progress has been a source of joy and inspiration. I also wish to express my appreciation to my other supervisors, Dr. T. Kparmwang and Prof. J.J. Owonubi for the guidance and encouragement they gave me.

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ABSTRACT

Field studies were conducted over a two-year period (1993 to 1994) on an Ultisol at Samaru ($ll^{0}ll^{I}N$, 7°38'E) to evaluate the effect of phosphate rocks and organic waste on maize growth and nutrition. In 1993, the treatments consisted of factorial combinations of three sources of phosphorus (single superphosphate, Sokoto phosphate rock and Togo phosphate rock), three rates of phosphorus (0, 30 and 60kg P_2O_5/ha), and three types of organic amendments (100% cowdung, 50% cowdung + 50% maize cob waste, and 100% maize cob waste) applied at 5t/ha. The treatment combinations were laid out in a split-plot design and cropped to maize. In 1994 the same plots were re-cropped to maize to test the residual effect of the treatments applied in 1993.

Maize performance was better with the application of phosphorus and oryanic amendment irrespective of the source. The 30kg P_2O_5/ha rate appears to be the optimum when inorganic phosphorus was applied with the organic amendments. In both years agronomic effectiveness of the P sources was in the order single superphosphate > Togo phosphate rock > Sokoto phosphate rock. The agronomic effectiveness of the phosphate rocks relative to single superphosphate was higher in the second year, indicating the high residual value of phosphate rocks.

Plant concentration of P and Ca were higher at higher P rates in both years. In 1993, P and Ca contents of the index leaves were significantly higher with single superphosphate than with the phosphate rocks which were statistically at par. However, in 1994 the differences in plant content of P and Ca between single superphosphate and Togo phosphate rock were not significant.

In both years, significantly higher P concentration was observed in the index leaves with the application of 100% maize cob waste than with 100% cowdung or 50% cowdung + 50% maize cob waste.

It was concluded that the application of organic waste reduced the inorganic phosphate fertilizer requirement of the crop.

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CHAPTER ONE

INTRODUCTION

Population pressure coupled with the rising energy costs and worldwide inflation has taxed heavily the ability of farmers to meet human food requirements. In sub-Saharan Africa, the per capita food production has actually declined in the last few decades (Brady, 1984). The proper management of soils therefore becomes more crucial in meeting human food requirement as population pressure increases.

Phosphorus deficiency is a major soil factor that limits food production in the humid and semi-arid tropics where most of the soil phosphorus is in forms that are unavailable to plants (Sanchez, 1976). The parent materials of most Nigerian soils are poor in apatite-bearing rocks, therefore the soils developed from them are low in native phosphorus (Anonymous, 1989). Udo and Ogunwale (1977) determined the total, organic and various inorganic forms of phosphorus in six Nigerian soil profiles and found the total P content to be low in most samples. They found a large fraction of the inorganic phosphorus in non-extractable or residual form especially in soils from the savanna zone. The high percentage of occluded and residual P and the low level of active P indicate a high degree of weathering and low P status of these soils. According to Sanchez (1976), when soluble sources of this element are supplied to the soils in the form of fertilizers, their phosphorus is often rendered "fixed" or unavailable even under the most ideal field conditions.

The Nigerian government spends million of dollars in foreign exchange annually to import single superphosphate and other phosphorus fertilizer materials, and later subsidises them to the farmers. Due to the drastic fall in the value of the Naira within the last few years and the usually low resources of the Nigerian farmers,

the local sourcing of cheaper P fertilizer materials has become imperative. Nigeria has phosphate rock deposits which could be useful for direct application as ground phosphate rock or partially acidulated material and may supply phosphorus at lower unit price than the single superphosphate.

The direct application of phosphate rock to soils as a source of fertilizer phosphorus is a practice that has been employed in Europe and USA with varying degrees of popularity over the years. Numerous experiments have been conducted during the past hundred years to determine the most favourable soil and cropping conditions for its use (Khasawneh and Doll, 1978). Certain soil properties significantly affect the availability of P from phosphate rock. These include soil moisture, free $CaCo_3$, humus, biological activity and the soil P status (Bai-fan *et al.*, 1990; Welte, 1978; Khasawneh and Doll, 1978). According to Welte (1978), the soils with high hydrogen ion potential, such as acid humic and acid mineral soils, represent favourable prerequisite for an acid treatment of phosphate rock by nature. Further, high Co_2 pressure resulting from the respiration of micro-organisms and roots accelerates the solubilization of phosphate rock even on soils with neutral reaction. However, in tropical savanna soil of Nigeria having very low organic matter content and therefore low microbial activity, the rate of solubilization of applied phosphate rock is often very low (Lombin, 1979; Uyovbisere and Lombin, 1990).

The combined application of phosphate rock with organic waste can appreciably improve the solubilization of P from the phosphate rock through the effect of organic matter in increasing biological activity, production of humic and fulvic acids which attack the phosphate rock, and the chelating effect of humus (Ikerra *et al.*, 1994). In addition, the application of organic waste adds organic P to

the soil thereby reduces the inorganic P fertilizer requirement and cost of P fertilization. Omotoso (1971) found sharp yield increases with inorganic phosphate application only when the soil organic P content was low in cacao plantations.

In this study, two types of organic amendments, cowdung and ground maize cob, were individually and jointly applied to the plots treated separately with single superphosphate, Sokoto phosphate rock and Togo phosphate rock. The information generated from this study would lead to cutting down on the cost of P fertilization and therefore increase the profit margin of farmer.

The specific objectives of this study were:

(a) To evaluate the effect of phosphate rock and organic waste on the growth and yield of maize (*Zea mays* .):

(b) To identify the optimum rate of P from the various sources that meets the requirement of the test crop:

(c) To evaluate the residual effect of the various P sources: and

(d) To compare the performance of phosphate rocks with that of single superphosphate.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Phosphorus Status of Nigerian Savanna Soils

Research works by Enwezor and Moore (1966a), Adepetu (1970) and Adepetu and Corey (1975) showed that the total phosphorus content in South-western Nigerian soils are lower in the savanna grasslands than in the rainforest. Goldworthy and Heathcote (1963) and Enwezor and Moore (1966b) reported the total P content of surface Savanna soils to vary from 80 to 150 mg/kg. In 334 topsoil samples from the Savanna, Jones and Wild (1975) reported total P content to range between 13 to 630 mg/kg with a mean of 143 mg/kg. These low values of P suggest widespread P deficiency in the region. The total P content seem to be influenced by parent rock, vegetation and cropping history. Uzu *et al.* (1975) reported higher total P for soils on basement complex than soils on sedimentary materials.

Organic phosphorus accounts for less than half of the total P in Nigerian savanna soils. Goldsworthy and Heathcote (1963) reported 36% of the total P in 54 savanna soils to be in organic form, Enwezor and Moore (1966) recorded 25% for 4 soils, while Ipinmidum (1972) found 39% for 12 selected savanna soils. This low levels of organic P is expected in view of the low level of organic matter in the soils of this region.

The magnitude of occurrence of various inorganic P fractions in Nigerian soils follow the order: Occluded-P > Iron-P > Aluminium-P > Calcium-P (Bates and Baker, 1960; Enwezor and Moore, 1966a. The chemical stage of weathering

determines the inorganic P form present in a soil. The proportion of iron-bonded P increases with weathering whereas that of Calcium-bonded P decreases under similar conditions. According to Lindsay and Vlek (1977) the transformation of one form of phosphate into another is mainly controlled by pH. Kamprath (1973) reported that the activity of Fe and Al increases with soil acidity and the relatively soluble Ca-bonded phosphates are converted into less soluble Fe and Al phosphates. Most of the soil inorganic P in Nigerian soils are found associated with Fe and Al minerals. Adepetu and Corey (1975) reported that most of the mineralized-P as well as any added P (fertilizer) was converted to Fe-P and Al-P. Also Udo and Uzu (1972) showed that over 80% of the added P was recovered as Fe-P and Al-P.

2.2 Reactions of Added Phosphate in Soils

When phosphatic fertilizers are applied to the soil and are dissolved by soil water, reactions occur among the phosphate, soil constituents and the non-phosphatic fertilizer compounds which remove P from the soil solution phase and render the phosphate less soluble (Sample *et al.*, 1980; Brady, 1984). This phenomenon is called phosphorus fixation or retention. Phosphorus could be retained by hydrous oxides of Fe, Al, Mn, and by Al, Fe and Mn ions; aluminosilicates; soil carbonates; and soil organic matter.

Hydrous oxides of Al and Fe retain large amounts of phosphate from the soil solution. According to Wild (1950), these compounds account for much of the P retention by acid soils. The quantity of phosphate fixed by hydrous oxides of Al and Fe in acid soil quite exceeds that due to precipitation by soluble Fe, Al and Mn cations. In savanna soils most of the P added to the soil is absorbed to Al initially,

although some Fe linkages are formed especially where the soil is acidic (Dabin, 1970).

Enwezor and Moore (1966b) found P adsorption to be related to clay content in four savanna soil profiles. This was also demonstrated by Udo and Uzu (1972), who showed that in some soils from eastern and western Nigerian, sorption was positively and significantly correlated with the clay content and exchangeable Fe and Al, and negatively and significantly with pH.

In calcareous soils, the added phosphate is precipitated by Ca and Mg as relatively insoluble compounds (Sanchez, 1976; Sample *et al.*, 1980).

There is evidence that organic matter can fix added phosphorus in the soil by forming complexes in association with cations such as Fe^{3+}, Al^{3+} and Ca^{2+} (Wild, 1950; Wier and Soper, 1963; Hinga, 1973; Holford and Mattingly, 1975). However most of the reactions of added phosphates with organic matter in the soil results in higher P concentration in the soil solution. Additions of organic matter, particularly to calcareous soils, reportedly increase phosphate solubility with time more than single additions of inorganic phosphate (O'Connor *et al.*, 1986; Meek *et al.*, 1979; Abbot and Tucker, 1973). Some breakdown products of organic matter have been found to reduce P retention in soils. Andrew (1985) found P sorption to be strongly inhibited by organic acid.

2.3 Mineralogy of Phosphate Rock

Phosphate rock or phosphorite is essentially a trade name covering a wide variety of rock types having diverse mineralogical composition and texture (McClellan, 1978).

Phosphate bearing minerals occur in all geologic settings - sedimentary,

metamorphic and igneous deposits. According to Khasawneh and Doll (1978) the sedimentary deposits are economically the most important of the three; with nearly 85% of the phosphate rock mined worldwide coming from such deposits. According to them, the physical and chemical characteristics of igneous and metamorphic rocks render them quite unreactive and nearly inert for direct application. They are coarsely crystalline substances and do not possess internal surfaces. On the other hand, sedimentary phosphate rocks are microcrystalline in nature, and consist of fairly open loosely consolidated aggregates of microcrystals in the form of laminae, pallets, oolites, nudules and skeletal shell fragments with relatively large specific surface area (Melellan, 1978; Khasawneh and Doll, 1978).

McClellan and Gremillion (1980) classified the phosphate rocks according to their mineralogical composition into three types. In order of increasing economic importance, they are Fe-Al phosphates, Ca-Fe-Al phosphates and Ca-phosphates. The most common minerals in the first class are wavellite $\{Al_3(PO_4)_2(OH)_3 5H_2O\}$, variscite $(AlPO_4 2H_2O)$, and strengite $(FePO_4 2H_2O)$. Economically significant deposits are found in Senegal, Liberia, and Brazil (Khasawneh and Doll, 1978; McClellan, 1978).

The second class comprises of an intermediate group of ores of widely varying composition. The principal minerals are crandallite $\{CaAl(PO_4)_2(OH)_5 H_2O\}$ and millisite $\{(Na, K) CaAl_6(PO_4)_4(OH)_9 3H_2O\}$(McClellan, 1978).

The third class also known as apatitic minerals are distinguished by their common crystal structure which is exemplified by fluorapatite $\{Ca_{10}(PO_4)_6 F_2\}$. Apatites exhibit a rather wide range of chemical composition, which causes a corresponding wide range in properties, and which is attributed to extensive isomorphous substitution in the apatitic crystal lattice (Khasawneh and Doll, 1978).

Apatitic rocks are characterized by a high degree of isomorphous substitution in the basic fluorapatite structure, with true stoichiometric fluorapatite being exceptionally rare (Lehr, 1967; McClellan and Lehr, 1969). They reported partial substitution of nearly all the ionic components in the fluorapatite structure: Ca^{2+} is mostly substituted for by Mg^{2+} and Na^{+}, and to a lesser extent by Sr^{2+}, Mn^{2+}, K^{+} and Fe. The phosphate tetrahedra are replaced mostly by carbonates and to a lesser extent by sulphate and silicates. The F^{-} ion is replaced by OH^{-} and Cl^{-}.

2.4 Factors Affecting Agronomic Efficiency of Phosphate Rock

According to Davies (1970) and Welte (1978), the value of phosphate rock for direct application is influenced by a number of factors - those concerned with the material itself (sources of rock), fineness of grinding; and those related to the land on which it is applied, i.e. soil type, soil reaction, free $CaCo_3$, phosphate status of the soil, humus, biological activity, soil moisture and the crops to be grown.

2.4.1 Soil factors

2.5.1.1 Soil reaction

The agronomic effectiveness of phosphate rock is higher on acid than on neutral or alkaline soils (Peaslee *et al.*, 1962; Ensminger *et al.*, 1967). Over the years, soil acidity has been considered the single most important factor responsible for enhanced availability of phosphorus from phosphate rock materials.

Soils with high H^{+}-potential, such as acid humic and acid mineral soils, represent favourable prerequisite for an acid treatment of phosphate rock by nature (Welte, 1978). In co-ordinated experiments between 1941 and 1956 in United

Kingdom. Cooke (1978) reported Gafsa phosphate rock to be nearly as effective as superphosphate for swedes and turnips grown on soils with pH values below 6.5.

According to Khasawneh and Doll (1978) francolite-type apatites are quite unstable at low pH levels, and they release phosphorus to react with Al and Fe in the soil matrix and form Al and Fe compounds which are more stable than apatites at lower pH levels.

Greenhouse experiments by Ellis *et al.* (1955) showed that liming decreased the availability of phosphorus from phosphate rock materials. When phosphate rock was applied one month prior to liming to pH 7, oats growth was better and P uptake was higher than when the order was reversed (Ellis *et al.*, 1955). Peaslee *et al.* (1962) also found that the availability of P in phosphate rock to sorghum grown on 19 soils decreased drastically with increasing soil pH, reaching nearly zero for soils with pH higher than 6.5.

2.4.1.2 Soil calcium

Soils affinity for Ca promotes the dissolution of phosphate rock because it provides a sink for the Ca that is released by the congruous dissolution of apatite (Khasawneh and Doll, 1978). Graham (1955) and Howe and Graham (1957) showed that the bonding energies for Ca in clay suspensions and in cation exchange resins were important factors in phosphate rock dissolution.

Work by Khasawneh and Engelstad (1975) on the effect of pH in submerged rice soils proved that a soil's affinity for Ca is a significant factor which enhances phosphate rock dissolution and the availability of it's P to plants. According to Welte (1978), on soils where the soil solution is rich in Ca-ions or free $CaCO_3$ prevails, phosphate rock does not react very effectively. The high Ca-potential reduces the

solubility, especially when CO_2 partial pressure is low as is often the case in cultivated fields.

2.4.1.3 Soil phosphorus

Similar to Ca, the level of P in the soil as expressed by the activity of phosphates, plays a role in the dissolution of phosphate rock. According to Khasawneh and Doll (1978), the soil matrix should provide a positive gradient in the electrochemical potential of both Ca^{2+} and phosphates to ensure the congruous dissolution of phosphate rock. The practical implication of this is that moderately fertile soils with relatively high soil solution concentration of P can derive little or no benefit from additions of phosphate rock.

The value of phosphate rock as an effective P fertilizer is limited to soils that are severely or moderately deficient in P, it has little or no value in soils of medium to high P status (Khasawneh and Doll, 1978; Bai-fan *et al.*, 1990).

2.4.1.4 Soil biological activity

According to Welte (1978), the higher the biological activity in soils of neutral or alkaline reaction and the more the content of convertible organic matter, the greater the probability that phosphate rock will show the same effectiveness as the highly soluble phosphate. This phenomenon may be explained by the very intensive metabolic processes in the soil as well as in the roots which result in the high production of carbon dioxide, organic acids, and chelates and the conversion of phosphorus from mineral into organic forms.

Many mycorrhizal fungal species when present enhance the plant uptake of P from phosphate rock. Dieldriehs (1991) and Eivazi and Weir (1989) found P uptake and yield of maize to be significantly enhanced when phosphate rock was applied to soils treated with different species of mycorrhizal fungi.

2.4.2 Plant factors

Experiments have confirmed differences among crops in their ability to derive P and Ca from phosphate rock. McClean (1956) reported that phosphate rock was not very effective for oats and lucerne but proved better for buckwheat. Edwards (1956) found that brassica crops responded well to phosphate rock, while potatoes did not. Cooke and Widdowson (1959) showed that swedes were quite responsive to P grass only moderately, and potatoes poorly so. Bottini (1958) stated that phosphate rock was better for legumes than cereals. Robertson and Hutton (1958) put several crops in order of their efficiencies of utilization of phosphate rock. They reported maize to utilize phosphate rock 82% as effective as superphosphate while peanuts, sorghum and oats were 88%, 64% and 80% as effective respectively.

Difference among crops must be related to their demand patterns for both Ca and P, and to how these demand patterns alter the composition of the soil solution at the root-soil interface (Khasawneh and Doll, 1978). Cooke (1956) postulated that crops with well-developed fibrous roots are best suited to utilize P from phosphate rock. Different crops species have different rooting habits, which are largely genetically determined, but can be significantly altered by subsoil pH, subsoil compactness, drainage, and pathological agents. Mycorrhizal associations are yet another aspect of how the extensity of root ramification into the soil can be altered

in such a way as to avail the root system of a larger probability of contacting or being physically close to phosphate rock particles so that it can derive more of its P from phosphate rock (Khasawneh and Copeland, 1973; Newman and Andrews, 1973; Khasawneh and Doll, 1978).

2.4.3 Phosphate rock factors

2.4.3.1 Reactivity of phosphate rock

Phosphate rock deposits differ in physical texture; mineral forms in which the P occurs and the nature and abundance of impurities. In studies of more than 300 rock samples from a collection of about 500 samples worldwide, Tennessee Valley Authority (TVA) scientists have found no two samples identical in physical and mineralogical properties (Young and Davies, 1970). These differences account for why some phosphate rocks produce good response when applied directly to soil while others do not. According to Young and Davies (1970), the extent to which the basic mineral has been altered by substitution of other chemical elements in its structure determines the efficiency of the phosphate rock as a direct fertilizer. Ores which contain apatite mineral with a high degree of chemical substitution are sufficiently soluble to supply phosphorus to some crops. Davies (1970) reported an increase in phosphate rock reactivity with increased carbonate content and a decrease in reactivity with increased fluorine content. In pot tests with pine seedlings, rice and maize, Young and Davies (1970) reported rocks with the greatest substitution to be almost equal to superphosphate in supplying phosphorus to these crops on some soils.

2.4.3.2 Fineness of grinding

Due to the extremely low solubility of phosphate rock, it reacts with acid components of soil to release P only in the immediate vicinity of the rock particles (Khasawneh and Doll, 1978). Consequently, the greater the degree of contact between phosphate rock and soil, the better is crop utilization of P in phosphate rock. According to Davies (1970), Khasawneh and Doll (1978), and Bai-fan *et al.* (1990), rock phosphate should be ground so that 80-90% will pass through a 100-mesh sieve. They found phosphate rock effectiveness to decline with increasing particle size for materials coarser than 100-mesh size, whereas for sizes less than 100-mesh the particle size effect was virtually non-existent.

2.5 Residual Effect of Phosphate Rock

Phosphate rock has been shown to persist in some soils for at least 40 years (Khasawneh and Doll, 1978). Therefore the residual effects of phosphate rock are of considerable practical interest.

Engelstad *et al.* (1974) evaluated the residual effects of various rates of both superphosphate and several sources of phosphate rock applied to rice by growing a second crop of rice without added P. They concluded that the general superiority of superphosphate (fresh and residual) over all sources of phosphate rock persisted through the second cropping. However, the residual effects of most phosphate rocks were substantial. McClean (1956), after two crops following single dressing, found that rock phosphate was very nearly as good as superphosphate. Almeida and Balbino (1960) worked with wheat grown in a ferrallitic soil of pH 5.6; in the first year superphosphate was superior to rock phosphate but in the second year an

increased yield was obtained from rock phosphate but not from superphosphate. Jackson and Burton (1960) found that after four years the residual value from rock phosphate was greater than that from superphosphate.

From experimental studies carried out (Khasawneh and Doll, 1978; Davies, 1970; Jackson and Burton, 1960), it appears that the residual effects of soluble P fertilizers are greater than those from phosphate rock in the first 3 to 4 years after application when equal amounts of P are applied.

2.6 The Effect of Manuring on Plant Availability of Phosphorus from Inorganic Sources

It has often been suggested that decomposing organic matter exerts a solvent action on inorganic phosphate fertilizers and as a result increases their availability to plants (Rogers *et al.*, 1953). Copeland and Merkle (1942) and Gerretson (1948) observed that organic matter increased the availability of rock phosphate added to the soil as fertilizer. Similar results were reported by Williams *et al.* (1963) and Widdowson and Penny (1968). Ikerra *et al.* (1994) reported that when phosphatic fertilizers were added to soils after pre-mixing with farmyard manure, the availability of phosphorus to plants was markedly better than when these materials were applied separately. Sharif and Chaudhry (1966) reported 30 to 40% higher available P by pre-mixing 22 mg/kg P as concentrated superphosphate and 44 metric tones per hectare of farmyard manure. El-Baruni and Olsen (1979) observed higher soluble P when manure and inorganic P were mixed than when added separately.

The effect of organic matter in making phosphorus from inorganic sources available is related to the action of micro-organisms in decomposing organic matter and producing organic acids which solubilize phosphorus from inorganic sources and

also form stable complex molecules with iron and aluminium which are responsible for phosphorus retention in acid soils (Dean and Rubins, 1947; Struthers and Sieling, 1950; and El-Harun and Olsen, 1979).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location

The field trial was carried out on the Institute for Agricultural Researeh (IAR) farm located in Samaru (latitude 11°11'N and longitude 7°38'E). The area has a mean annual rainfall of about 1050mm stretching from May to September (Kowal and Knabe, 1972). The soil was classified as oxic haplustult following Soil Taxonomy System (USDA Soil Survey Staff, 1975), and is formed on drift material overlaying basement complex (Klinkenberg and Higgins, 1968).

3.2 First Cropping (1993)

3.2.1 Design and treatment

The treatments comprised of three sources of phosphorus at three rates with three sources of organic matter at 5t/ha (air dry) to aid solubilization of the added phosphate.

The phosphorus sources were: single superphosphate (SSP), Togo phosphate rock (TPR) and Sokoto phosphate rock (SPR) applied at the rates of 0, 30 and 60 kg P_2O_5/ha. The organic manure sources comprised of 100% cowdung (CD), 50% cowdung + 50% ground maize cob waste (CD/MC), and 100% ground maize cob waste (MC). The maize cob waste was ground to pass through a 40 mesh sieve. All the organic amendments were applied to the soil four weeks before planting to allow decomposition. The phosphate rocks were in the raw unacidulated form, ground to pass through a 100-mesh sieve.

There were twenty-seven factorial combinations of the treatments and one absolute control allocated in split-plot design and replicated three times with organic amendment as the main factor and phosphorus source and rate as subfactors. The plots were cropped to maize (*Zea mays* L.).

3.2.2 Sources and amounts of fertilizers used

Urea was uniformly applied to the plots at the rate of 120kg N/ha in two split-doses, one at planting and the other six weeks later. Muriate of potash was applied at planting at the rate of 30 kg K_2O/ha. Phosphorus application was according to treatment requirement.

3.2.3 Records and agronomic measurements

Beginning from four weeks after planting (WAP, plant height was measured fortnightly using a staff rod. Days to 50% silking were recorded for each plot and index leaves were sampled at this period for laboratory analysis. After harvest the following observations were taken:

(a) Cob length

(b) Cob diameter (middle of the cob)

(c) Number of grains per cob

(d) Grain yield per hectare

(e) 1000-grain weight

(f) Kernel bulk density

(g) Stover yield per hectare

Relative agronomic efficiency (RAE) of the phosphate rocks was calculated using the formula of Reinhorn *et al.* (1978) as follows:

$$\frac{YR - Yc}{Ys - Yc} \times 100$$

where YR, Ys and Yc are yields obtained with phosphate rock, superphosphate and the control respectively.

3.2.4 Laboratory analysis

3.2.4.1 Soil sampling and preparation

Composite surface (0-15cm) samples were taken from the entire field before allocating the treatments and from each each plot after the harvest. The soil samples were air-dried on trays in the greenhouse. After drying, the clods were broken using pestle and mortar and the ground soil sieved through 2mm-mesh sieve. The sieved samples were stored in polythene bags for routine physical and chemical analysis.

3.2.4.2 Soil analysis

Particle-size analysis was carried out by the hydrometer method (Day, 1965). Soil pH was determined in 1:2.5 soil: water suspension with a glass electrode pH-meter. Organic carbon was determined by the wet-oxidation method of Walkley-Black as described by Allison (1965). Exchangeable acidity was determined by shaking the soil with 1N KCl and titrating with 0.5N NaOh (Juo, 1979). Exchangeable bases were displaced with 1N NH_4OAc buffered at pH 7.0. Potassium and sodium in the extract were determined by flame photometry while Ca and Mg were determined by atomic absorption spectrophotometry. Effective cation exchange capacity was calculated by the summation of exchangeable bases and exchange acidity. Available phosphorus was determined by the Bray-I method. Total N was determined by macro-Kjeldahl procedure described by Bremner (1965).

Copper, manganese, zinc and iron were extracted with 0.1 N HCl and determined on the atomic absorption spectrophotometer.

3.2.4.3 Plant tissue analysis

A 0.5g sample of plant material was weighed into 125ml erlenmeyer flask and digested with an acid mixture of 4.0ml perchloric acid, 32.5ml nitric acid and 1ml sulphuric acid. Potassium in the diluted digest was determined by flame photometry, while Ca, Mg, Fe, Mn, Zn and Cu were determined by atomic absorption spectrophotometry. Phosphorus digest was determined calorimetrically by the vanadomolybdate method (Juo, 1979). Nitrogen in plant tissue was determined by the micro-Kjeldahl method outlined by Bremner (1965).

3.3 Second Cropping (1994)

The plots were cropped again in the 1994 season to test the residual effects of the treatments applied during the previous year. Nitrogen and potassium fertilizers were applied to the plots as in the first cropping season. Soil and plant tissue sampling, preparation and analysis were as in the first year.

3.4 Statistical Analysis

All the data collected were subjected to analysis of variance (ANOVA) using the GENSTAT V (1980) package for statistical analysis.

CHAPTER FOUR

RESULTS

4.1 Physical and Chemical Properties of the Soil and Organic Materials Used

Table 1 shows the physical and chemical properties of the soil from the experimental site at the commencement of experiment. The soil was dominated by sand separate. It is slightly acidic, and low in organic carbon, total nitrogen and available phosphorus. The effective cation exchange capacity (ECEC) was also low, being 3.51 cmol/kg soil. This low level of ECEC may be due to the low organic matter content of the soil and the dominance of sand-size particles. Typical of savanna soils, the exchangeable bases and micronutrient contents of this soil were low.

The percentage base saturation on ECEC was 90.09 indicating that the exchange complex of this soils is saturated with cations. The exchangeable Ca/Mg ratio was 4.75 which does not exceed the critical value of 5.0 (Horvath and Todd, 1968). The exchangeable Mg/K ratio was 1.57, this is lower than the critical Mg/K ratio of 2.0 to 2.5 suggested by Pratt *et al.* (1957) as such, there seems to be some slight imbalance between exchangeable Mg and K in this soil.

Nutrient element concentration of the organic materials used for the trial are shown in Table 2. Cowdung has high concentrations of N, Mg, K, Fe, Mn, Cu and Zn while maize cob has higher concentrations of C, Ca, and P. The nutrient levels in the maize cob are comparable to the levels reported by Rierra *et al.* (1991) and Omojola (1993).

Table 1: Some physico-chemical properties of the soil used.

Parameters	Values
Sand (gkg^{-1})	720.0
Silt (gkg^{-1})	120.0
Clay (gkg^{-1})	160.0
Texture	Sandy loam
pH 1:2.5 w/vH_20	5.2
Organic carbon gkg^{-1}	6.0
Total N gkg^{-1}	0.30
C:N ratio	20.0
Bray-1 P ($mgkg^{-1}$)	4.2
ECEC ($cmol/kg^{-1}$)	3.51
Exchangeable Ca ($cmol/kg^{-1}$)	2.00
Exchangeable Mg ($cmol/kg^{-1}$)	0.42
Exchangeable Na ($cmol/kg^{-1}$)	0.47
Exchangeable K ($cmol/kg^{-1}$)	0.27
Base saturation (%)	90.09
Ca/Mg ratio	4.75
Mg/k ratio	10.57
Fe ($mgkg^{-1}$)	80.0
Mn ($mgkg^{-1}$)	65.0
Cu ($mgkg^{-1}$)	1.10
Zn ($mgkg^{-1}$)	21.50

Table 2: Nutrient contents of organic materials used.

Nutrient	Cowdung	Maize cob
Total N gkg^{-1}	38.0	10.6
Total P gkg^{-1}	3.8	9.0
Carbon gkg^{-1}	209.7	796.0
C/N ratio	5.52	75.09
C/P ratio	55.55	88.44
Ca gkg^{-1}	9.60	20.0
Mg gkg^{-1}	4.20	0.50
K gkg^{-1}	12.90	6.0
Na gkg^{-1}	0.4	0.30
Mn ($mgkg^{-1}$)	380	250
Cu ($mgkg^{-1}$)	38	10
Zn ($mgkg^{-1}$)	105	86
Fe ($mgkg^{-1}$)	2850	1000

4.2 Effect of Phosphorus Source and Organic Amendment on Maize Performance

4.2.1 Plant height

In both 1993 and 1994, single superphosphate produced significantly taller plants than the Togo phosphate rock and Sokoto phosphate rock at all periods of growth (Table 3). The differences in plant height between TPR and SPR were not statistically significant during both years. All the three P sources produced significantly taller plants than the control.

Analysis of the combined data for 1993 and 1994 also revealed the same trend (Table 4). Relative agronomic efficiencies (RAE) of the phosphate rocks on plant height at various intervals of growth are shown in Table 5. Relative agronomic efficiency of 45.07 to 60.84% was observed with TPR in 1993, this improved to between 76.35 and 83.92% in 1994. For SPR, RAE ranged from 39.10 to 53.85% in 1993 and 71.90 to 80.35% in 1994. The higher RAE observed in the second year reflects the high residual value of phosphate rocks in the soil.

The effect of rate of phosphorus on plant height was not significant in 1993 (Table 6), however, in 1994 significantly taller plants were observed at higher P rates as from 6 WAP. Combined data analysis for the two years showed increased plant height at higher rates of P application, although differences in plant height between 30 kg P_2O_5/ha and 60kg P_2O_5/ha were not significant (Table 7).

Effect of the interaction between P source and rate on plant height was significant at all stages of growth in the first year and up to 10 WAP in the second year (Figures 1 to 6). Single superphosphate at 30 and at 60kg P_2O_5/ha produced taller plants.

Table 3: The effect of source of phosphorus on plant height.

Treatment	Plant height (cm)					
	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP
			1993			
Control	17.8	13.8	80.8	116.9	144.3	145.7
SSP	24.9	58.4	134.6	174.1	186.2	188.2
TRP	21.0	44.2	109.6	151.7	168.2	170.7
SRP	20.7	42.2	108.0	147.7	162.3	166.0
LSD (0.05)	1.86	5.10	8.45	11.60	7.55	7.59
			1994			
Control	14.3	25.7	39.4	53.1	73.9	76.7
SSP	28.0	55.3	87.6	120.0	128.1	128.6
TRP	26.3	48.3	76.4	104.6	118.1	118.9
SPR	25.3	47.5	74.1	101.2	116.8	118.4
LSD (0.05)	1.11	2.76	3.89	5.37	5.19	4.86

Table 4: The effect of source of phosphorus on plant height (pooled over years).

Treatment	Plant height (cm)					
	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP
Control	16.1	28.8	60.1	85.09	109.1	111.2
SSP	26.45	56.9	111.1	147.1	157.2	158.5
TRP	23.7	46.3	93.0	128.2	143.2	144.8
SRP	23.0	44.9	91.1	124.5	139.2	143.1
LSD (0.05)	2.17	5.81	9.27	12.86	9.13	8.84

Table 5: Relative agronomic efficiency of phosphate rocks on height at various intervals.

	1993		1994	
WAP	TRP	SPR	TRP	SPR
4	45.07	40.85	83.92	80.29
6	46.62	39.10	76.35	73.65
7	51.67	50.56	76.76	71.99
10	60.84	53.85	76.98	71.90
12	57.04	42.96	81.55	79.15
14	58.55	47.54	81.31	80.35

Table 6: Effect of rate of phosphorus application on plant height

	Plant height (cm)					
kgP_2O_5/ha	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP
			1993			
0	21.4	45.7	110.2	151.9	169.0	171.7
30	22.5	48.0	120.0	159.8	172.2	174.1
60	22.8	51.2	122.0	161.5	175.5	197.2
LSD (0.05)	NS	NS	NS	NS	NS	NS
			1994			
0	25.6	48.1	75.1	102.3	115.7	117.1
30	26.8	50.2	83.4	109.0	119.9	120.7
60	27.3	52.9	83.4	114.4	127.4	128.1
LSD (0.05)	NS	6.31	8.26	11.25	11.52	10.84

Table 7: Effect of rate phosphate application on plant height (pooled over years).

	Plant height (cm)					
Treatment	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP
0	23.5	46.9	92.6	127.1	142.4	144.4
30	24.7	49.1	99.8	134.4	146.1	147.4
60	25.0	52.0	102.7	138.2	151.4	153.7
LSD (0.05)	1.25	3.36	5.36	7.43	5.27	5.10

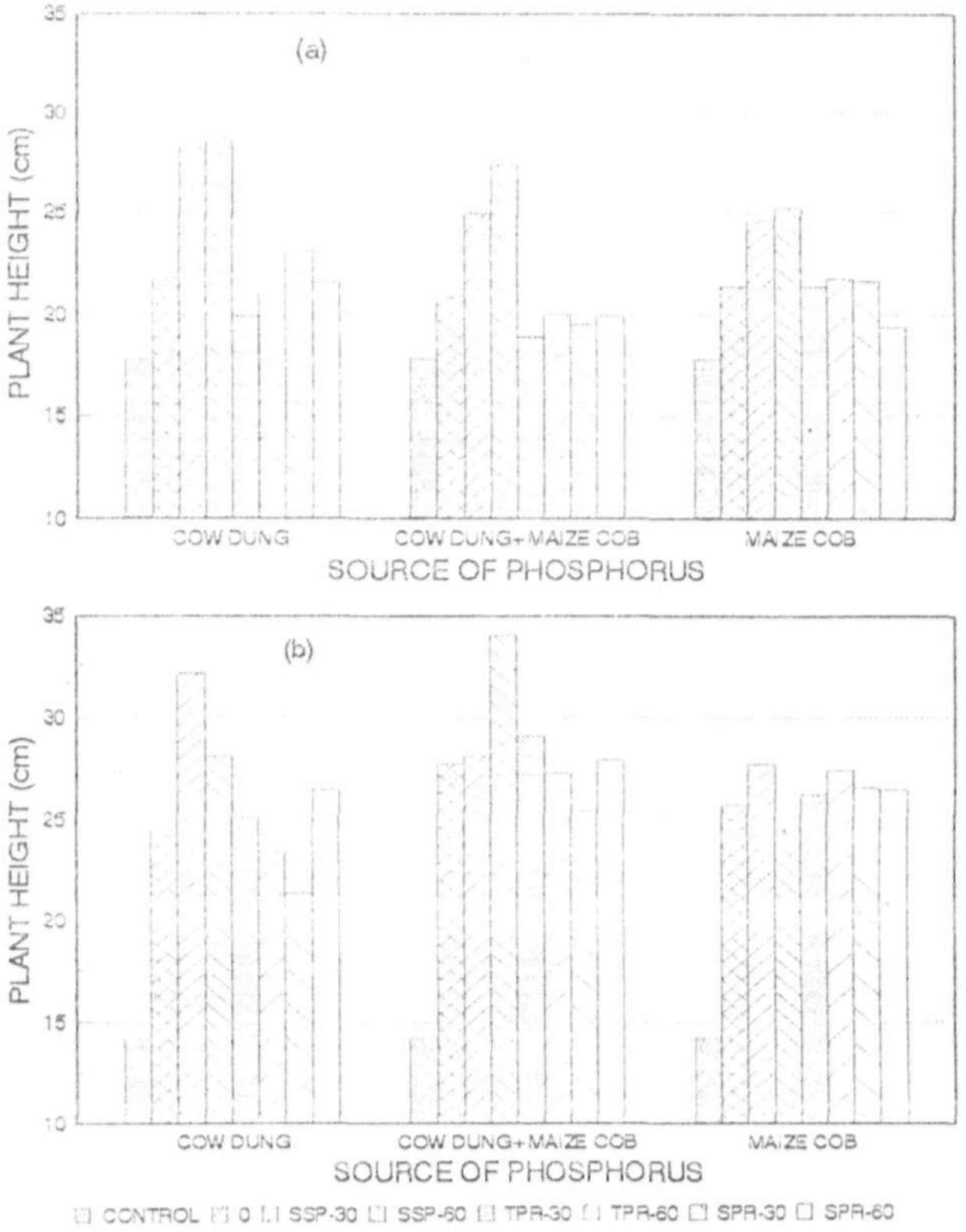


Fig. 1-The effect of P-Source and organic ammendments on plant height at 4WAP (a) 1993 (b) 1994.

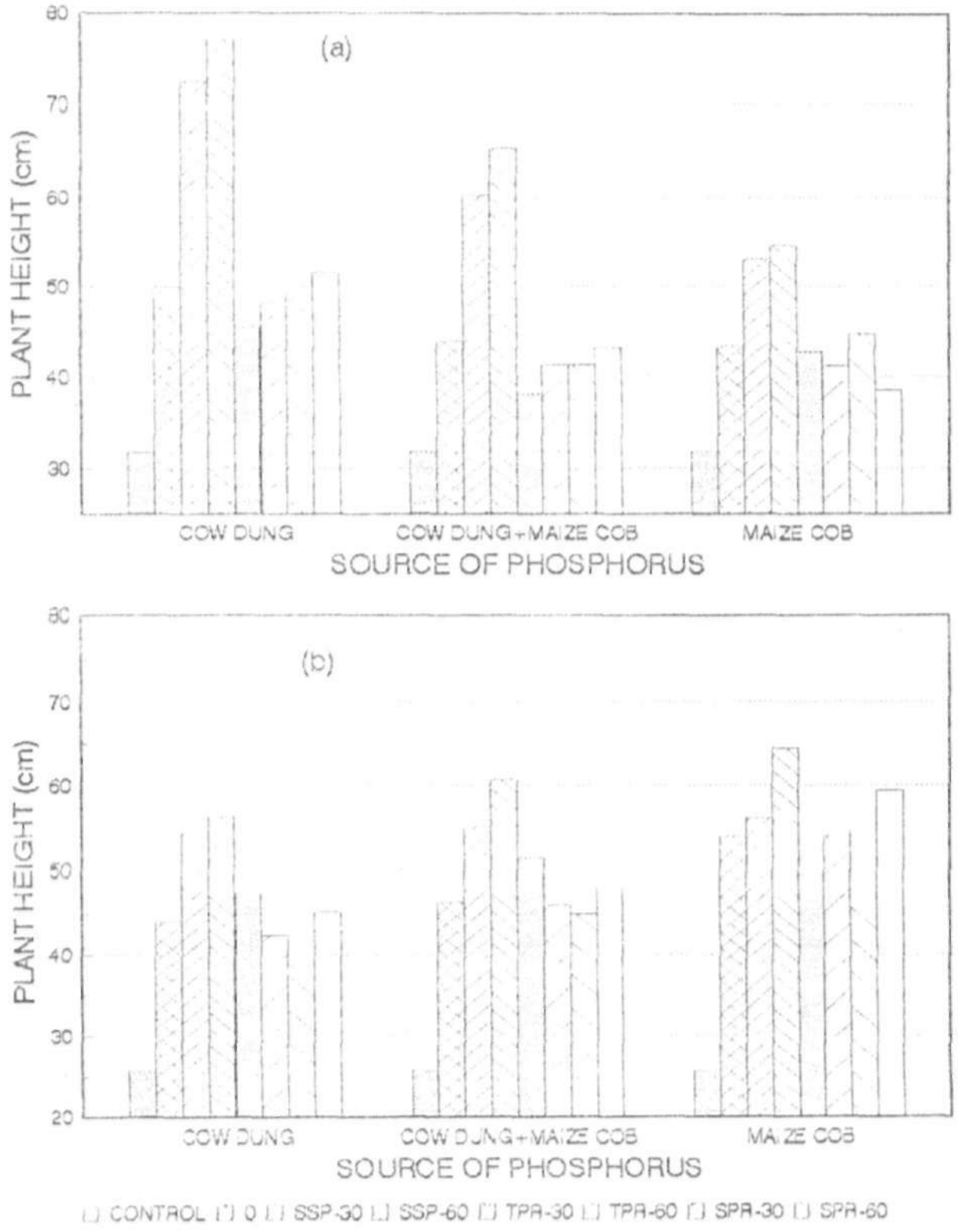


Fig.2-The efffect of P-Source and organic ammendments on plant height at 6WAP (a) 1993 (b) 1994.

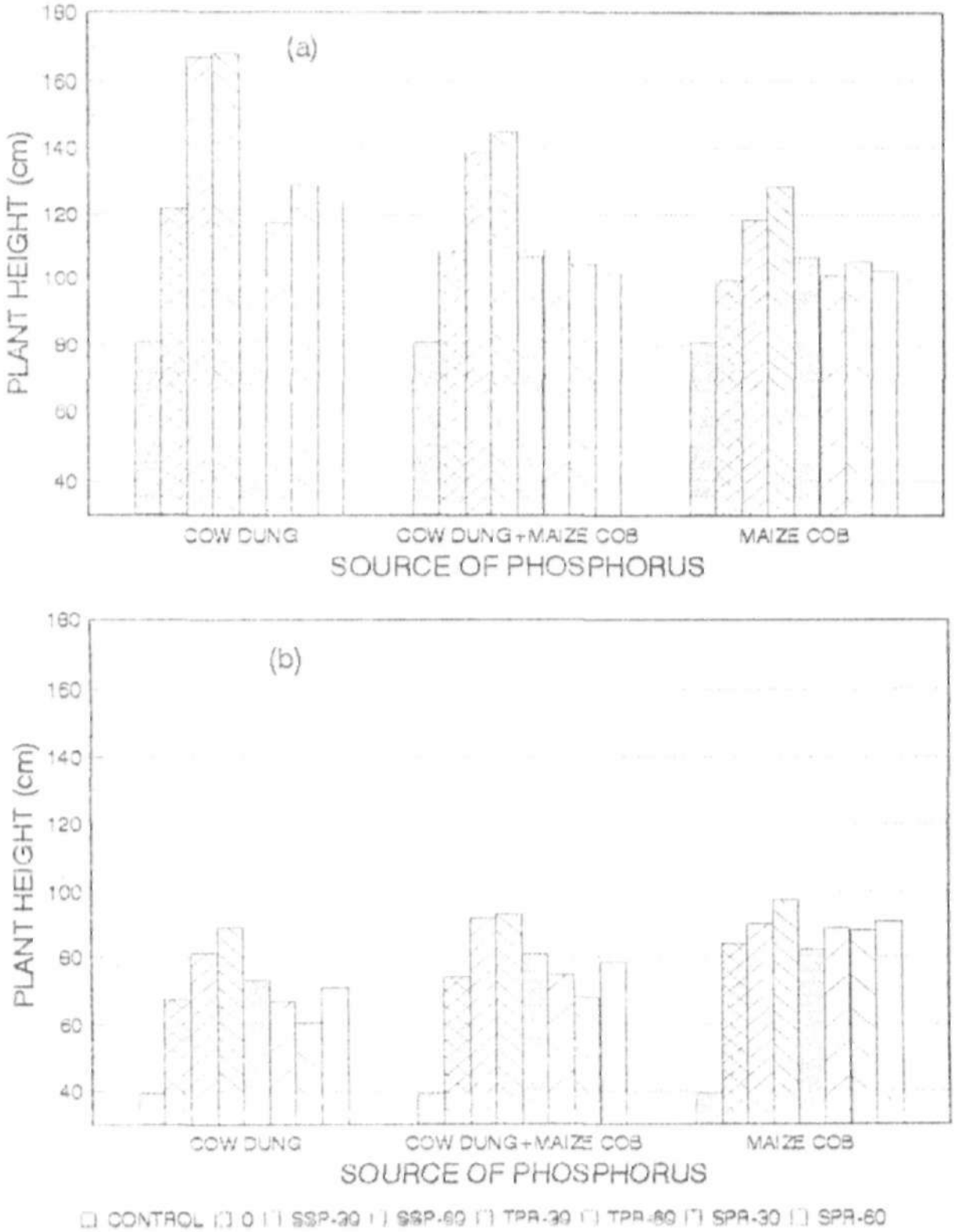


Fig.3-The effect of P-Source and organic ammendments on plant height at 8WAP (a) 1993 (b) 1994.

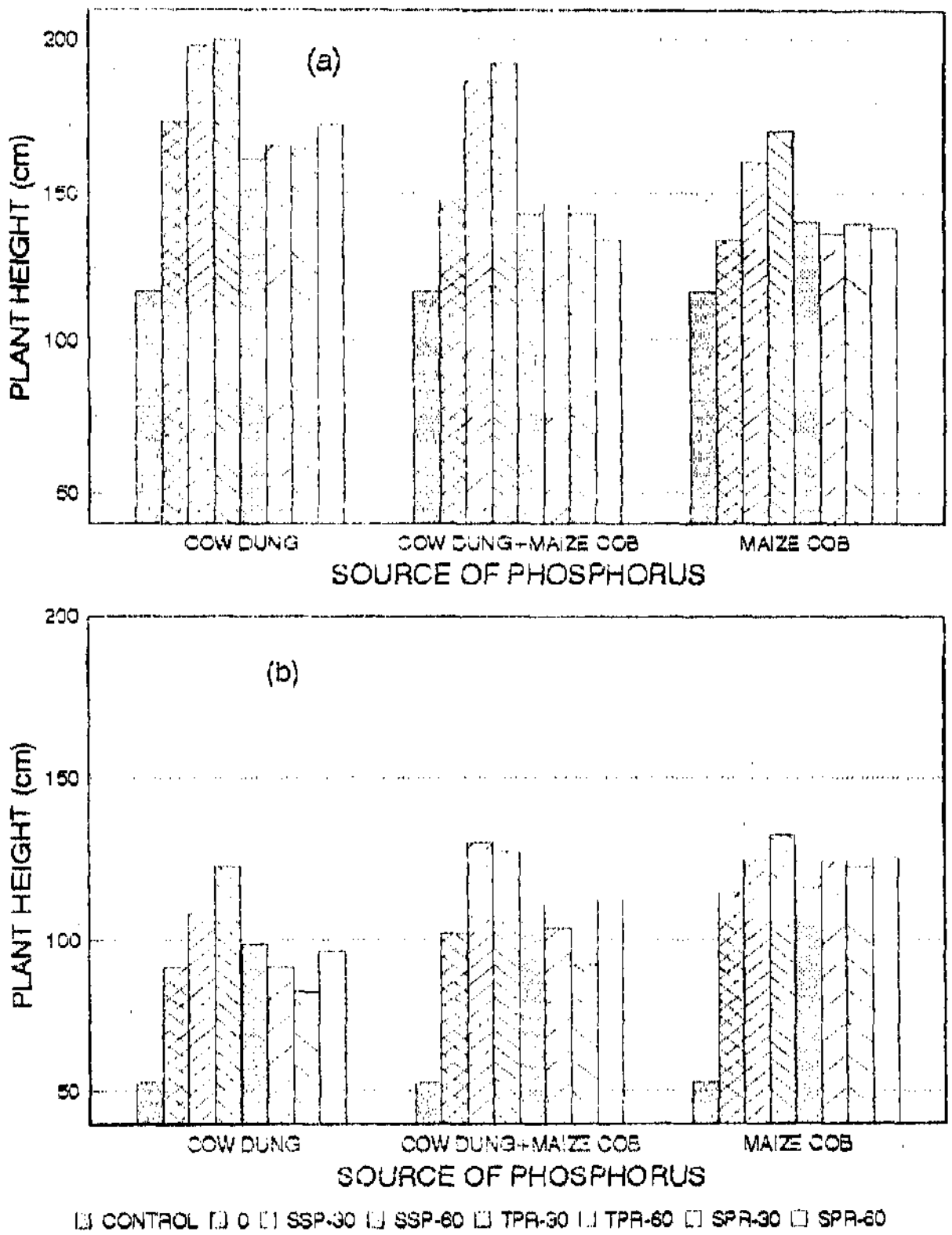


Fig.4- The effect of P-Source and organic ammendments on plant height at 10WAP (a) 1993 (b) 1994

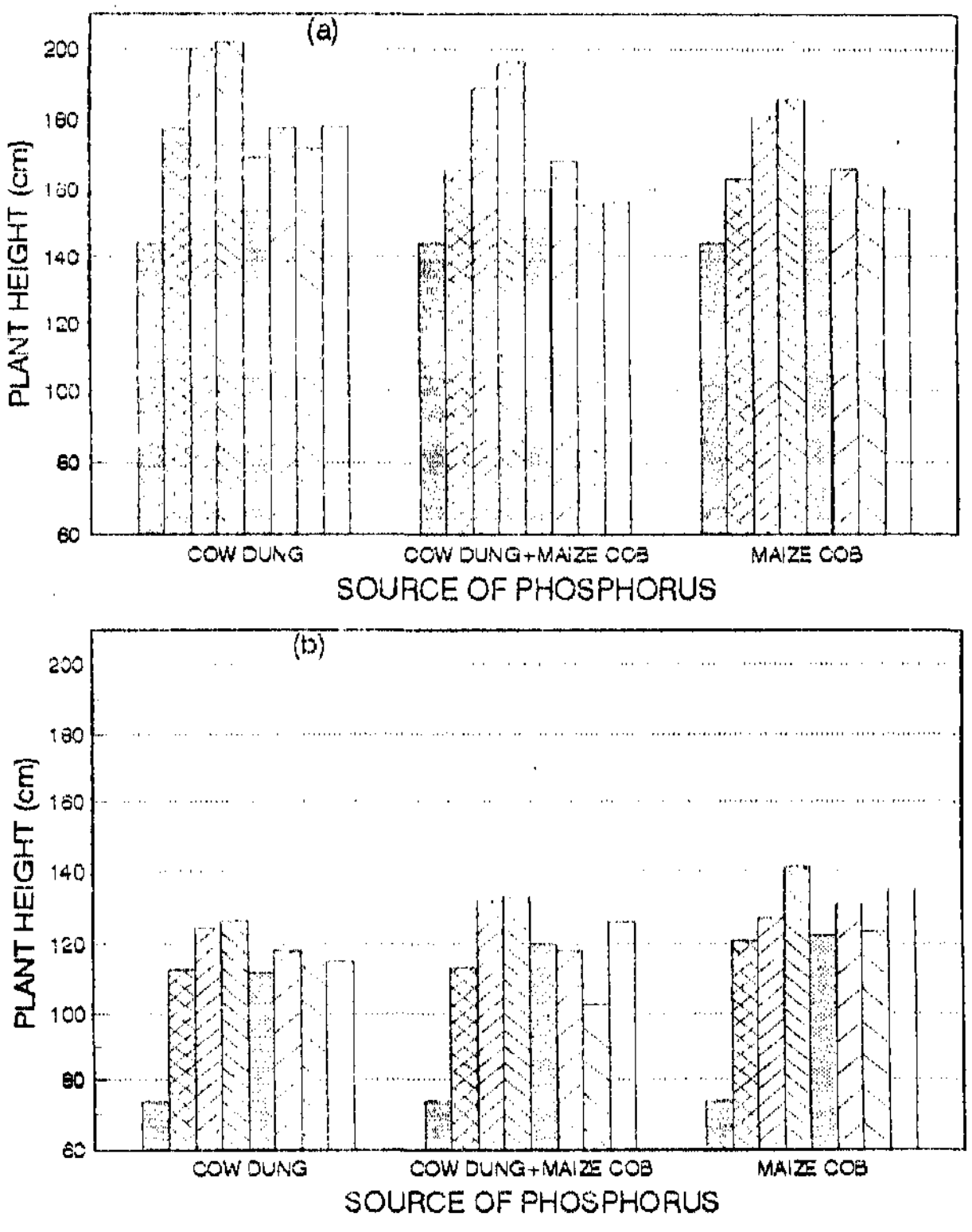


Fig.5- The effect of P-Source and organic ammendments on plant height at 12WAP (a) 1993 (b) 1994

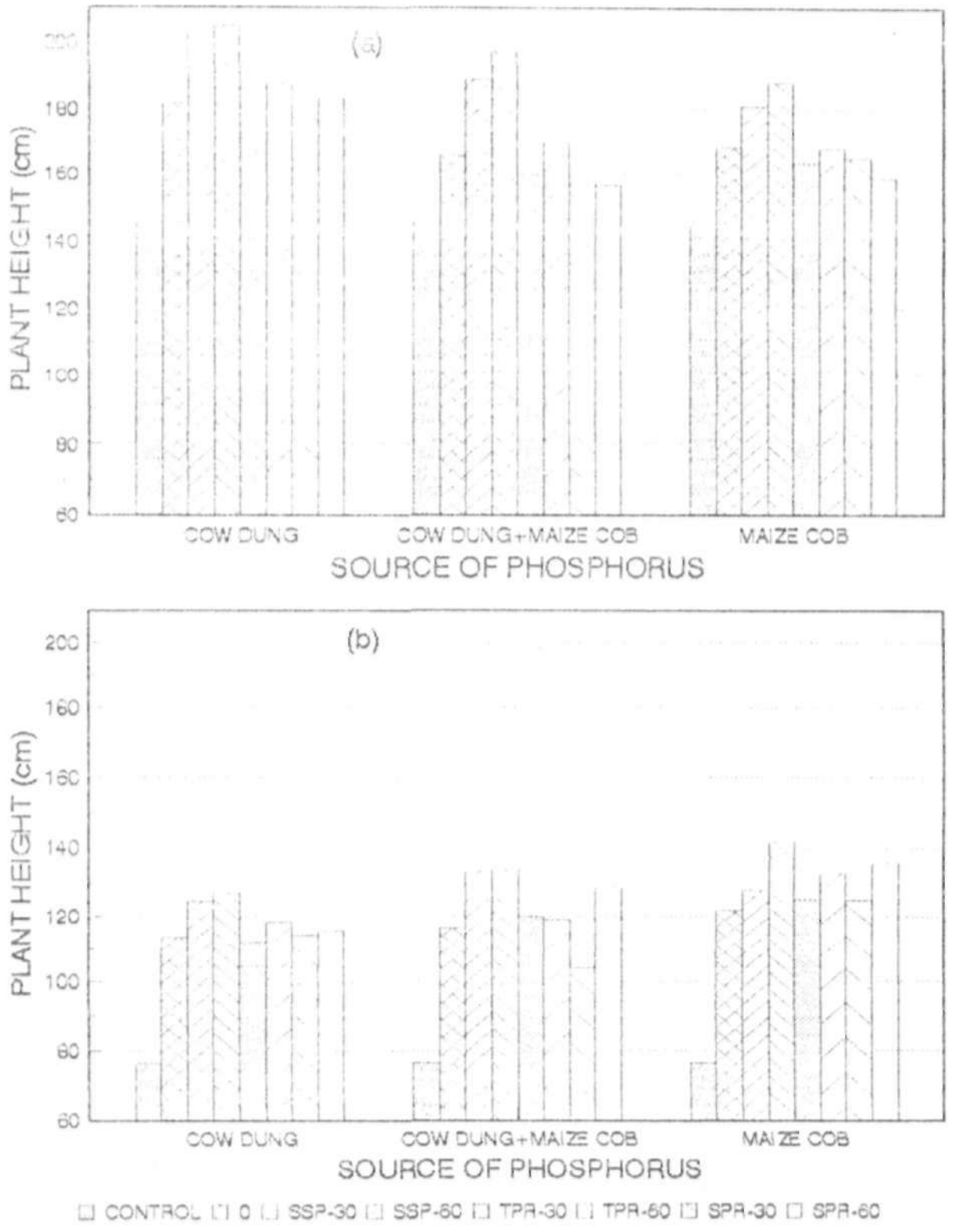


Fig.6- The effect of P-Source and organic ammendments on plant height at 14WAP (a) 1993 and (b) 1994.

The effect of organic amendment on plant height is shown in Table 8. Application of organic amendment significantly improved plant height over the control. In 1993 the trend in plant height among the organic amendments was in the order cowdung (CD) > cowdung/maize cob waste (CD/MC) > maize cob waste (MC) at all stages of growth. The exact reverse of this trend was observed in 1994. Results of the mean data analysis for the two years (Table 9) showed no significant plant height differences among the organic amendments.

The effects of the interaction between source of P and organic amendments and between organic amendment and rate of P on plant height were not significant in both years.

4.2.2 Cob length and diameter

In both the years, cob length produced by TRP and SPR were comparable, while those produced by SSP were significantly longer (Tables 10 and 11). All the three P sources produced significantly longer cobs than the control. Combined data analysis for the two years also reflected the same pattern (Table 12).

The effect of rate of P application on cob length was significant in 1993. In 1994 differences in cob length between 30 and 60kg P_2O_5/ha were not significant, however both rates produced significantly longer cobs than 0kg P_2O_5/ha (Table 13). Mean data analysis for the two years showed 60kg P_2O_5/ha producing significantly longer cobs than 0kg P_2O_5/ha (Table 14). Interaction between P source and rate was found to be significant in 1993 (Table 15) but not in 1994. Combined data analysis for the two years also showed significant interaction between P source and rate.

Table 8: The effect of organic amendment on plant height.

Treatment	Plant height (cm)					
	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP
			1993			
C	17.83	31.8	80.8	116.9	144.3	145.7
CD	23.09	53.1	130.5	176.0	181.4	188.4
CD/MC	21.50	46.8	114.7	154.4	168.6	170.7
MC	22.01	44.9	106.9	143.2	166.8	166.0
LSD (0.05)	NS	1.03	4.47	7.02	7.47	8.77
			1994			
C	14.27	25.67	39.40	53.1	73.9	76.7
CD	25.53	46.29	71.55	96.8	116.6	116.8
CD/MC	27.90	49.44	78.81	108.8	119.2	120.8
MC	26.22	55.41	87.77	120.2	127.2	128.3
LSD (0.05)	1.44	5.32	6.38	8.585	8.88	8.38

Table 9: Effect of organic amendment on plant height (pooled over years).

Treatment	Plant height (cm)					
	4WAP	6WAP	8WAP	10WAP	12WAP	14WAP
C	16.05	28.74	60.10	85.00	109.10	111.20
CD	24.31	49.70	101.03	136.40	149.00	152.60
CD/MC	24.70	48.12	96.76	131.60	143.90	145.75
MC	24.12	50.16	97.34	131.70	147.00	147.15
LSD (0.05)	0.62	2.66	6.40	5.97	5.06	5.96

Table 10: The effect of source of phosphorus on some performance of maize (1993).

Treatment	Performance parameter						
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob
Control	9.77	3.66	140	1671	69	0.7107	243
SSP	13.71	4.66	212	4142	67	0.7559	399
TPR	12.71	4.74	194	3489	67	0.7438	380
SPR	12.33	4.62	189	3313	67	0.7443	468
LSD (0.05)	0.54	NS	10.4	377.5	0.62	0.0091	NS

Table 11: The effect of source of phosphorus on some performance of parameters of maize (1994).

Treatment	Performance parameter						
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob
Control	8.17	3.01	128	1189	90	246	2424
SSP	11.61	4.22	200	3210	77	378	5906
TPR	10.69	3.96	186	2718	79	345	4936
SPR	10.58	3.85	178	2626	79	337	5027
LSD (0.05)	0.40	0.14	8.1	287.7	1.33	16.2	4573

Table 12: The effect of source of phosphorus on some performance parameters of maize (pooled).

Treatment	Performance parameter						
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob
Control	8.97	3.34	134	1430	80	0.6725	245
SSP	12.58	4.54	206	3676	72	0.7399	389
TPR	11.70	4.35	190	3104	73	0.7250	363
SPR	11.46	4.24	184	2970	73	0.7212	353
LSD (0.05)	0.35	0.09	6.68	243	0.75	0.0074	16.43

The application of organic amendments produced longer cobs than the control in both years (Tables 16 and 17). In 1993 differences in cob length among the organic amendments were not significant. However, in 1994 significantly longer cobs were produced by MC followed by CD/MC. Mean data analysis for the two years showed no significant differences in cob length among the organic amendments (Table 18).

Effects of the interaction between P source and organic amendments on cob length were not significant in both the years.

Sources of phosphorus did not significantly affect cob diameter in 1994, however in 1994 SSP produced significantly wider cobs than TPR and SPR which had comparable effect (Tables 10 and 11). Effect of rate of P application on cob diameter was not significant in both years. No interaction effects were observed between P source and rate on cob diameter.

The application of organic amendment improved the cob diameter over the control in both years (Tables 16 and 17). Differences in cob diameter among the organic amendments were however not significant in 1993. In 1994 MC produced significantly wider cobs than CD. Combined data analysis for the two years showed no significant differences in cob diameter among the organic amendments. Effect of the interaction between P source and organic amendment was not significant in both years.

4.2.3 Kernel bulk density and kernel number per cob

The effect of P source on kernel bulk density is shown in Tables 10 and 11. In both years, kernels with significantly greater bulk density were obtained with SSP;

Table 13: The effect of source of phosphorus on some performance parameters of maize.

Treatment	Performance parameter							
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob	Stover yield (kg ha)
				1993				
0	12.50	4.64	198.1	3422	67	0.7497	373.7	-
30	13.03	4.74	199.4	3756	67	0.7464	383.2	-
60	13.05	4.86	197.1	3766	67	0.7478	390.2	-
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	-
				1994				
0	10.31	3.93	172.1	2252	79	0.7056	338.6	4969
30	11.07	4.05	192.4	3007	79	0.7059	362.4	5249
60	11.49	4.05	199.3	3360	77	0.7171	358.0	5651
LSD (0.05)	0.468	NS	10.94	355.9	2.0	0.0102	NS	502

Table 14: The effect of rate of phosphorus on performance of maize (pooled over years).

	Performance parameter						
Kg P_2O_5/ha	Cob length (cm)	Cob diameter (cm)	Kernel bulking density (g/cc)	Kernel number per cob	Days to 50% silking	1000-grain weight (g)	Grain yield (kg/ha)
0	11.41	4.29	0.7277	357	73	185.1	2837
30	12.05	4.40	0.7262	373	73	195.9	3382
60	12.27	4.46	0.7325	374	72	198.2	3563
LSD (0.05)	0.71	NS	NS	NS	0.87	7.70	208.67

Table 15: Effect of the interaction between source and rate of phosphorus application cob length.

Treatment	1993	1994	Mean
SSPx0	12.74	11.08	11.91
SSPx30	13.64	11.46	12.55
SSPx60	14.24	12.28	13.26
TPRx0	12.68	10.18	11.68
TPRx30	12.68	10.18	11.68
TPRx60	12.29	10.85	11.57
SPRx0	11.58	9.67	10.62
SPRx30	12.78	10.72	11.75
SPRx60	12.62	11.34	11.98
LSD (0.05)	1.22		0.71

Table 16: The effect of organic amendment on maize performance (1993).

Treatment	Performance parameter						
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob
C	9.77	3.56	140	1671	69	0.7107	243
CD	12.99	4.76	202	3621	66	0.7436	383
CD/MC	12.70	4.70	196	3664	67	0.7520	385
MC	12.76	4.80	197	3658	67	0.7484	379
LSD (0.05)	2.03	0.60	11.07	1131.1	0.56	0.01	5.53

Table 17: The effect of organic amendment on maize performance (1994).

Treatment	Performance parameter							
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob	Stover yield (kg/ha)
C	8.17	3.76	128	1189	90	0.6343	246	2424
CD	10.22	3.90	179	2431	80	0.6933	323	4669
CD/MC	10.96	3.96	187	2778	79	0.7131	352	6043
MC	11.74	4.17	198	3345	75	0.7223	384	5157
LSD (0.05)	0.92	0.15	16.26	762.57	2.33	0.008	26.0	832.77

the effects of TPR and SPR on kernel bulk density were comparable. All the the three P sources produced significantly greater kernel bulk density over the control(C) in both years. The same trend was observed when the combined data for the two years were analysed (Table 12). The effect of rate of P application on kernel bulk density did not manifest in the first year (Table 13), however greater kernel bulk density was observed at higher P rates in 1994. Combined data analysis showed P rate having no effect on kernel bulk density (Table 14).

The application of organic amendment increased the kernel bulk density over the control in both years (Tables 16 and 17).

In 1993 differences in kernel bulk density among the organic amendments were not significant, however, in 1994 MC produced significantly higher kernel bulk density over CD (Tables 16 and 17). Analysis of the mean data for the two years also revealed maize cob waste producing significantly higher kernel bulk density than cowdung (Table 18). Effect of

the interaction between P source and organic amendment on kernel bulk density was not significant in both years.

Differences in kernel number per cob did not manifest among the P sources in 1993, but in 1994 SSP produced significantly more kernels per cob than TPR which had comparable effect (Tables 10 and 11). In both the years all the three P sources produced significantly more kernels per cob over the control (C). The same pattern as in the second year was observed with the combined data for the two years (Table 12).

Table 18: The effect of organic amendment on maize performance (pooled over the years).

Treatment	Performance parameter						
	Cob length (cm)	Cob diameter (cm)	1000-grain weight (g)	Grain yield (kg/ha)	Days to 50% silking	Kernel bulk density (g/cc)	Kernel number per cob
C	8.97	3.71	134	1430	80	0.6725	245
CD	11.61	4.33	191	3026	73	0.7185	353
CD/MC	11.88	4.33	192	3221	73	0.7326	369
MC	12.25	4.48	198	3502	71	0.7354	382
LSD (0.05)	0.98	0.17	7.77	510.0	1.36	0.005	38.02

The various P rates did not produce significant differences in kernel number per cob, however, the number was generally higher at higher P rates. Application of organic amendment significantly increased the kernel number per cob over the control (Tables 16 and 17). Differences in kernel number per cob among the organic amendments were significant only in 1994.

4.2.4 Days to 50% silking and 1000-grain weight

The influence of P source on days to 50% silking is shown in Tables 10 and 11. Differences did not appear in the first year, however, in the second year plants treated with SSP silked significantly earlier than those treated with TPR and SPR which had comparable effect. In both years days to 50% silking was significantly earlier with the sources than with the control. Analysis of the mean data showed crops that received SSP silking significantly earlier than those treated with TPR and SPR (Table 12). Tables 13 and 14 show the effect of rate of P application on days to 50% silking. Phosphorus rate did not significantly influence days to 50% silking in the first year. Results for the second year and mean for the two years showed 60kg P_2O_5/ha silking significantly earlier than 30 and 0kg P_2O_5/ha which were statistically at par.

Days to 50% silking was significantly earlier with the application of organic amendments in both years (Tables 16 and 17). In 1993 plants treated with CD silked earlier than those treated with CD/MC or MC, but in 1994 those treated with MC silked significantly earlier. Combined data analysis for the two years also showed plants treated with maize cob waste silking significantly earlier than those treated with cowdung/maize cob waste and cowdung (Table 18).

Interaction effect of P source and organic amendment on days to 50% silking was not significant in both years.

In both years 1000-grain weight was greater in plants treated with SSP than in those treated with TPR and SPR (Tables 10 and 11). All the sources produced greater 1000-grain weights than the control. The same pattern was observed with the combined data for the two years (Table 12).

Effect of P rate on 1000-grain weight did not manifest in the first year (Table 13). Results for the second year and mean for the two years (Table 14) revealed greater 1000-grain weight at higher P rates.

Differences in 1000-grain weight among the 3 organic amendments were not significant in both 1993 and 1994 (Tables 16 and 17). However, greater 1000-grain weights were observed over the control with all the three organic amendments.

4.2.5 Grain and stover yield

The effect of P source on grain yield per hectare is shown in Tables 10 and 11. Higher grain yields were obtained with SSP than with TPR and SPR in both years. The difference in grain yield between TPR and SPR was not significant, but generally TPR produced higher yields than SPR. In 1993 RAE on grain yield was 73.57% for TPR and 66.45% for SPR, this values increased to 75.66% and 71.10% respectively in 1994. In both years all the sources performed significantly better than C. The same trend was observed with the mean data for the two years (Table 12). Effect of rate of P application on grain yield was not significant in the first year, however in the second year grain yields increased with increasing rate of P application although the difference between 60kg P_2O_5/ha and 30kg P_2O_5/ha were not

Table 19: Effect of the interaction between phosphorus source and rate on grain yield.

	Grain yield (kg/ha)		
Treatment	1993	1994	Mean
SSPx0	3588	2370	2979
SSPx30	4242	3399	3821
SSPx60	4596	3925	4261
TPRx0	3463	2246	2855
TPRx30	3384	2928	3156
TPRx60	3320	3045	3183
SPRx0	3216	2139	2678
SPRx30	3641	2695	3168
SPRx60	3282	3109	3196
LSD (0.05)	754.8	575.65	485.9

statistically significant (Table 13). Combined data for the two years also showed the same pattern as in the second year (Table 14). Interaction between P source and rate significantly affected grain yield in 1993 with SSP at 60 and 30kg P_2O_5/ha giving significantly higher yields (Table 19). This interaction was however not significant in 1994. Significant interaction between P source and rate was also observed when the combined data for the two years were analysed.

Tables 16 and 17 show the effect of organic amendment on grain yield. In 1993 differences in grain yield did not manifest among the organic amendments, but in 1994 maize cob waste produced significantly higher grain yield than cowdung. Combined data for the two years showed no significant grainyield differences among the organic amendments (Table 18). In both years higher yields over the control were observed with the amendments. Effect of interaction between organic amendment and P source on grain yields was not significant in both years.

Due to logistic reasons stover yield were not recorded in 1993. In 1994, all the P sources produced higher stover yields over the control (Table 11). Significantly higher stover yields were produced by SSP over TPR and SPR which had comparable effect. Effect of P rate on stover yield for 1994 is shown in Table 16. Differences in yield between 0 and 30kg P_2O_5/ha and between 30 and 60kg P_2O_5/ha were not significant. Significant stover yield differences were however observed between 60 and 0kg P_2O_5/ha.

4.3 Effect of Phosphorus Source and Organic Amendment on Nutrient Content of Index Leaves

Tables 20 and 21 show the effect of P source on nutrient element content of index leaves at 50% silking. The various phosphorus sources gave generally higher

Table 20: Effect of phosphorus source on nutrient element concentration of index leaves at 50% silking.

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
1993									
Control	15.9	0.8	14.1	5.7	1.9	117	64	109	12
SSP	28.4	3.0	21.4	6.1	2.1	154	70	93	10
TPR	28.9	2.3	20.6	6.0	2.1	137	72	101	10
SPR	29.1	2.1	22.5	6.1	2.1	128	70	101	11
LSD (0.05)	0.24	0.03	0.14	NS	NS	17.74	5.63	11.17	1.12
1994									
Control	17.7	0.9	14.8	4.0	2.0	270	67	70	9
SSP	29.2	2.6	16.2	4.4	2.1	184	89	72	10
TPR	30.3	2.5	16.5	4.5	2.2	188	85	69	11
SPR	28.9	2.2	16.5	4.2	2.0	186	87	74	11
LSD (0.05)	0.15	0.02	0.07	0.02	NS	14.32	7.00	NS	1.40

Table 21: Effect of phosphorus source on nutrient element concentration of index leaves at 50% silking (pooled over years).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
	1993								
Control	16.7	0.9	14.5	4.9	2.0	194	66	90	11
SSP	28.8	2.8	18.8	5.3	2.1	169	80	83	11
TPR	29.6	2.4	18.5	5.3	2.2	163	79	85	11
SPR	29.0	2.2	19.5	5.2	2.1	157	79	88	11
LSD (0.05)	0.08	0.01	0.08	0.02	NS	12.33	3.55	NS	NS

nutrient contents over control except in the case of Zn and Cu in 1993 and Fe in 1994 where the control gave slightly higher contents.

In 1993, higher plant contents of P and Fe were recorded with SSP, and higher K content with SPR. The 3 P sources have comparable effect on the concentrations of other nutrient elements in the index leaves.

In 1994, SSP and TPR produced comparable concentrations of P and Ca in the index leaves which were significantly higher than the concentrations produced by SPR. Higher concentrations of Zn were recorded with SPR and SSP. Combined analysis of 1993 and 1994 data showed Fe concentration to be higher in the absolute control plots.

Influence of rate of P application on nutrient contents of index leaves is shown in Table 22. Generally higher nutrient contents were observed at 60 and 30kg P_2O_5/ha than 0kg P_2O_5/ha in both the years. Although concentration of P in the index leaves was observed to be higher at higher rates in 1993, the difference was not significant. However, in 1994, significantly higher concentrations of P were recorded with increasing rates of P application. The same trend sufficed when the combined data for 1993 and 1994 were analysed (Table 25). Zinc concentrations were significantly higher at 30kg P_2O_5 than at 0 or 60kg P_2O_5 in both years.

Effect of interaction between P source and rate on nutrient contents of index leaves is shown in Tables 23 and 24. In 1993 higher P and Ca contents were observed in the index leaves when SSP at 60 and 30kg P_2O_5/ha were applied. In 1994, SSP and TRP at 60kg P_2O_5/ha produced significantly higher concentrations of P in the index leaves, while TPR at 30 and 60kg P_2O_5/ha gave higher Ca concentrations. Analysis of the combined data for the two years showed SSP at 60 and 30kg P_2O_5/ha

Table 22: Effect of phosphorus source on nutrient element concentration of index leaves at 50% silking.

	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Kg P_2O_5/ha	---------- gkg^{-1} ----------					---------- mgkg^{-1} ----------			
				1993					
0	27.6	2.4	20.3	5.7	2.0	144	66	92	11
30	29.4	2.5	22.2	6.1	2.1	134	74	109	11
60	29.2	2.6	22.1	6.0	2.1	143	72	94	11
LSD (0.05)	NS	NS	0.14	NS	NS	NS	5.62	11.17	NS
				1994					
0	28.7	2.1	16.3	4.2	2.0	187	94	71	10
30	29.7	2.4	16.9	4.5	2.2	187	88	74	11
60	29.9	2.8	16.7	4.4	2.1	184	79	70	11
LSD (0.05)	NS	0.02	NS	0.20	NS	NS	7.00	2.88	NS

nutrient contents over control except in the case of Zn and Cu in 1993 and Fe in 1994 where the control gave slightly higher contents.

In 1993, higher plant contents of P and Fe were recorded with SSP, and higher K content with SPR. The 3 P sources have comparable effect on the concentrations of other nutrient elements in the index leaves.

In 1994. SSP and TPR produced comparable concentrations of P and Ca in the index leaves which were significantly higher than the concentrations produced by SPR. Higher concentrations of Zn were recorded with SPR and SSP. Combined analysis of 1993 and 1994 data showed Fe concentration to be higher in the absolute control plots.

Influence of rate of P application on nutrient contents of index leaves is shown in Table 22. Generally higher nutrient contents were observed at 60 and 30kg P_2O_5/ha than 0kg P_2O_5/ha in both the years. Although concentration of P in the index leaves was observed to be higher at higher rates in 1993, the difference was not significant. However, in 1994, significantly higher concentrations of P were recorded with increasing rates of P application. The same trend sufficed when the combined data for 1993 and 1994 were analysed (Table 25). Zinc concentrations were significantly higher at 30kg P_2O_5 than at 0 or 60kg P_2O_5 in both years.

Effect of interaction between P source and rate on nutrient contents of index leaves is shown in Tables 23 and 24. In 1993 higher P and Ca contents were observed in the index leaves when SSP at 60 and 30kg P_2O_5/ha were applied. In 1994, SSP and TRP at 60kg P_2O_5/ha produced significantly higher concentrations of P in the index leaves, while TPR at 30 and 60kg P_2O_5/ha gave higher Ca concentrations. Analysis of the combined data for the two years showed SSP at 60 and 30kg P_2O_5/ha

Table 23: Effect of the interaction between source and rate of phosphorus on the nutrient element concentration of index leaves at 50% silking (1993).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
SSP-0	25.7	2.7	19.9	5.5	1.8	142	64	79	9
SSP-30	31.9	3.2	21.0	6.2	2.1	154	70	93	12
SSP-60	27.5	3.1	23.2	6.5	2.3	167	74	107	11
TPR-0	27.3	2.5	19.8	5.7	2.0	164	69	99	9
TPR-30	28.0	2.2	19.6	6.1	2.1	123	78	120	9
TPR-60	31.3	2.2	22.4	6.1	2.1	124	70	85	10
SPR-0	29.9	1.9	21.0	5.8	2.2	124	66	98	9
SPR-30	28.6	2.4	25.8	6.0	2.1	123	74	114	11
SPR-60	29.0	2.1	20.7	5.3	1.9	136	70	90	11
LSD (0.05)	0.42	0.05	0.24	0.07	NS	30.73	9.76	19.35	1.94

Table 24: Effect of the interaction between source and rate of phosphorus on the nutrient element concentration of index leaves at 50% silking (1994).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
SSP-0	27.3	2.1	15.5	4.3	2.0	162	93	71	9
SSP-30	29.6	2.8	18.1	4.5	2.1	197	92	74	10
SSP-60	30.1	3.0	16.9	4.4	2.1	193	82	71	11
TPR-0	29.2	3.3	17.7	4.3	2.0	197	97	70	12
TPR-30	30.3	2.4	16.0	4.6	2.2	177	83	70	12
TPR-60	31.3	3.0	16.0	4.6	2.1	192	75	67	9
SPR-0	29.6	2.0	16.0	4.6	2.0	202	91	71	11
SPR-30	29.2	2.1	16.5	4.5	2.1	188	90	79	11
SPR-60	27.8	2.5	17.2	4.1	2.0	168	81	70	11
LSD (0.05)	NS	0.02	0.12	NS	NS	24.81	12.07	NS	NS

Table 25: Effect of rate of phosphorus application on nutrient element concentration of index leaves at 50% silking (pooled over years).

	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Kg P_2O_5/ha	---------- gkg^{-1} ----------					---------- mgkg^{-1} ----------			
0	28.2	2.3	18.3	5.0	2.0	166	80	82	11
30	29.6	2.5	19.6	5.3	2.2	161	81	92	11
60	29.6	2.7	19.4	5.3	2.1	163	76	82	11
LSD (0.05)	0.09	0.02	0.09	0.01	NS	NS	NS	7.96	NS

Table 26: Effect of the interaction between source and rate of phosphorus application on nutrient concentration of index leaves (pooled over years).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
SSP-0	26.5	2.4	17.7	4.9	1.9	152	79	75	9
SSP-30	20.8	3.0	19.6	5.4	2.1	196	81	84	11
SSP-60	28.8	3.1	20.1	5.5	2.2	180	78	89	11
TPR-0	28.3	2.4	18.8	5.0	2.0	181	83	85	11
TPR-30	29.2	2.3	17.8	5.4	2.2	150	81	95	11
TPR-60	31.3	2.6	19.2	5.4	2.1	158	73	76	10
SPR-0	29.8	2.0	18.5	5.0	2.1	163	79	85	10
SPR-30	28.9	2.3	21.2	5.3	2.1	156	82	77	11
SPR-60	28.4	2.3	19.0	4.7	2.0	152	78	70	11
LSD (0.05)	0.16	0.03	0.16	0.04	NS	NS	NS	NS	NS

Table 27: Effect of organic amendments on nutrient element concentration of index leaves at 50% silking.

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	---gkg^{-1}---					---mgkg^{-1}---			
	1993								
C	15.9	0.8	14.1	6.1	1.9	117	64	12	109
CD	22.5	2.2	22.9	5.4	2.4	188	73	12	66
CD:MC	34.5	2.3	22.2	6.2	2.0	124	74	11	104
MC	29.4	3.0	19.4	6.2	1.8	108	65	10	125
LSD (0.05)	0.40	0.05	0.24	0.04	0.02	20	7.7	1.1	10.6
	1994								
C	17.7	0.9	14.8	3.9	2.0	270	67	9	70
CD	27.0	2.3	16.2	4.2	2.0	214	94	10	72
CD:MC	30.7	2.5	17.4	4.2	2.2	179	84	12	74
MC	30.6	2.6	16.3	4.6	4.3	165	83	11	69
LSD (0.05)	0.15	0.01	NS	0.03	NS	11.55	4.61	1.84	2.40

giving significantly higher P concentrations in the index leaves, while SSP at 60 and 30kg P_2O_5/ha gave higher Ca contents (Table 26).

Effect of organic amendment on the nutrient content of the index leaves is shown in Table 27. In both years nutrient content was higher with the application of organic amendment except in the case of Cu and Zn in 1993 and Fe in 1994 where higher content was recorded with the control. In both years higher P and Ca contents were observed with maize cob waste while cowdung/maize cob waste gave higher N content. The same trend was recorded when the combined data for the two years were analysed (Table 30).

Tables 28 and 29 show the effect of the interaction between P source and organic amendment on the nutrient concentrations of index leaves at 50% silking. Interaction between maize cob waste and SSP gave higher concentrations of P and Ca in the index leaves in both years. Analysis of the combined data for the two years also showed MC x SSP giving higher contents of P and Ca, closely followed by MC x TPR (Table 31).

4.4 Effect of Phosphorus Source and Organic Amendment on some Soil Chemical Properties

Tables 32 and 33 show the effect of P source and organic amendment on some soil chemical properties at harvest. The application of organic amendment had a depressing effect on pH in 1993. In both 1993 and 1994, significantly more organic carbon was recorded in plots treated with maize cob waste. In 1993, levels of Bray-1 P, exchangeable bases and ECEC were significantly higher in plots that received cowdung. However, in 1994 the differences were not significant. Generally higher levels of exchangeable bases, ECEC and Bray-1 P were recorded over the control

Table 28: Effect of the interaction between phosphorus source and organic amendment on nutrient concentration of index leaves (1993).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
CDxSSP	24.0	3.0	22.2	5.3	2.3	213	71	70	14
CDxTPR	20.5	1.7	21.5	5.1	2.2	207	70	61	10
CDxSPR	22.9	1.8	25.1	5.7	2.7	142	78	70	12
CD/MCxSSP	31.9	2.7	22.4	6.3	2.0	136	73	93	12
CD/MCxTPR	35.7	2.2	21.6	6.5	2.1	103	77	95	10
CD/CxSPR	36.0	1.9	22.6	5.9	1.9	132	73	124	11
MCxSSP	29.2	3.2	19.6	6.7	1.9	113	64	117	10
MCxTPR	30.4	3.0	18.8	6.3	2.0	101	70	148	8
MCxSPR	28.6	2.7	19.8	5.5	1.6	110	60	110	9
LSD (0.05)	NS	0.05	NS	0.06	0.03	31.07	NS	18.70	NS

Table 29: Effect of the interaction between phosphorus source and organic amendment on nutrient concentration of index leaves (1994).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
CDxSSP	26.7	2.3	16.9	4.3	1.9	205	94	74	6
CDxTPR	28.1	2.3	15.6	4.3	1.8	225	92	69	15
CDxSPR	26.4	2.3	15.9	4.1	2.1	212	95	72	8
CD/MCxSSP	32.7	2.7	17.3	4.2	2.2	195	92	73	13
CD/MCxTPR	30.6	2.7	17.5	4.4	2.3	178	80	68	10
CD/<CxSPR	28.9	2.0	19.2	4.1	2.1	185	81	81	13
MCxSSP	28.2	2.9	16.2	4.7	2.1	172	82	70	12
MCxTPR	32.2	2.5	16.4	4.7	2.2	162	82	69	8
MCxSPR	31.3	2.3	16.2	4.5	1.9	163	86	68	12
LSD (0.05)	NS	0.03	NS	NS	NS	NS	NS	4.66	2.63

Table 30: Effect of organic amendment on nutrient element concentration of index leaves (pooled over years).

Treatment	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	gkg^{-1}					mgkg^{-1}			
Control	16.7	0.9	14.5	4.9	2.0	194	66	11	90
CD	24.8	2.3	19.6	4.8	2.2	201	84	11	69
CD/MC	32.6	2.4	19.8	5.2	2.1	152	86	12	88
MC	30.0	3.2	17.9	5.4	3.1	137	74	11	97
LSD (0.05)	0.07	0.02	0.13	0.03	NS	10.65	5.98	NS	5.00

Table 31: Effect of the interaction between phosphorus source and organic amendment on nutrient concentration of index leaves (pooled over years and rates).

	Nutrient element concentration								
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Treatment	---gkg^{-1}---					---mgkg^{-1}---			
CDxSSP	25.4	2.7	19.6	4.8	2.1	209	83	72	10
CDxTPR	24.3	2.0	18.6	4.7	2.0	216	81	65	13
CDxSPR	24.7	2.1	20.5	4.9	2.4	177	87	71	10
CD/MCxSSP	32.3	2.7	19.9	5.3	2.1	166	83	83	13
CD/MCxTPR	33.2	2.5	19.6	5.5	2.2	141	79	82	10
CD/MCxSPR	32.5	2.0	19.9	5.0	2.0	159	77	103	12
MCxSSP	28.7	3.1	17.9	5.7	2.0	143	73	94	11
MCxTPR	31.3	2.8	17.5	5.5	2.1	132	76	109	8
MCxSPR	30.0	2.5	18.0	5.0	1.8	137	73	89	11
LSD (0.05)	NS	0.03	NS	0.03	NS	19.65	NS	10.37	1.40

Table 32: Effect of phosphorus source and rate on soil chemical properties at harvest.

Treatment	Soil property												
	pH (ratio)	Organic carbon (gkg^{-1})	Total N (gkg^{-1})	Bray-1 P (mg kg^{-1})	Exchangeable bases (cmol kg^{-1})				ECEC (cmol kg^{-1})	Available micronutrient (mg kg^{-1})			
					Ca	Mg	K	Na		Zn	Mn	Fe	Cu
					1993								
Control	5.3	4.3	0.3	3.58	1.84	0.49	0.45	0.25	3.63	8.67	57.00	54.50	1.56
SSP	5.0	8.3	0.5	6.32	2.76	0.77	0.45	0.39	5.07	9.02	64.10	50.13	1.53
TPR	5.0	6.3	0.5	5.56	2.29	0.63	0.35	0.37	4.30	8.41	49.60	44.51	1.42
SPR	5.1	6.9	0.5	5.64	2.34	0.63	0.34	0.36	4.38	8.41	49.60	45.50	1.40
LSD (0.05)	0.14	0.09	0.01	1.04	0.16	0.06	NS	0.06	0.23	0.41	5.21	3.47	0.08
					1994								
Control	4.47	37.9	2.8	2.98	1.58	0.43	0.10	0.07	2.97	10.50	26.53	34.00	2.13
SSP	4.66	71.6	5.4	5.26	2.00	0.51	0.19	0.07	3.56	9.89	36.88	37.67	1.65
TPR	4.55	51.1	4.7	5.92	1.70	0.45	0.14	0.11	3.20	9.31	30.38	33.61	1.62
SPR	4.60	56.9	4.8	5.81	1.99	0.63	0.16	0.09	3.54	9.45	32.17	35.19	1.73
LSD (0.05)	NS	0.09	0.05	0.54	0.17	0.18	0.04	0.04	0.21	0.81	2.98	NS	0.16

Table 33: Effect of organic amendment on some soil chemical properties at harvest.

Treatment	Soil property												
	pH (ratio)	Organic carbon (gkg^{-1})	Total N (gkg^{-1})	Bray-1 P ($mg\ kg^{-1}$)	Exchangeable bases ($cmol\ kg^{-1}$)				ECEC ($cmol\ kg^{-1}$)	Available micronutrient ($mg\ kg^{-1}$)			
					Ca	Mg	K	Na		Zn	Mn	Fe	Cu
					1993								
C	5.3	4.30	0.3	3.58	1.84	0.490	0.45	0.25	3.63	8.67	1.56	54.50	57.00
CD	5.1	6.13	0.5	7.32	2.54	0.727	0.47	0.44	4.91	8.39	1.43	47.82	52.5
CD MC	4.9	6.48	0.5	4.93	2.46	0.662	0.31	0.43	4.59	8.68	1.48	45.99	52.8
MC	5.1	8.92	0.5	5.27	2.38	0.643	0.36	0.25	4.26	8.76	1.44	44.13	56.2
LSD (0.05)	0.13	0.11	0.015	2.32	0.05	0.05	0.10	0.15	0.26	NS	0.06	7.67	NS
					1994								
C	4.47	3.79	2.8	2.98	1.58	0.430	0.100	0.070	2.97	10.50	2.13	34.00	26.53
CD	4.47	5.24	4.6	5.89	1.82	0.602	0.145	0.090	3.33	8.93	1.78	32.36	30.29
CD MC	4.63	5.60	5.4	5.69	1.92	0.470	0.151	0.108	3.45	9.08	1.58	37.64	35.99
MC	4.72	7.26	4.9	5.43	1.96	0.516	0.198	0.075	3.54	10.65	1.64	36.50	33.99
LSD (0.05)	NS	0.105	0.01	0.91	0.33	NS	0.075	0.05	0.36	0.77	0.07	NS	1.23

Table 34: Effect of rate of phosphorus application on soil chemical properties at harvest.

Kg P_2O_5/ha	Soil property												
	pH (ratio)	Organic carbon (gkg^{-1})	Total N (gkg^{-1})	Bray-1 P ($mg\ kg^{-1}$)	Exchangeable bases ($cmol\ kg^{-1}$)				ECEC ($cmol\ kg^{-1}$)	Available micronutrient ($mg\ kg^{-1}$)			
					Ca	Mg	K	Na		Zn	Mn	Fe	Cu
					1993								
0	4.9	8.5	0.6	5.72	2.71	0.74	0.33	0.43	4.95	8.60	53.6	40.89	1.40
30	4.9	8.0	0.6	6.93	2.63	0.75	0.43	0.41	4.48	8.89	57.2	46.37	1.43
60	5.0	7.9	0.5	7.13	2.66	0.73	0.32	0.41	4.92	8.30	47.5	42.15	1.41
LSD (0.05)	NS	NS	NS	1.04	NS	NS	NS	NS	NS	0.41	5.21	3.47	NS
					1994								
0	4.7	7.10	5.7	6.07	2.03	0.51	0.18	0.09	3.61	9.13	37.73	36.37	1.51
30	4.6	6.61	5.8	6.49	1.98	0.64	0.22	0.09	3.54	9.70	33.96	35.41	1.50
60	4.7	6.63	5.6	7.13	2.02	0.55	0.16	0.12	3.63	8.87	34.34	36.22	1.53
LSD (0.05)	NS	NS	NS	0.61	NS	NS	0.04	NS	NS	NS	NS	NS	NS

when P was applied irrespective of the source. Higher levels of Bray-1 P were recorded at higher P rates in both years (Table 34). Levels of available micronutrient were highest at 30kg P_2O_5/ha in the first year. Effect of P rate on available micronutrients was not significant in the second year.

4.5 Correlation Studies

The matrix of coefficient of correlation between some plant performance parameters and the nutrient contents of index leaves are given in Tables 35 and 36. All performance parameters except days to silking correlated positively and very significantly with P, N, K, Mg and Mn contents of index leaves in 1993. Days to 50% silking was negatively correlated with plant content of N, P, K, Mg, Fe and Mn (r = -0.536**) (r = 0.372**), (r = -0.336**), (r = -0.322**), (r = -309**) and (r = -0.206*) respectively.

In 1994 highly significant negative correlations were observed between Fe concentration of index leaves and all plant performance parameters except days to silking (Table 36). Significant correlations were observed between all the performance parameters and N, P, Ca, and Mn contents of the index leaves.

Table 37 shows the matrix of coefficient of correlation between soil chemical properties at harvest and P, Ca, and Fe contents of index leaves at 50% silking. Correlations between soil pH and P content of leaves was found to be negative and significant in both 1993 and 1994 (r = -0.331**) and (r = -0.203*) respectively. Correlation between soil Bray-1 P and P content of index leaves was (r = -0.377**) in 1993 and (r = -0.701**) in 1994, while correlations between organic carbon content of soil and plant content of P were (r = -0.627**) and (r = -0.409**) in

1993 and 1994 respectively. There were strong correlations between P concentration of leaves and exchangeable Ca, P concentrations and ECEC, and between Fe concentration of leaves and ECEC in both the years.

Table 35: Correlation between maize performance and nutrient element concentration of index leaves (1993).

	Plant performance							
Nutrient	Cob length	Cob diameter	1000-grain weight	Grain yield per cob	Days to 50% silking	Kernel bulk density	Kernel number per cob	Plant height at 14 WAP
N	0.4540**	0.4386**	0.4440**	0.4718**	-0.3356**	0.3981**	0.4781**	0.2133**
P	0.5528**	0.5273**	0.5916**	0.5669**	-0.3723**	0.5377**	0.5167**	0.4770**
K	0.4571**	0.4634**	0.4524**	0.4429**	-0.5353**	0.1765	0.4958**	0.5110**
Ca	0.0776	0.8273	0.1484	0.0988	0.1760	0.2052*	0.0127	-0.1727
Mg	0.3317**	0.3284**	0.3275**	0.3285**	-0.3217**	0.2247**	0.2951**	0.3276**
Fe	0.1938	0.1893	0.2337*	0.1716	-0.3085**	-0.0069	0.1907	0.3276**
Mn	0.3097**	0.2787**	0.2542**	0.2805**	-0.2055*	0.1753	0.2572**	0.4038**
Zn	-0.1573	-0.0536	-0.2384*	-0.1151	0.0107	-0.2980**	-0.0565	-0.1308
Cu	-0.1657	-0.3154**	-0.1865	-0.1905	0.1835	-0.0373	-0.1941	-0.0461

** *Significant at 1% level of probability.* * *Significant at 5% of probability.*

Table 36: Correlation between maize performance and nutrient element concentration of index leaves (1994).

Nutrient	Plant performance								
	Cob length	Cob diameter	1000-grain weight	Grain yield per hectare	Days to 50% silking	Kernel bulk density	Kernel number per cob	Plant height at 14 WAP	Stover yield per hectare
N	0.6718**	0.6999**	0.6839**	0.6305**	-0.7215**	0.7577**	0.6788**	0.7727**	0.6702**
P	0.6812**	0.6742**	0.7274**	0.6912**	-0.7243**	0.6701**	0.6170**	0.7712**	0.6790**
K	0.1137	-0.1033	0.0384	0.1868	-0.0558	0.1421	0.0423	0.1293	0.1670
Ca	0.4407**	0.3939**	0.3121**	0.4576**	0.4116**	0.3818**	0.3850**	-0.4275**	0.2347**
Mg	0.1563	0.0980	0.0497	0.1511	-0.0965	0.0539	0.2016*	0.0684	0.0427
Fe	-0.5713**	0.5120	-0.5524**	0.5257**	-0.5544**	-0.6718	0.4961**	-0.5932**	0.4249**
Mn	0.2927**	0.3065**	0.3394**	0.2413*	-0.4026**	0.3084	0.2651**	0.4375**	0.3887**
Zn	0.0572	0.0831	0.0567	0.0691	-0.0340	0.0004	0.1635	0.4375**	0.2342*
Cu	0.1401	0.1242	0.1699	0.1075	0.0814	0.1337	0.1191	0.0952	0.1649

** *Significant at 1% level of probability.*

* *Significant at 5% level of probability.*

Table 37: Matrix of coefficient (r) between soil chemical properties at harvesting and P, Ca and Fe contents of index leaves at 50% silking.

Nutrient in index leaves	Soil chemical property							
	pH	Organic carbon	Bray-1 P	Exchangeable calcium	ECEC	Zn	Fe	Cu
				1993				
P	-0.3310**	0.6274**	0.3767	0.5226**	0.4356**	0.1415	-0.3303**	-0.0765
Ca	-0.3049**	-0.0144	-0.1827	0.0450	0.1341	09986	-0.0116	0.1102
Fe	0.1902	-0.0942	-0.2777**	0.2049*	-0.3420**	-0.3420**	0.0509	-0.0490
				1994				
P	-0.2032*	0.4088**	0.7009**	0.3212**	0.3950**	-0.2526	0.2048	-0.5287
Ca	0.2676**	0.2550**	0.2705**	0.1214	0.1384	0.1827	0.0310	-0.2676**
Fe	-0.3855**	-0.4377**	-0.4291**	-0.3255**	-0.3610**	-0.0352	-0.0887	0.4673**

** *Significant at 1% level of probability.* * *Significant at 5% level of probability.*

CHAPTER FIVE

DISCUSSION

5.1 Effect of Phosphorus Source and Organic Amendment on Plant Performance

In both the years, plant performance was better in plots treated with P, this response to P application is expected in view of the low available P status of the experimental plot soil (Table 1). During both the years, maize performance with single superphosphate was better than with Togo and Sokoto phosphate rock with respect to all the parameters measured. The performance of the phosphate rocks relative to single superphosphate was, however, better in the second year as reflected by their higher relative agronomic efficiencies on plant height and grain yield. This result is supported by the earlier observations of Engelstel *et al.* (1974) and Lombin (1979). They observed superior performance of soluble phosphate fertilizers over phosphate rocks in the first two years of application. They reported the relative agronomic efficiencies of phosphate rocks to increase in the second year.

Though not statistically significant, maize performance was generally better with Togo than with Sokoto phosphate rock. This result contradicts the earlier observation of Sobulo *et al.* (1992) who reported superior crop performance with Sokoto than with Togo phosphate rocks.

Cob diameter, grain yield per hectare and kernel number per ear, though not significant, were generally higher with increasing P rates. The effect of rate of P application on plant height, 1000-grain weight, kernel bulk density and days to silking started manifesting only in the second year, and the difference between 30 and 60kg

P_2O_5/ha with respect to these parameters was not significant. This indicates that though the initial P level in the soil was low, moderate levels of P application is sufficient to stimulate good growth. Such low requirements of P as illustrated by this result has been attributed to low sorption capacity of most Savanna soils (Mokwunye, 1977; Batiano *et al.*, 1986).

Grain yield values obtained with all three P sources at all rates are higher than the values obtained by Amapu *et al.* (1994; 1995) in a similar trial on the same soil but without the application of organic material (Appendix 1). This therefore indicated that the application of inorganic P together with organic amendments produced superior plant performance than the lone application of inorganic P. This is supported by the finding of Ikerra *et al.* (1994) who reported higher grain yield values when inorganic P was applied together with organic materials.

In the first year, interaction between phosphate source and rate influenced plant height significantly during the first 10 weeks after planting; with SSP at 60 and 30kg P_2O_5/ha being superior. This interaction was not observed in the second year. This may be due to the initial unavailability of P from phosphate rock sources in the first 10 weeks after planting the first year crop. The decomposition of added organic materials with time and their ability to enhance the dissolution of phosphate rocks and to minimise subsequent fixation of the released P could have caused the non-significant P source x P rate interaction in 1994. Ikerra *et al.* (1994) found the decomposition of farmyard manure to significantly improve the dissolution of P from phosphate rocks.

With all the three P sources plant performance was generally better in the first year. Lombin (1979) and Sobulo *et al.* (1992) also found crop performance to

be better in the year of P application. According to Kang and Osiname (1979) and Uyovbisere and Lombin (1990), although the residual fertility of low P sorption soils may be high, the maize crop always benefits from freshly applied phosphate. Another factor that might have contributed to the lower crop performance in the second year was the erratic rainfall pattern experienced in 1994 (Appendices 2 and 3).

The magnitude of crop performance in terms of plant heights were in the order CD > CD/MC > MC in 1993 at all periods of growth, and this was reversed to MC > CD/MC > CD in 1994. The superior performance of cowdung in the first year could be due to its lower C:N ratio (Table 2) and faster rate of decomposition and to the influence of the decomposition products on soil physical and chemical properties. According to Parr and Papendick (1978), residues with C:N ratios below 30 are usually associated with fast decomposition rate. Olsen *et al.* (1970) reported on the positive effect of organic matter decomposition on soil permeability, water holding capacity, soil aeration, micronutrient contents, exchangeable bases and available phosphorus.

The generally superior plant performance in height and other parameters observed with maize cob waste in the second year could in part be attributed to the higher P content of maize cob waste (Table 2) and its subsequent release on decomposition with time and to the influence of the decomposition products in solubilizing phosphates from inorganic source.

Stover yields in the second year were better with cowdung/maize cob waste, probably due to its greater ability to make N available to the plants at all periods of growth because of its content of both fast decomposing and slow decomposition organic materials.

5.2 Effect of Phosphate Source and Organic Amendment on Nutrient Content of Index Leaves

With all the three P sources, plant contents of N, P, K and Ca was generally higher at higher rates of P fertilization but differences between 30 and 60kg P_2O_5/ha were not statistically significant. The increase in Ca content could be due to the higher exchangeable Ca contained in the P sources (Appendix 1) and to the application of organic waste. Chien *et al.* (1987) and Ikerra *et al.* (1994) have reported higher soil exchangeable calcium with higher rates of P fertilization and the application of farmyard manure.

In 1994, differences between the effects of SSP and TPR on the P and Ca concentrations of index leaves were not significant. This was a result of the dissolution of TPR and the subsequent release of P and Ca. Phosphorus and Ca contents were significantly lower with SPR. This is in contrast with the earlier observation of Sobulo *et al.* (1992) who reported Sokoto phosphate rock to be more soluble than Togo phosphate rock on soils from Uyo and Onne.

Mean for the two years showed Fe and Zn concentrations of index leaves to be higher in the control plots. This could be due to the low soil P level in the control plots. Badanur and Venkata (1973) reported decrease in available Zn when P was applied to acid soils. Mandal and Haldar (1980) found that applied P decreased DTPA-extractable Fe and Fn in the soils.

Significantly higher P uptake was recorded with maize cob waste than with cowdung/maize cob waste or cowdung alone. Interaction between SSP and maize cob waste gave the highest P uptake in both the years. This is attributable to the higher P content of maize cob waste. White and Ayoub (1983) studied the effect of

decomposition of plant residues with varying C:P ratios on P availability to plants and concluded that residues with C:P ratios less than 123 significantly increased P availability even on high P-containing soils.

Nitrogen concentrations in the index leaves were higher with cowdung/maize cob waste and with maize cob waste. This could be due to the ability of maize cob to absorb applied urea and only release the N slowly thereby preventing its leaching. Omojola (1993) observed that maize cob ground to pass through a 40-mesh sieve provided good absorption for urea, forming a gel-like mixture with the soil and slowly releasing N to plants mostly by microbial activity. He found maize performance and N uptake after two greenhouse croppings to be better with the urea/maize cob mixture than with urea alone.

Plant contents of N, P, K, Mg and Mn were generally higher with the application of organic amendments. This may be due to the nutrients released by the organic residues on decomposition. Aina and Egolum (1980) and Cheng (1987) reported increased plant uptake of N, P, K, and Mg with the application of organic amendment.

5.3 Effect of P Source and Organic Amendment on some Soil Chemical Properties at Harvest

Soil pH decreased with the application of organic amendment in 1993, and with cropping. The release of organic acids on decomposition of added organic matter could have a depressing effect on soil pH. Uyovbisere and Lombin (1990) reported a decrease in soil pH with cropping in a three year phosphatic fertilizer trial in Samaru.

.993, available soil micronutrient were higher at 30kg P_2O_5/ha. This level, therefore, appears to be the optimum, at higher P levels micronutrient availability was reduced. Antagonistic effect of P on Fe, Cu and Zn availability have been reported by many researchers (Mandal and Haldar, 1980; Badanur and Venkata, 1973).

The eventual decomposition of added organic matter with time and subsequent release of more micronutrient into the soil solution may be responsible for the disappearance of the effect of P rate on available soil micronutrient contents in the second year.

Higher levels of soil organic carbon content recorded in soils treated with maize cob waste was due to the higher organic carbon content of the material.

5.4 Correlation Between some Soil Properties, Plant Nutrient Content and Plant Performance

Bray-1 P and soil organic carbon content were very significantly correlated with P content of index leaves in both years. However, the correlation with organic carbon was higher in the first year while correlation with Bray-1 P was higher in the second year. This was probably because a greater part of the P taken up by the plant in the first year was in the organic form, but with the decomposition of organic matter and the mineralization of organic P more P was absorbed in the inorganic form. According to Brady (1984) plants can absorb some forms of organic phosphorus, mainly phytin and phytin derivatives.

Another reason for the strong correlation between soil organic carbon content and P concentration in plant could be the effect of soil organic matter in dissolution of phosphate rocks and in reducing phosphate sorption in the soil.

Strong correlations observed in both years between exchangeable Ca and P uptake is due to the release of Ca into the soil solution with the dissolution of P from phosphate rock as earlier mentioned. Negative correlations were observed between P uptake and soil pH in both years. This was due to the effect of acidity on phosphate rock dissolution. Many researchers have reported on the positive effect of decreasing soil pH on phosphate rock dissolution (Peaslee *et al.*, 1962; Ensminger *et al.*, 1967; Bai-Fan *et al.*, 1990).

Negative correlations were seen between P content of index leaves and available Fe in the soil in both years, and between Fe content of leaves and grain yield in the second year. This could be attributed to the antagonistic interaction between P and Fe availability to plants as earlier mentioned.

Grain yield and other yield parameters were strongly correlated with Mg content of index leaves in the first year. This was due to the slight Mg/k imbalance in the trial soil at the commencement of the experiment (Table 1). Corey (1973) reported that Mg/k imbalance in soil could cause yield depression due to induced Mg deficiency. During the second year correlations between Mg uptake and grain yield and other yield components were not significant, probably due to the effect of the decomposition of added organic matter in correcting the Mg/k imbalance.

CHAPTER SIX

SUMMARY AND CONCLUSION

Phosphorus deficiency is a major soil factor limiting food production in the northern guinea Savanna, and the successful production of high nutrient requiring crops such as maize is only possible with P fertilization. Due to the high cost of soluble phosphate fertilizers, cheaper sources of P must be sourced locally in view of the very low resources of Nigerian peasant farmers who produce most of the food crops consumed in this country.

A field trial was initiated to evaluate the effect of the direct application of ground phosphate rocks from Sokoto and Togo on the growth and yield of maize and to compare their performances against single superphosphate. In the first year, Sokoto phosphate rock, Togo phosphate rock and single superphosphate were applied at 0, 30 and 60kg P_2O_5/ha with either cowdung, maize cob or maize cob + cowdung mixture at the rate of 5t/ha to aid dissolution of the added phosphates. The treatments were laid out in a split-plot design and replicated three times, with organic amendment as the main factor and P source and rates as subfactors. Urea and muriate of potash were uniformly applied to the plots at the rates of 120kg N/ha and 30 K_2O/ha respectively based on soil test values. In the second year residual effect of the P applied the previous year was tested. Only urea and muriate of potash were added to the plots at 120kg N/ha and 30 K_2O/ha respectively.

From the study the following observations were made:

1. Maize performance as measured by grain yield, plant height, cob length and diameter, days to silking, kernel number per cob, kernel bulk density and

stover yield was generally better with the application of phosphate sources and organic amendments in both years relative to control.

2. Agronomic efficiencies of the two phosphate rocks relative to single superphosphate improved in the second year. The efficiency of Togo phosphate rock was superior to that of Sokoto phosphate rock in both years.
3. Single superphosphate was significantly superior to Togo and Sokoto phosphate rocks in terms of maize performance. Togo phosphate rock was however slightly superior to Sokoto phosphate rock in all the maize performance parameters measured in both years.
4. Phosphate rates of 30 and 60kg P_2O_5/ha generally produced better performance than 0kg O_5/ha. The difference between 30 and 60kg P_2O_5/ha in terms of maize performance was generally not significant in both years.
5. Phosphate uptake was generally better with maize cob waste than with cowdung/maize cob waste mixture or cowdung.

From the foregoing, the following conclusions can be drawn:

1. The two phosphate rocks released sufficient amounts of P to influence maize yields and P uptake, though not to the same extent as single superphosphate.
2. Application of organic amendments improved P uptake and maize performance.
3. Maize performance and P uptake with Togo phosphate rock was generally superior than with Sokoto phosphate rock.
4. With the application of organic amendments, only small levels of inorganic P application is required for maize growth in this soil. Phosphorus rate of 30kg P_2O_5/ha appears to be optimum.

5. Relative effectiveness of the phosphate rocks was better in the second year than the first year due to residual effect.

6. Maize performance was generally better in year of P application.

Further field studies are required to evaluate how various other organic waste materials that abound in our environment could be used to complement inorganic P applied to the soil and reduce the rate of application of inorganic P fertilizer. This will go a long way in increasing the profit margin of the resource-poor peasant farmers who constitute the main food crop producers in this country.

REFERENCES

Abbot, J.S., and T.C. Tucker. 1973. Persistence of manure phosphorus availability in calcareous soil. *Soil Sci. Soc. Am. J.* 37: 60-63.

Adegoke, O.S., T.R. Ajayi and M.A. Rahama. 1994. Fertilizer raw material situation in Nigeria. In: Lombin *et al.* (eds.). Organic fertilizer in the Nigerian Agriculture: Present and Future. Fed. Min. Agric. Nat. Res., Abuja, pp.51-66.

Adepetu, J.A. 1970. The relative importance of organic phosphorus to crop nutrition in soils of western Nigeria. M.Phil. Thesis. Univ. of Ife, Ile-Ife.

Adepetu, J.A. and R.B. Corey. 1975. Organic phosphorus as a predictor of plant available phosphorus in soils of southern Nigeria. *Soil Sci.* 122: 159-164.

Aina, P.O. and E. Egolum. 1980. The effect of cattle feedlot manure and inorganic fertilizer on the improvement of subsoil productivity of Iwo soil. *Soil Sci.* 129: 212-217.

Allison, L.E. 1965. Organic carbon. In: C.A. Black (ed.) *Methods of Soil Analysis, Agron. Monograph 9. No.2, Amer. Soc. Agron.*, Madison, Wisconsin, pp. 1367-1378.

Almeida, L.A.V. and L.R. Balbino. 1960. Comparison of some phosphate fertilizers in a red ferrallitic soil of Angola. *Bull. Docum. Ass. Int. Fabr. Superph.* No.27: 15-28.

Amapu, I.Y., V.O. Chude and E.N.O. Iwuafor. 1994. Evaluation of Sokoto phosphate rock for direct application. Farm. Syst. Res. Prog., Crop Sch. Meet. Inst. Agric. Res., Samaru, Nigeria.

Amapu, I.Y., V.O. Chude and E.N.O. Iwuafor. 1995. Evaluation of Sokoto phosphate rock for direct application. Farm. Syst. Res. Prog., Crop. Sch. Meet. Inst. Agric. Res., Samaru, Nigeria.

Andrew, E. 1985. The adsorption of inorganic phosphate by a sandy soil as influenced by dissolved organic compounds. *Soil Sci.* 140: 251-255.

Anonymous. 1989. Factors affecting fertilizer use efficiency. In: Enwezor *et al.* (ed.) *Fertilizer use and management practices for crops in Nigeria*. Fert. Proc. Dist. Div., Fed. Min. Agric., Lagos. pp. 14-15.

Badanur, V.P. and B.V. Venkata. 1973. Influence of phosphorus build up on availability of macronutrients in red soils of Bangalore. *Soil Sci.* 116: 292-294.

Bai-Fan, J., L. Ru-kun, L. Ching-Kwei. 1990. A review of the studies on PR for agric. use in China. *Fert. Res.* 26: 1-2.

Barnes, J.S., and Kamprath, E.J. 1975. Availability of North Carolina rock phosphate applied to soils. North Carolina Agricultural Experiment Station Tech. Bull. No. 229, Raleigh, N.C.

Bates, J.A.R. and T.C.N. Baker. 1960. Studies on a Nigerian forest soil. II Distribution of phosphorus in the profile and in various soil fractions. *J. Soil Sci* 11: 257-265.

Bationo, A., S.K. Mughogho and A.U. Mokwunye. 1986. Agronomic evaluation of phosphorus fertiliser in tropical Africa. In: A.U. Mokwunye and P.L.g. Vlek (eds.) Management of Nitrogen and Phosphorus Fertilizers in Sub-Saharan Africa. pp. 283-318 Martinus Nighoff Publishers. Lancaster.

Bottini, E. 1958. On the efficacy of micropulverised phosphates as fertilizers. *Ann. Sper. Agr.* 12: 503-523.

Brady, N.C. 1984. The Nature and Properties of Soils. Macmillan Publishing Company, New York. 750p.

Bremmer, J.M. 1965. Total Nitrogen. In: C.A. Black (eds.) Method of Soil Analysis. Monograph 9 No. 2. Amer. Soc. Agron., Madison, Wisc., U.S.A. pp. 226-234.

Cheng, B.T. 1987. Sawdust as a greenhouse growing medium. *J. Plant Nutrition* 10: 1437-1466.

Chien, S.H., E.J. Sompons, O.J. Hena and D.J. Hellums. 1987. Greenhouse evaluation of phosphorus availability from compacted phosphate rocks with urea or urea and Triple superphosphate. *Fert. Res.* 14: 245-256.

Cooke, G.W. 1956. The value of rock phosphate for direct application. *Emp. J. Exp.* 2: 295-306.

Cooke, G.W. and F.V. Widdowson. 1959. Field experiments on phosphate fertilizer: A joint investigation. *J. Agric. Sc.* 53: 46-306.

Cooke, G.W. 1978. Experimental work in the United Kingdom on the agricultural value of phosphate rock. In: Seminar on Phosphate Rock for Direct Application. IFDC. Muscles Shoals. Alabama. USA. pp. 304-324.

Copeland, O.L. and F.G. Merkle. 1992. Influence of certain soil treatments on the fixation and availability of applied phosphate. *Soil Sci. Soc. Am. Proc.* 6: 321-327.

Corey, R.B. 1973. Factors affecting the availability of nutrients to plants. In: L.M. Walsh and J.B. Beaton (eds.). Soil Testing and Planting Analysis. *Soil Sci. Amer.*, Madison, Wisconsin.

Dabin, B. 1970. *Methods d'etude de la fixation du phosphore sur le sols tropicaux. Cot. Fib. Trop.* 25: 213-234.

Davies, G.R. 1970. Value of phosphate rock as a fertilizer. *N.A.A.A. Advisory Papper No.8*. Ministry of Agric., Fisheries and Food, Middlessex, England.

Day, P.R. 1965. Hydrometer method of particle-size analysis. **In**: C.A. Black (ed.). Methods of Soil Analysis. Agron. Monograph 9 No. 2. Amer. Soc. Agron., Madison, Wisconsin, USA. pp. 562-566.

Dieldrichs, C. 1991. Influence of different P sources on the efficiency of several tropical endomycorrhizal fungi promoting growth of *Zea mays* L. *Fert. Res.* 128: 124-128.

Edwards, G.H.A. 1956. Observations on the response of crops to rock phosphate. International Society of Soil Science, Paris, Comm. 4: pp.13-20.

Eivazi, F. and C.C. Weir. 1989. Phosphorus and mycorrhizal interaction on uptake of phosphorus and trace elements by maize. *Fert. Res.* 21: 19-22.

El-Baruni, B. and S.R. Olsen. 1979. Effect of manure on solubility of phosphorus in calcareous soils. *Soil Sci.* 128: 219-225.

Ellis, R., Jr., M.A. Quader, E. Truog. 1955. Rock phosphate availability as influenced by soil pH. *Soi Sci. Soc. Am. Proc.* 19: 484-487.

Engelstad, O.O., A. Jugsujinda, S.K. Debatta. 1974. Response by flooded rice to phosphate rocks varying in citrate solubility. *Soil Sci. Soc. Amer. Proc.* 38: 524-529.

Ensminger, L.E., R.W. Pearson, W.H. Arminger. 1967. Effectiveness of rock phosphate as a source of phosphorus to plants. US Dept. Agr., *ARS Bull.* 41-125.

Enwezor, W.O. and A.W. Moore. 1966a. Comparison of two methods for determining organic phosphorus in some Nigerian soils. *Soil Sci.* 102: 284-285.

Enwezor, W.O. and A.W. Moore. 1966b. Phosphorus status of some Nigerian soils. *Soil Sci.* 102: 322-428.

Enwezor, W.O., E.J. Udo, K.A. Ayotade, J.A. Adepetu and V.O. Chude (eds.) 1988. A review of soil and fertilizer use research in Nigeria Vol. 5. Fert., Proc. and Dist. Dept., Fed. Min. Agric., Water Res. and Rural Development, Lagos.

GENSTAT V. 1980. Mark 4.03 Lawes Agricultural Trust. Rothamstead Experimental Station.

Gerrestsen, F.C. 1948. Influence of micro-organisms on phosphate intake by the plant. *Pl. Soil* 1: 51-81.

Goldsworthy, P.R. and R.G. Heathcote. 1963. Fertilizer trials with groundnuts in northern Nigeria. *Emp. J. Expl. Agric.* 31: 351-366.

Graham, E.R. 1955. The availability of natural phosphates according to energy changes. *Soil Sci. Soc. Am. Proc.* 19: 26-29.

Hinga, G. 1973. Phosphate sorption capacity in relation to properties of several types of Kenya soils. *East Afr. Agric. For. J.* 38: 400-404.

Holford, I.C.R. and G.E.G. Matingly. 1975. The high and low energy phosphate adsorbing surfaces in calcareous soils. *J. Soil Sci.* 26(4): 407-417.

Harvath, D.J. and J.R. Todd. 1968. Magnesium supplements for cattle. **In**: Proc. 23rd Annual Texas Nutrition Conference. Houston, Texas. pp. 96-104.

Howe, D.O. and E.R. Graham. 1957. Salt concentration factors in the availability of phosphorus from rock phosphate as revealed by the growth and composition of alfalfa. *Soil Sci. Soc. Am. Proc.* 21: 25-28.

Ikerra, T.W.D., P.N.S. Mnkeni and Bal Ram Singh. 1994. Effects of added compost and farmyard manure on P release from Minjingu phosphate rock and its uptake by maize. *Norwegian Journal of Agric. Sci.* 8: 13-23.

Ipinmidun, W.B. 1972. Organic phosphorus in some northern Nigerian soils in relation to soil organic carbon and as influenced by parent rock and vegetation. *J. Sc. Fd. Agric.* 23: 1099-1105.

Jackson, J.E. and G.W. Burton. 1960. A five-year comparison of rock phosphate and concentrated superphosphate for several forage crops. *Agro. J. 52:* 692-694.

Jones, M.J. 1973. Time of application of nitrogen fertilizer to maize at Samaru, Nigeria. *Expt. Agric.* 9: 113-120.

Jones, M.J. and A. Wild. 1975. Soils of West African Savanna. Tech. Comm. No. 55 Commonwealth Bureau of Soils, Harpenden, England, 246p.

Juo, A.S.R. 1979. Selected Methods for Soil and Plant Analysis. IITA Manual Series No.1, Ibadan, Nigeria.

Kamprath, E.J. 1973. Phosphorus. **In**: P.A. Sanchez (ed.). A Review of Soils Research in Tropical Latin America. *North Carolina Agr. Exp. Sta. Bull.* 219: 138-161.

Kang, B.T. and O.C. Osiname. 1979. Phosphorus response of maize grown on Alfisols of southern Nigeria. *Agron. J.* 71: 873-877.

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Khasawneh, F.E. and J.P. Copeland. 1973. Cotton root growth and uptake of nutrients: relations of phosphorus uptake to quantity, intensity and buffering capacity. *Soil Sci. Soc. Am. Proc.* 37: 250-254.

Khasawneh, F.E. and E.C. Doll. 1978. The use of phosphate rock for direct application to soil. *Advances in Agronomy* 30: 159-206.

Klinkenberg, K. and Higgins, G.M. 1968. An outline of northern Nigerian soils. *Nig. J. Sci.* 2: 91-115.

Kowal, J. and D.T. Knabe. 1972. An Agroclimatological Atlass of the Northern States of Nigeria, with explanatory notes. Ahmadu Bello University Press, Zaria, Nigeria.

Lehr, J.R. 1967. Variations in composition of phosphate ores and related reactivity. Proc. 17th Ann. Meet. Fert. Ind. Roundtable, Washington D.C. pp. 61-67.

Lindsay, W.L. and P.L.G. Vlek. 1977. Phosphate minerals. **In:** J.B. Dixon and S.B. Weed (ed.). *Minerals in Soil Environment. Soil Sci. Soc. Am.*, Madison, Winsc. pp. 639-672.

Lombin, G. 1979. Evaluation of the direct and residual effects of ground rock phosphate in relation to other phosphate carriers in the northern Savanna. *Samaru Miscellaneous Paper* 88, Institute for Agricultural Research, Samaru, Zaria, Nigeria.

Mandal, L.N. Haldar. 1980. Influence of phosphorus and zinc application on the availability of zinc, copper, iron, manganese and phosphorus in waterlogged rice soils. *Soil Sci.* 130: 251-257.

McLean, E.O. 1956. Factors affecting yield and uptake of phosphorus by different crops: II: rock phosphate and superphosphate, separate and in combination, under extended cropping. *Soil Sci.* 82: 181-192.

McClellan, G.H. 1978. Mineralogy and reactivity of phosphate rock for direct application. Seminar on Phosphate Rock for Direct Application. IFDC, Muscle Shoals, Alabama, USA. pp. 57-74.

McClellan, G.H. and L.R. Gremillion. 1980. **In:** Evaluation of phosphate rock materials. F.E. Khasawneh, E.C. Sample and E.J. Kamprath (eds.). The Role of Phosphorus in Agriculture. *Soil Sci. Soc. Am.*, Madison. pp. 43-79.

McClellan, G.H. and J.R. Lehr. 1969. Crystal chemical investigation of natural apatites. *American mineralogist* 54: 1374-1391.

Meek, B.D., L.E. Graham, T.J. Donovan, and K.S. Mayberry. 1979. Phosphorus availability in a calcareous soil after high loading rates of animal manure. *Soil Sci. Soc. Am. J.* 43: 741-743.

Mokwunye, A.U. 1977. Phosphorus fertilizers in the Nigerian Savanna soils. I. Use of phosphorus sorption isotherms to estimate the phosphorus requirement of maize at Samaru. *Trop. Agric.* 54: 265-271.

Newman, E.I. and R. Andrews. 1973. Uptake of phosphorus and potassium in relation to root growth and root density. *Plant and Soil* 38: 49-69.

Notholt, A.J. 1974. Phosphate rock: world production, trade and resources. Proceedings of the first industrial minerals. International Congress, London, pp. 104-120.

O'Connor, G.A., K.L. Knudsen, and G.A. Conney. 1986. Phosphorus solubility in sludge-amended calcareous soils. *J. Environ. Qual.* 15: 308-312.

Olsen, R.S., R.F. Hensler and J.O. Attoe. 1970. Effect of manure application, aeration and soil pH on soil P transformation and on certain soil test values. *Soil Sci. Soc. Am. Proc.* 34: 222-225.

Omojola, M. 1993. Modification of urea with maize cobwaste for use as slow release fertilizer. Ph.D. Thesis, Ahmadu Bello University, Zaria.

Omotoso, T.I. 1971. Organic phosphorus contents of some cocoa growing soils of southern Nigeria. *Soil Sci.* 112: 195-199.

Parr, J.F. and R.I. Papendick. 1978. Factors affecting the decomposition of crop residues by micro-organisms. **In**: Oschwarld, W.R. (ed.). Crop Residue Management Systems. ASA Special Publication No. 31, Madison Wisc. USA, pp. 101-129.

Peaslee, D.E., C.A. Anderson,G.R. Burns, and C.H. Black. 1962. Estimation of relative value of phosphate rock and superphosphate to plants on different soils. *Soil Sci.* Soc. *Am. Proc.* 26: 566-570.

Pratt, P.F., W.W. Jones and F.T. Bingham. 1957. Magnesium and potassium contents of orange leaves in relation to exchangeable Mg and K in the soil at various depths. *Proc. Amer. Soc. Hort. Sci.* 70: 245-251.

Rhenorn, T., J. Higgins and S. Axelrod. 1978. Relation of phosphate rock availability to some soil properties and cultivation time. Seminar on Phosphate Rock for Direct Application. IFDC, Muscle Shoals, Alabama, U.S.A.

Rierra, F.A., R. Alvarez and J. Coca. 1991. Production of furfural by acid hydrolysis of corn cobs. *J. Chem. Tech. Biotechnol.* 50: 149-155.

Robertson, W.K. and C.E. Hutton, 1958. An evaluation of ten P sources by growth of 4 field crops. *Agron. J.* 50: 24-28.

Rogers, H.T., R.W. Pearson, and L.E. Ensminger. 1953. Comparative efficiency of various phosphatic fertilizers. **In:** W.H. Pierra and A.G. Norman (eds.). Soil and fertilizer phosphorus in Crop Nutrition, pp. 189-242. Academic Press, New York.

Sample, E.C., R.J. Soper and G.J. Racz. 1980. Reactions of phosphate fertilizers in soils. **In:** The Role of Phosphorus in Agriculture. F.E. Khasawneth, E.C. Sample, and E.J. Kamprath (eds.). *Am. Soc. Agron.*, Madison, Wis., pp. 263-310.

Sanchez, P.A. 1976. *Properties and Management of Soils in the Tropics*. John Wiley and Sons, New York, 618p.

Sharif, M. and F.M. Chaudlhry. 1966. Effect of sodium and calcium salts on phosphate uptake, 'A' value and superphosphate transformation. *Nucleus* 3: 32-34.

Sobulo, R.A., F.I. Oguntoyimbo, M.A. Baten and A.R. Omonade. 1992. Evaluation of Sokoto rock phosphate as source of phosphorus in Nigerian soils. 20th Ann. Conf. Soil Sci. Soc. Nig., Ilorin.

Struthers, P.H., and D.H. Sieling. 1950. Effect of organic anions on phosphate precipitation by iron and aluminium as influenced by pH. *Soil Sci.* 69: 205-213.

Udo, E.J. and J.A. Ogunwale. 1977. Phosphorus fractions in selected Nigerian soils. *Soil Sci. Soc. Am. J.* 41: 1141-1146.

USDA Soil Survey Staff. 1975. Soil Taxonomy: A basic system for making and interpreting soil surveys. USDA Handbook 436. US Govt. Printing Office, Washington, D.C. 750p.

Uyovbisere, E. and G. Lombin. 1990. Comparative evaluation of selected fertilizer materials under field conditions in the sub-humid Nigerian Savanna II. Phosphatic fertilizers. *Samaru J. Agric. Res.* 7: 139-149.

Uzu, F.O., A.S.R. Juo and A.A.A. Fayemi. 1975. Forms of phosphorus in some important agricultural soils of Nigeria. *Soil Sci.* 120: 212-218.

Weir, C.C. and R.J. Soper. 1963. The solubility studies of phosphorus in some calcareous Manitoba soils. *J. Soil Sci.* 14: 256-260.

Welte, E. 1978. Viewpoints on the utilization of rock phosphate for direct application. **In:** Seminar on Phosphate Rock for Direct Application, IFDC, Muscle Shoals, Alabama, USA. pp. 325-337.

White, R.E. and A.T. Ayoub. 1983. Decomposition of plant residues of variable C/P ratio and the effect on soil phosphate availability. *Pl. Soil* 74: 163-173.

Widdowson, F.V. and A. Penny. 1968. Results of an experiment at Rothamsted testing FYM and N, P and K fertilizers on five arable crops and permanent grass. *J. Agric. Sci.* 70: 53-58.

Wild, A. 1950. The retention of phosphate by soil: A review. *J. Soil Sc.* 1: 221-238.

Williams, R.J.B., G.W. Cooke, and F.V. Widdowson. 1963. Results of an experiment at Rothmsted testing FYM and N, P and K fertilizers on five arable crops. *J. Agric. Sci* 60: 353-357.

Young, R.D. and C.H. Davies. 1970. Phosphate rock: elusive, valuable ore. *War on Hunger* vol. IV No. 2. pp.1-7.

Appendix 1: Chemical constitution of phosphate rocks from Sokoto and Togo (Source: Adegoke *et al.* (1994).

Constitutents (%)	Sokoto rock	Togo rock
P_2O_5	36.25	36.60
S_1O_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

Appendix 2: Effect of source and rate of phosphorus on maize grain yield (Source: Amapu *et al.* (1994, 1995).

	rate (kg P_2O_5/ha)				
Source	0	30	60	SE±	LSD
			1993		
SSP	2347b	3177a	3058a	87.33	**
TPR	2347b	2489a	2584a	220.70	NS
SPR	2347b	2773a	2892a	100.77	*
			1994		
SSP	967c	1671b	2069b	130.9	**
TPR	967b	1657ab	2144a	242.9	*
SPR	967b	1567ab	1929a	26.1	*

SSP = Single superphosphate
TPR = Togo phosphate rock
SPR = Sokoto phosphate rock
** = Significant at 1% level
* = Significant at 5% level.

Appendix 3: Record of 1993 daily rainfall (in mm) observed at Samaru.

Date	April	May	June	July	Aug.	Sept.	Oct.
1		18.8			10.2	14.9	
2			29.6	3.3			
3					22.3		
4		3.5		25.4	3.2	53.2	
5			29.4			2.2	
6						12.7	
7		0.5	13.2	TR			
8					17.7	1.9	
9							
10				13.5		16.8	
11							
12			6.1		12.3	33.2	
13							
14							
15					13.1		
16		7.1					
17	3.1				63.3	6.9	
18		5.1			37.7	16.5	
19				15.6			
20	1.2			32.1	11.1	8.4	
21		1.0		75.0	19.7		
22			25.1				
23		2.7	3.0	34.6	21.2		
24		12.5		1.2	12.1	2.3	
25	1.2	22.2		50.0			
26			4.7			12.8	
27		19.8		8.5	6.3		
28							
29	2.8		28.1	8.2			
30		2.7	16.6	1.6	11.2		
31		17.7			31.2		
Total	8.3	113.6	155.8	269.9	300.0	181.8	0.0

Source: Department of Meteorological Services, I.A.R., Samaru, Zaria.

Appendix 4: Record of 1994 daily rainfall (in mm) observed at Samaru.

Date	April	May	June	July	Aug.	Sept.	Oct.
1		34.0					
2		2.7	1.0		1.5		14.2
3					13.5	1.8	7.3
4					11.7	0.4	2.1
5					18.6	0.8	
6			10.8		8.6	2.2	
7				26.2	9.4	2.6	
8				27.7		10.8	
9					31.2	3.0	2.1
10			13.1				0.5
11						1.2	
12	1.5				10.0	7.5	2.5
13					6.4	21.8	
14				12.3		5.0	
15			37.8		30.8		20.8
16		11.9	7.6				
17	10.6	4.8	22.7	3.6			
18			20.6	2.2	12.7		13,7
19					2.5	3.1	
20				43.4		14.6	
21	1.4		33.5		5.0		
22					12.2		
23	4.1				30.0		5.6
24		6.8	18.5	3.0	1.0		
25					2.0		0.3
26	2.8	6.4	39.6	1.1	2.2		
27		53.5					
28				49.7	2.8	2.1	
29						1.3	
30			27.0		3.7		
31					0.4		
Total	20.4	120.1	231.9	169.2	215.9	82.5	69.2

Source: Department of Meteorological Services, I.A.R., Samaru, Zaria.