STUDIES ON SOIL TEST CORRELATION, CALIBRATION AND INTERPRETATION FOR PHOSPHORUS FERTILIZER RECOMMENDATION ON MAIZE (Zea mays L.)

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A thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfillment for the award of the Degree of Doctor of Philosophy in Soil Science.

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DECEMBER, 1997

DECLARATION

I hereby declare that this thesis has been written by me and is the record of my own research work. It has not been presented before in any previous application for a higher degree and is not being concurrently submitted in candidature of any other degree.

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CERTIFICATION

This thesis titled "**STUDIES ON SOIL TEST CORRELATION, CALIBRATION AND INTERPRETATION FOR PHOSPHORUS FERTILIZER RECOMMENDATION ON MAIZE (*Zea mays* L.)**" by Emeruche Kalu Nto meets the regulations governing the award of the degree of DOCTOR OF PHILOSOPHY of Ahmadu Bello University, Zaria, and is approved for its contributions to scientific knowledge and literary presentation.

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DEDICATION

Affectionately dedicated to
my dear wife, Margaret Mgbekeocha,
our children, Nnanyere, Ezinne, Nneoma,
Chioma and Okore,
through whose love, patience, understanding
and encouragement
I am able to achieve this.

ACKNOWLEDGEMENT

I express my sincere and heart-felt thanks to all the people who contributed in one way or the other to the success of this study.

I am particularly grateful to my major supervisor and Chairman Supervisory Committee, Dr. V.O. Chude, for his encouragement and continual discussion throughout this investigation, and for his invaluable suggestions, guidance and help during the writing up of the thesis. I also express my profound gratitude to my former major supervisors, Dr. L.A. Nnadi with whom I started the study, and Prof. G. Lombin who guided me through the field, greenhouse and laboratory investigations. I am very grateful to all members of my supervisory committee, Prof. K.B. Adeoye and Dr. E.N.O. Iwuafor for their guidance, suggestions and encouragement. I thank the Head of Department, Prof. J.J. Owonubi for his encouragement, understanding and continual fighting for the extension of my registration.

I extend my gratitude and thanks to my dear friend Mr. I.Y. Amapu who helped me in too many wonderful ways-in the classroom, greenhouse, computer and at home. He and his dear wife Nourice were a great help and inspiration to me.

I am highly indebted to Mr. Victor A. Odigie and his laboratory staff for all the help I received during the laboratory analysis. I also express my profound gratitude to Drs. S.A.S. Olorunju and O.E. Asiribo, and to Mr. M.O. Otitoju who helped me with computer analysis of the data.

I express my gratitude and heart-felt thanks to the Director, Federal Department of Agricultural Land Resources, Dr. S. Anande-Kur, for kindly approving a part-time programme to me and fully supporting financially all aspects of the project. I sincerely thank the Head, Soil Testing Division, Dr. Sheriff O. Sanni, under whose Division the project was carried out. I am particularly grateful to him for his full support and

encouragement without which the study could not have been completed. I am also grateful to Mr. C.O. Ezendu, my former Head of Division, under whom I started this project. I thank in a special way Dr. E.O.U. Okoye who helped me in many ways including aspects of the soil classification. I sincerely thank Mr. J.C. Aduwa who as the Head, State Based Unit, Jos, had the responsibility of overseeing the field work. He inspired me with his commitment and zeal. I am also very grateful to Messrs Jude Adamu and N.A. Opara and the entire field staff of FDALR, Jos, who laboured even under very harsh and unfavourable conditions to ensure a successful execution of the field fertilizer rate studies. I thank Dr. S.M.C. Oparaugo who, as the Principal, Federal Soil Conservation School, Kuru, provided me with accommodation and other facilities during the field work. I commend highly Dr. O.A. Ogunsola who adequately took care of my office whenever I was away in the field. I also express my profound gratitude to Mr. & Mrs. I.L. Amajuoyi, Mr. and Mrs. I.A. Chikezie and Dr. & Mrs. L.A. Ikpaahindi who helped me in many ways while I worked.

Mr. and Mrs. John O. Okoli and Mr. and Mrs. M.A. Ajadi deserve a special mention. Their contributions to the execution of the project and to my general well-being cannot be quantified. Without their financial and moral support I would have had difficulties in getting the work completed on schedule. I am very grateful to them.

I express my heart-felt thanks to the Programme Manager and staff of PADP, Jos, Programme Manager and staff, PADC, Jos, Programme Manager and staff of BNARDA, Makurdi, Officers-in-charge, LBR&RDA, Ugbema and Farm Centre, Yandev, and Zonal Coordinator, MANR, Ankpa, for providing the experimental sites and facilities for site preparation, and for helping in the procurement of inputs.

I am especially grateful to Mr. C.C. Onyekwelu who, apart from helping me with machinery in the field, provided a very conducive accommodation for me in Abuja

for preparing the thesis. Without his support and that of his dear wife I could not have coped with the pressure of my posting to Abuja.

I am deeply grateful to Mr. and Mrs. Nnaoke Ufere, my very dear relations in the United States of America. They took on themselves the full responsibility of supporting the family financially and morally while I worked. Above all, they provided the money with which I made my trips and carried out the production of the thesis.

I wish to express my love and appreciation to all members of my family. My dear wife, Margaret Mgbekeocha, was simply wonderful in her encouragement and support. She provided me the love, care and understanding I needed even when she was left most of the time to bear, in its entirely, the responsibility of taking care of the family. Without her contribution this work could not have been completed. I also give my love to my children who were denied much of this while I worked. I very much appreciate the special help and encouragement I received from Franklin A. Okore, and from Inyang, Okafor, Justina, Chidinma, Augustina, Agartha and other relations too numerous to mention.

I am very grateful to Mr. David E.S. Inim who meticulously and painstakingly typed the thesis in a very record time. I highly commend his efforts.

Above all, I thank the Almighty God for His love, mercies and compassion. To Him be the glory.

ABSTRACT

The study was carried out in the southern Guinea savanna zone of Nigeria to develop a soil testing programme which leads to the establishment of a rational basis for phosphorus fertilizer recommendations to crops. To achieve this, correlation studies to determine the best extractant of available phosphorus, and calibration studies to develop site specific fertilizer recommendation practices were carried out.

Thirty-six surface soil samples collected across Benue, Plateau and parts of Kogi States were used for the correlation studies. Eight soil test methods, Mehlich 1, Mehlich 2, Bray 1, Bray 2, Olsen's, Modified Mehlich 1, Mississippi, and AB-DTPA were used to extract phosphorus from the soils. Pot experiments were set up in the greenhouse using maize as the test crop. Two treatments, P_0 without phosphorus, and P_1, with adequate amount of phosphorus, were used. Maize was grown for 35 days. Forage dry matter yields and phosphorus uptake were determined.

Ten sites were selected for the field fertilizer rate studies which were carried out for two cropping seasons, 1988 and 1989. Six phosphorus fertilizer rates, 0, 20, 40, 60, 80 and 100 kg P_2O_s/ha, were used. Surface soil samples were collected before maize planting and fertilizer application. Available phosphorus was extracted with the eight soil test methods.

The results showed that each soil test method extracted a wide range of phosphorus from the soils. The effectiveness of the methods in solubilising quantities *of* phosphorus from the soils was Bray 2 > Olsen's > Mehlich 2 > Modified Mehlich 1 > Bray 1 > Mehlich 1 > AB-DTPA > Mississippi, with a mean extractable phosphorus of 5.54, 5.47, 4.50, 4.0, 3.57, 2.86, 1.74 and 1.22 mg kg^{-1}, respectively.

The herbage dry matter yields of maize at P_0 varied among the soils and ranged from 1.03 to 13.72 g/pot. Analysis of variance showed that the yields varied significantly at the 0.1 % probability level with a high coefficient of variation of 21.1 %. The phosphorus uptake at P_0 also varied very significantly with the soils and ranged from 1.29 to 24.0 mg/pot.

Actual yield, relative yield, actual yield increase and phosphorus uptake were used to evaluate the effectiveness of the soil test methods. In general, the precision of prediction was relative yield > actual yield > phosphorus uptake > actual yield increase. The effectiveness of the extractants varied with the yield parameters. In all, Mehlich 1, Modified Mehlich 1 and Bray 1 were the best predictors, in that order.

From the correlation studies it was found that all the eight soil test methods were suitable for solubilising available phosphorus from these soils. However, Mehlich 1 which was the most precise and effective and the least influenced by soil properties is recommended for soil testing in the southern Guinea savanna.

The results of the field fertilizer rate studies showed that maize grain yields varied from treatment to treatment in each site, from site to site for each treatment, and from year to year for each site-treatment. In general, the soils in all the 19 site-years responded significantly to phosphorus fertilization although the degree *of* response varied from site to site and year to year.

The critical levels of extractable phosphorus were determined by both Cate-Nelson graphical and analysis of variance methods. The results were as follows: Mehlich 1, 7.25 and 7.29 mg kg^{1}, Mehlich 2, 13.0 and 13.20 mg kg^{1}, Bray 1, 8.0 and 7.83 mg $kg^{"1}$, Bray 2, 8.0 and 6.76 mg kg', Olsen's, 7.25 and 6.94 mg kg^{1}, Modified

Mehlich 1, 6.75 and 6.36 mg kg^{1}, Mississippi, 1.20 and 1.12 mg kg^{1}, and AB-DTPA, 2.70 and 2.60 mg kg^{-1}, for the two methods, respectively.

The Mitscherlich-Bray equation, Log(A-y) = Log A-C,b, and its expanded form, Log(A-y) = LogA - C,b - Cx, were used for calibrating the responses of maize to phosphorus fertilization. The correlation factors, C,, obtained for Mehlich 1, Mehlich 2, Bray 1, Bray 2, Olsen's, Modified Mehlich 1, Mississippi and AB-DTPA soil tests were 0.047, 0.040, 0.056, 0.048, 0.069, 0.045, 0.243 and 0.156, respectively. Also the efficiency factor, C, for band applied phosphorus fertilizer was calculated as 0.014. Based on the Mitscherlich-Bray relationships and a graphical approach, arbitrary values of percent sufficiencies, *y,* of 10 to 93% which cover a full range of soil deficiencies, and corresponding soil test values, b, phosphorus fertilizer recommendations, *x,* were obtained. Calibration curves and tables were produced for the various soil test methods for use in interpreting soil test data to farmers.

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LIST OF ABBREVIATIONS

CL	-	Clay content
OC	-	Organic carbon content
Ex	-	Exch-Exchangeable
MI	-	Mehlich No.1
MII	-	Mehlich No.2
BI	-	Bray No.1
BII	-	Bray No.2
OL	-	Olsen's
MMI	-	Modified Mehlich No.1
MIS	-	Mississippi
AD	-	Ammonium Bicarbonate-DTPA
CEC	-	Cation Exchange Capacity
ECEC	-	Effective Cation Exchange Capacity.

CHAPTER ONE

INTRODUCTION

The results of numerous fertilizer trials conducted throughout Nigeria have led to the recognition of the importance of chemical fertilizers in increasing crop yields (Vine, 1953; Watson and Goldsworthy, 1964; Hardcastle, 1968; Amon and Adetunji, 1973; Balasubramanian *et al.*, 1980; Sobulo and Osiname, 1985). Some of these fertilizer trials ultimately led to the formulation of fertilizer recommendations based on a general knowledge of a range of nutrient additions that resulted in optimum crop yields under satisfactory soil and management conditions. The levels of chemical fertilizers recommended for specific crops, as would be expected, varied from one agro-ecological zone to another. However, for each ecological zone, there were usually little, if any, variations in the amounts recommended for a large group of soils of varying physical, chemical and mineralogical characteristics.

The initial fertilizer recommendations were "blanket" because they grouped soils of varying fertility levels and other characteristics. Subsequent improvement involved recommendations based on soil types whereby soils were grouped according to parent material, texture, site characteristics, and so forth. After soils have been put into production, fertility status is likely to be changed by fertilization, crop removal, erosion, tillage, and other cultural practices. Under good management and fertilizer programmes, soils generally improve in fertility, while those with poor management and inadequate fertilization will likely be depleted. Since management may cause similar soils to differ greatly in fertility status, general fertilizer recommendations based on soil type may no longer be satisfactory for maximum economic returns from the use of fertilizers (Cope and Evans, 1985).

Depletion or build up now calls for a specific technology in determining the fertility status of the soil.

Nitrogen and phosphorus had been the major nutrient elements that appeared limiting to crop production on a number of Nigerian soils. Varied responses were recorded with these elements for a number of crops (Amon, 1965; Hauck, 1966; Goldsworthy, 1967; Heathcote and Stockinger, 1970; Amon and Adetunji, 1970; Bache and Rogers, 1970; Agboola and Corey, 1976; Baker *et al.*, 1977; Balasubramanian *et al.*, 1978; Osiname, 1979). Because of known deficiencies of nitrogen and phosphorus in the savanna zone (Balasubramanian *et al.*, 1978) particularly to cereal crops, many soils now receive heavy fertilizer applications irrespective of whether or not there is a need for fertilization or the quantity applied.

If inadequate amounts of phosphorus are supplied to plants by native or residual phosphorus from fertilizer, it is necessary to apply this element in the form of fertilizer to correct the deficiency. The amount of native and residual phosphorus which could be available for use by growing crops in a particular soil and the amount of phosphate fertilizer to be supplemented for profitable crop production are usually estimated by "soil testing".

A number of techniques are available for assessing the phosphate requirements of soils and crops. These include phosphate sorption techniques (Beckwith, 1965; Ozanne and Shaw, 1968; Fox and Kamprath, 1970; Mokwunye, 1977; Enwezor, 1979; Sobulo, 1981), chemical extractants (acids, bases, combination of acids and bases, buffered salts and organic chelating agents), ion exchangers, electrodialysis, and isotopic dilution and exchangeability (Truog, 1930; Morgan, 1935; Bray and Kurtz, 1945, McAuliffe *et al.*, 1948; Williams, 1950; Mehlich, 1953; 1978; Olsen *et al.*, 1954; Amer *et al.*, 1955; Sahrawat, 1977; Soltanpour and Schwabb, 1977). These methods have been found

satisfactory under different conditions. Some of the approaches like sorption technique, ion exchange, electrodialysis, and isotopic dilution and exchange are tedious and time consuming, and cannot be adopted for routine work. The simplest and most widely applied procedure for determining the fertilizer needs of soils and crops is through the rapid chemical extraction of soils. The term "soil testing" has, therefore, been used exclusively to describe the process of making fertilizer recommendations through the interpretation and evaluation of results of rapid chemical extractions of essential nutrients from soils.

The amount of nutrient extracted in a soil test is of little use until it has been calibrated to crop response in field experiments. A good soil testing programme involves the calibration of the soil test values with crop yields and the development of systems for interpreting the results so that they can be used for making fertilizer recommendations.

Reliable soil tests based on sound field and laboratory research at many locations over a number of years are the only basis for:

(a) determining the fertilizer needs of specific crops and soils;

(b) achieving reliable and economic fertilizer recommendations;

(c) avoiding wastage of fertilizers; and

(d) minimising soil and water pollution through the addition of excessive amounts of chemical fertilizers.

This study was undertaken because aggressive and systematic soil testing programme is yet to be embarked upon in most parts of Nigeria. This is more so in the vast savanna region despite its potentials for producing most of Nigeria's food and cash crops. The study was carried out in the Southern Guinea savanna agro-ecological zone because it forms part of the savanna region where phosphorus is strikingly deficient and the use of phosphatic fertilizers has consistently been on the increase.

The objectives of this study were as follows:

(a) To choose the extractant that "best" predicts the availability of phosphorus to maize (*Zea may L.*) in the soils from southern Guinea savanna zone;

(b) To determine the responses of maize to phosphorus fertilization on soils of the southern Guinea savanna ecological zone;

(c) To calibrate the phosphorus soil test data against the responses of maize to added units of phosphorus fertilizers under field conditions; and

(d) To make an effective and economic phosphorus fertilizer recommendations for maize based on soil tests for the southern Guinea savanna agro-ecological zone of Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 Initial Phosphorus Status of Nigerian Soils

Enwezor and Moore (1966) studied the phosphorus status of some Nigerian soils and concluded that the total phosphorus values for both the forest and savanna soils were low. They attributed the generally low total phosphorus contents in the soils to the low phosphorus levels in the parent materials, the great age of the soils and intensive weathering. The soils of the savanna zone were shown to have much lower phosphorus levels and phosphate retention capacities than those of the rainforest zone. Similar findings were made by Adepetu and Corey (1975). The total phosphorus values were found to be in the range of 68 to 788 mg kg^{-1} (Bates and Baker, 1960; Enwezor and Moore, 1966; Uzu *et al.*, 1975). Udo (1985) while studying the phosphorus status of major Nigerian soils found that there is a wide variation in abundance of total phosphorus in the soils; the range being from as low as 68 mg kg^{-1} in some acid coastal plain sands to over 2000 mg kg^{-1} in soils derived from basaltic rocks and deltaic deposits. He concluded that, in general, the well-drained soils have low total phosphorus content; the average content in Ultisols and Alfisols being about 430 and 190 mg kg^{-1}, respectively.

Fractionation studies of total phosphorus in various soils of Nigeria have been carried out to determine the percentages of the various forms [organic and inorganic](Enwezor and Moore, 1966; Adepetu, 1970; Omotoso, 1971; Adepetu and Corey, 1975; Udo, 1985). It has been found that organic phosphorus contributes a significant proportion of the total phosphorus in the plough layer of soils of south-western

Nigeria. Omotoso (1971) put the percentage of total phosphorus that is in organic form in these soils as between 20 and 70%. Adepetu (1970) reported that soil phosphorus contained on the average 47% organic phosphorus in forest soils and 57% in savanna soils. Adepetu and Corey (1975) found organic phosphorus to be in the range of 36 to 79% of total phosphorus contents of soils of the same zone. Enwezor and Moore (1966) found that the percentage of total phosphorus in organic form is in the range of 17 to 72%. Udo (1985) found that the organic phosphorus forms about 40% of the total phosphorus in the well-drained soils and about 30% in the poorly drained soils.

Some earlier workers (Bates and Baker, 1960; Enwezor and Moore, 1966), have reported that the magnitude of occurrence of various inorganic phosphorus fractions in Nigerian soils is in the order: occluded P > Fe-P > Al-P > Ca-P. Most of the inorganic forms are found to be in association with Fe and Al minerals.

The total phosphorus contents of soils do not necessarily give an indication of the availability of the nutrient. This is because the availability of phosphorus to plants is determined by the forms in which the phosphorus exists in the soil (Agboola and Sobulo, 1981). Most of the phosphorus may be held in forms that may not be available to the current crop.

Phosphorus deficiencies have been shown to be widespread in Nigeria. This is more so in the savanna region. Udo (1985) using two soil test methods, Bray-1 and Olsen's, showed that in general most of the Nigerian virgin Ultisols (mainly from the rainforest zone) have values of available phosphorus above the critical range of 8.0 to 17.0 mg kg^{-1} for Bray-1 (Lungu, 1965; Agboola and Obigbesan, 1974; Warmsley and Forde, 1976; Okeya, 1977; Kang and Osiname, 1979) and 11.0 to 12.0 mg kg^{-1} for Olsen's (Okeya, 1977; Ayodele, 1986), whereas almost all Alfisols (mainly found in the drier savanna zone) studied have

values below the critical range. That phosphorus deficiencies are more prevalent in the savanna region, particularly with cereal crops, has been established by many other workers (Sobulo and Osiname, 1985; Lombin, 1987; Sobulo and Adepetu, 1987). Sobulo and Adepetu (1987) pointed out that in the Jos Plateau ecological zone, it is hardly possible to raise maize crop successfully in the absence of applied phosphorus fertilizer.

Agboola and Corey (1976) conducted experiments at different sites in the maize growing areas of Western State covering soils derived from igneous and metamorphic rocks from forest and savanna zones of the state and showed that nitrogen (N) and phosphorus limit the yield of maize in both the forest and savanna zones. Enwezor and Moore (1966) showed that responses to phosphorus fertilization were less common and less dramatic in the forest region than in the savanna, probably because of the high levels of organic phosphorus in the topsoils of the forest zone. Enwezor (1977a) also showed that the soils of the lowland forest areas and those derived from basement complex rocks gave fewer responses to phosphate fertilization when planted to maize than soils from the savanna regions and those derived from sedimentary rocks. Sobulo (1980) estimated available phosphorus in both the derived and Guinea savanna zones using Bray-1 method and showed that the values obtained were very low compared with the critical level of 6-8 mg kg^{-1}. This finding was confirmed by Adepetu (1986) who indicated that the savanna grassland soils of the south-western Nigeria have Bray-1 available phosphorus below 8 mg kg^{-1}. It has also been shown that over 95% of the land area of south-western Nigeria have low to medium levels of available phosphorus in the plough layer of the soil (Ataga and Omoti, 1978; Adepetu, 1986).

Juo and Fox (1977), working on benchmark soils of the West African sub-region, showed that the coarse-textured upland soils and the hydromorphic soils have relatively low

standard phosphorus requirements whereas the well leached and more weathered profiles derived from basic rocks of volcanic origin have the highest phosphate fixing capacities within the toposequence. According to them the soils with low phosphorus requirements comprise a large area of the arable land in the savanna and forest zones of West Africa. This confirms the findings of many workers that (i) the phosphorus level of most Nigerian soils is very low, (ii) the phosphate sorption capacities of the soils are relatively high, and (iii) the phosphorus requirements are generally low in spite of the high sorption capacities (Enwezor and Moore, 1966; Sobulo and Adepetu, 1987).

2.2 Factors Affecting Phosphorus Availability to Crops

It has long been known that most of the native phosphorus in soils cannot be utilised by growing plants. Even when the total content of native phosphate is high many soils are deficient in available phosphorus. It has also been known for many years that when soluble sources of this element are supplied to soils in the form of water-soluble fertilizers, most of the phosphorus is immobilised or rendered insoluble and unavailable to higher plants. It has been estimated that only 10 to 30% of applied fertilizer phosphorus is recoverable in the crop that is planted immediately after its application (Bear and Toth, 1942), the balance is retained, and most of this fixed or immobilised, in the soil.

The retention and availability of phosphorus applied to soils have been associated with several soil factors and conditions. Some of these include: (a) Soil pH. (b) soluble or exchangeable iron (Fe), aluminium (Al), and manganese (Mn), (c) presence of Fe- and Al-containing minerals, (d) exchangeable calcium (Ca) and calcium minerals, (e) clay and clay minerals, (f) amount and degree of humification of organic matter, and (g) initial phosphate status of soils. Some of these soil factors are inter-related in their influence on phosphate

sorption and availability, their effects being largely pH dependent. The following discussions are on the effects of these factors on phosphate sorption since this determines the degree of availability of added or residual phosphorus to crops.

2.2.1 Effects of Soil pH and Exchangeable Fe, Al, Ca and Mg

Soil pH has been recognised as one of the most important factors associated with phosphate sorption or availability in soils. It has been shown that phosphate adsorption is the primary process of phosphate retention in acid soils since acid reactions favour the activities of the oxides and oxyhydroxides of iron and aluminium (Hsu, 1964).

Phosphate sorption increases with decrease in pH to about pH 3.0 (Haseman *et al.*, 1950; Chatterjee and Datta, 1951) except for some clay minerals like montmorillonite and some soils like those from the savanna zones of Nigeria where sorption increases with increase in pH (Hall and Baker, 1971; Mokwunye, 1975). Muljadi *et al.* (1966a) and Rajan *et al.* (1974) showed that the capacity of hydrous alumina to adsorb phosphate was greater at pH 5.1 than at 6.2. Rajan *et al.* (1974) attributed this to higher positive charge and to lesser competition between OH^- ions and phosphate ions at pH 5.1 than at 6.2. In general, the pH of maximum adsorption or less phosphate availability occurs at low pH values where the surface is positively charged (Parfitt, 1977).

In recognition of the importance of soil pH in phosphate retention and availability much work has been done to determine the actual role of soil pH. Most of the work involved statistical treatments of sorption data and the pH of soils. Most of the findings show that soil pH is negatively correlated with phosphate sorption. The negative correlations suggest that phosphate sorption increases with decreasing pH, and vice versa. However, th appears to be no consistent level of significance between pH and phosphate

sorption. Harter (1969) showed that pH was not correlated with adsorbed phosphorus extractable by sodium hydroxide. Lopez-Hernandez and Burnham (1974) found no significant correlations between pH and phosphate sorption for a group of tropical and British soils. Similar results have been reported by Ahenkorah (1968) for some cocoa-growing soils of Ghana, and by Evans and Smillie (1976) for some Irish soils. On the other hand, Udo and Uzu (1972) who worked on Nigerian forest soils showed that the pH of their soils was negatively correlated with retained phosphorus at the 5% level of significance. Since exchangeable aluminium was highly correlated with phosphate retention at the 0.1% probability level, they pointed out that this significant correlation between pH and phosphate retention might have resulted from a correlation at the 1% level between pH and exchangeable aluminium.

The formation of insoluble (unavailable) phosphates in acid soils has been associated with the precipitation of added phosphorus by exchangeable Fe and Al. Kittrick and Jackson (1956) proposed that the process provides a unified theory of phosphate fixation which explains the whole range of observed facts of phosphate reactions with Fe, and Al and Ca soil systems. It has been shown, however, that the soil activity does not permit the existence of exchangeable ions (Hsu, 1965) and that Fe^{3+} and Al^{3+} cannot exist in reasonable amounts in most soils (Larsen *et al.*, 1959; Weir and Soper, 1963; Hsu and Rennie, 1962; Hsu, 1965; Muljadi *et al.*, 1966b). These ions can only exist in soils of very acid reaction. Hsu (1964), and Reeve and Sumner (1970) showed that the activity of Fe^{3+} and Al^{3+} in solution is limited by pH, being negligible at pH 5.0 and above.

In soils with pH values above 6.5 phosphate retention is mainly through precipitation by calcium and magnesium compounds. Such soils have high amounts of exchangeable calcium and, sometimes, calcium carbonate. Added phosphorus will react with

Ca^{2+} and the carbonate forming insoluble phosphate precipitates. At pH 7.5 magnesium also enters into the reaction with phosphorus resulting in further fixation by precipitation (Bear and Toth, 1942). Lewis and Racz (1969) indicated that it is most likely that the high pH and large amounts of calcium and magnesium found in soil solutions of calcareous soils resulted in the rapid precipitation of the added phosphorus very close to the fertilizer source.

2.2.2 Effect of Oxides and Oxyhydroxides of Fe and Al

It has been shown that the oxides and oxyhydroxides of Fe and Al exist in large amounts in acid soils (Midgley, 1940), and almost universally in all soils (Hsu, 1964). Syers *et al.* (1971) illustrated that secondary iron- and aluminium- containing soil compounds are invariably implicated in sorption of phosphorus in acid soils. They and Gorbunov *et al.* (1961) showed that short range order (amorphous) hydrated oxides of iron and aluminium and short range order aluminosilicates are particularly effective in phosphate adsorption. Hsu (1965) indicated that of all known compounds in acid and neutral soils, the amorphous aluminium hydroxides and iron oxides are the most highly adsorptive for phosphorus. Holford and Mattingly (1975) also suggested that the hydrous oxides provide the principal sites, even in calcareous soils, on which phosphorus is strongly adsorbed.

A number of workers have shown that phosphate retention is greatly reduced in soils where amorphous iron oxides and aluminium hydroxides have been removed (Russell and Low, 1954; Ellis and Truog, 1955). Kanwar (1956) showed that the removal of the sesquioxides from the two soils he studied led to 75 to 80% reduction in the phosphate retention capacity. Bromfield (1965) using different extractants which are capable of removing different forms of iron and aluminium from soils showed that the residues obtained after extraction and acid-washing sorbed less phosphorus than the original soil.

2.2.3 Effect of Clays and Soil Clay Content

The amount and nature of clay in soils have been shown to influence the retention and availability of added phosphorus in soils. Kanwar (1956) reported that most caly minerals, as they occur in soils, are not very adsorptive for phosphate. Coleman (1944a,b) established that the reactivity of clays with phosphate is dependent on the activity of their component iron and aluminium. Syers *et al.* (1971) showed that disordered kaolinites are capable of sorbing more phosphorus than the well-ordered ones. Murphy (1939) concluded from investigations on the role of kaolinite in phosphate fixation that the efficiency of applied water-soluble phosphorus as a source of nutrients for plants is a function of the kind of clay minerals present in the soil. He showed that if the clay is kaolinite, a low efficiency is inevitable, while soils with a montmorillonitic clay complex will have a higher degree of phosphorus efficiency. It has been conclusively shown that phosphorus is retained to a greater extent by 1:1 than 2:1 clays. Soils high in kaolinitic clays, such as are found in areas of high rainfall and high temperatures, will retain larger quantities of added phosphorus than those containing the 2:1 type (Tisdale and Nelson, 1975).

Much efforts have been made to determine how soil clay contents predict variations in phosphate sorbing capacities of soils. Except for a few reports which showed significant but poor correlations between clay contents and phosphate sorption (Saunders, 1965; Udo and Uzu, 1972; Lopez-Hernandez and Burnham, 1974). most others showed that the soil clay content is not significantly correlated with phosphate sorption (Ahenkorah, 1968; Evans and Smillie, 1976; Juo and Fox, 1977). Lopez-Hernandez and Burnham (1974) found that soil clay content affects phosphate sorption at low levels of significance in tropical soils. They attributed this partly to the relationship between extractable Al and clay content.

However, Udo and Uzu (1972) attributed the close correlation they obtained between clay content and phosphate sorption for a group of Nigerian forest soils to a causal relationship. They proposed that clay forms a part of a complex gel, and that this gel, consisting of hydrated Fe_2O_3 along with smaller amounts of organic matter, Al_2O_3 and associated $Si(OH)_4$ and phosphate, is a major site for phosphate sorption.

2.2.4 Effect of Organic Matter

The exact role of organic matter in phosphate sorption and availability has been the subject of much investigation. Some reports have indicated that organic matter has some phosphate retention power. Hesse (1971) reported that small amounts of phosphorus can be retained by organic matter. Lopez-Hernandez and Burnham (1974) obtained evidence to show that organic matter may sorb phosphorus under certain conditions. In freely drained British and tropical soils they found no significant correlations between organic matter and phosphate sorption, but in the poorly drained British soils a highly significant positive partial correlation ($P<0.001$) was obtained. They claimed that this correlation implies that the organic matter in poorly drained soils can sorb phosphorus even from weak solutions. This deduction was supported by their observation that sorption by well humified peat is not much below the average of sorption by mineral soils.

Ahenkorah (1968) showed that organic carbon is very closely correlated with phosphate retention ($P<0.001$). He proposed a direct combination of organic carbon and phosphorus with the phosphate being held in a chelated form. He pointed out that with such combination an increase in organic carbon content would lead to an increase in organic phosphorus if it is assumed that organic phosphorus is the sum of the chelated phosphorus and the phosphate forming the integral part of the organic material. Harter (1969) who

found significant correlations between organic matter and NaOH-extractable phosphorus ($P<0.01$), organic matter and NH_4F-extractable phosphorus ($P<0.001$), organic matter and NH_4F-extractable Al ($P<0.01$) and organic matter and free oxides ($P<0.05$) proposed that phosphorus extractable by NH_4F was primarily bonded to organic matter in the soil rather than to Al. He suggested that when phosphorus is added to soils it immediately reacts with organic matter. He went on to propose that phosphorus is retained by some type of anion exchange with organic matter. Harter assumed that with time the phosphorus is transformed into a less available iron and aluminium phosphates, as well as incorporated into the organic matter.

A series of investigations have yielded results to show that a number of organic anions like citrate, oxalate, tartrate, malonate, succinate, malate, lactate, and polygalacturonate are very effective in decreasing phosphate sorption and thus increasing phosphate availability to plants. These anions are reported to prevent the precipitation of phosphorus by iron and aluminium. Depending on the suspension pH, these organic anions form stable complexes with Fe and Al (Swenson *et al*., 1949; Struthers and Sieling, 1950; Bradley and Sieling, 1953; Nagarajah *et al*., 1970). It has also been shown that organic matter has a beneficial effect in making applied phosphorus more available to plants by:

(a) reducing soil-phosphate contact;

(b) producing carbon dioxide during organic matter decomposition which will dissolve some phosphatic materials and reduce the amount of active iron in the soil (Scarseth, 1945);

(c) forming less firmly fixed and slowly available organic phosphate (Jackman, 1955); and

(d) the mineralisation of the tied-up phosphates by micro-organisms with the resultant release of phosphorus (Midgley and Dunklee, 1945; Dalton *et al.*, 1952).

Mattson *et al.* (1950) showed that humus preparations reduce phosphate fixation, and Larsen *et al.* (1959) also presented data to show that humic acids greatly reduce the capacity of organic acids to fix phosphorus from solutions. Greenland (1971) proposed that organic matter decreases the proportion of high-energy sites and, therefore, increases the proportion of labile phosphorus on the low-energy ones. Consequently, the availability of phosphorus to plants is increased due to the rapid equilibration between low-energy adsorbed phosphorus and solution phosphorus.

There is yet another group of evidence that living organic matter in soils may not be as beneficial in reducing phosphate sorption as has been reported. Willett and Higgins (1978) assessed the effect of organic matter on phosphate sorption in poorly drained rice soils. They showed that the addition of organic matter as a source of oxidisable material for microbial activity accelerated the reduction and appearance of ferrous compounds, and caused corresponding increase in phosphate sorption. Iron oxides and aluminium hydroxides in their amorphous forms have relatively small particle sizes and positively charged surfaces. These compounds are known to be highly reactive with phosphorus. Much evidence has indicated that organic anions prevent the crystallisation of amorphous iron oxides and aluminium hydroxides (Schwertmann *et al.*, 1968; Cornell and Schwertmann, 1979). So, organic matter fraction in soils may maintain iron and aluminium in forms that are highly phosphate sorbing for a number of reports have shown that organic complexes of iron and aluminium are the major phosphate sorption sites in soils (Williams *et al.*, 1958; Saunders, 1965; Saini and MacLean, 1965; Appelt *et al.*, 1975).

2.2.5 Phosphorus Status of the Soil

The initial phosphate content of a soil determines the degree of retention and availability of added phosphorus. There is a pronounced relationship between amount of added phosphorus retained by soil and the R_2O_3: P_2O_5 ratio of the soil (Tisdale and Nelson, 1975). This ratio is a measure of the amount of phosphorus present in relation to the iron and aluminium oxide content of the soil. A wide ratio indicates a small amount of phosphorus present or a low phosphorus saturation value. Under such conditions larger amounts of added phosphorus are fixed than when the ratio is narrow.

The practical implications of this relationship is that for soils with high initial phosphorus contents, (a) amount of phosphorus to be applied as fertilizer will be reduced, and (b) the phosphorus in the soil could be utilised to greater extent.

2.3 Crop Response to Phosphorus Fertilization

Most of the well-weathered and highly acid soils of tropical Africa except those derived from volcanic parent materials are invariably low in total and available phosphorus (Enwezor and Moore, 1966; Bouyer, 1971; Uzu *et al*., 1975; Loganathan and Sutton, 1987). This is due primarily to the low contents of total phosphorus in the parent materials from which the soils were derived (Cope and Evans, 1985; Udo, 1985; Esu, 1987). The result of this low level of available phosphorus is pronounced deficiency of phosphorus in nearly all crops and its harmful effect on crop production. Agronomic studies have shown that phosphorus deficiency is widespread and becomes the next plant nutrient problem after nitrogen when bush fallow is cleared (Jones, 1974a; Sobulo and Osiname, 1981; Bationo *et al*., 1986; Uyovbisere and Lombin, 1991).

Fertilizer trials conducted on food crops in humid West Africa have shown good and consistent responses to phosphorus fertilizer application (Goldsworthy and Heathcote, 1963; Goldsworthy, 1967). The degree of responses obtained depended on whether the sites had just been cleared from long bush fallows, or had been under continuous cultivation, or had earlier received phosphorus fertilizer application (Adetunji, 1974; Kang and Juo, 1979).

Balasubramanian *et al.* (1978) found that with improved management methods, responses to phosphorus application have been very striking with maize. Bationo *et al.* (1986) carried out evaluation of phosphorus fertilizers in humid, sub-humid and semi-arid zones of sub-Saharan Africa and found that maize and millet responded significantly to phosphorus fertilization. Maduakor (1991) determined the nature of response of maize to rates of phosphorus from four sources in acid soils of south-eastern Nigeria. He showed that maize responded highly significantly to phosphorus application. Amon and Adetunji (1973) also working on Ilora and Fashola soils in the rainforest zone and Eruwa soil in the savanna zone of south-western Nigeria found that maize responded highly significantly to phosphorus application in the three sites. Balasubramanian *et al.* (1980) who worked on savanna soils found that grain yields of maize increased significantly as fertility level rose from 22.5 kg P/ha to 45 kg P/ha. However, their data showed that significant yield increases were obtainable beyond phosphorus addition of 45 kg P_2O_5/ha for improved maize cultivars. Osiname (1979) carried out phosphorus response trials on maize at Ikenne and Ilesha in the rainforest zone and Eruwa in the savanna zone of south-western Nigeria. He found that maize responded significantly to phosphorus application up to 80 kg P_2O_5/ha at Ikenne. The grain yield of maize increased steadily as phosphorus application was increased to 160 kg P_2O_5/ha at Ilesha. However, he found that at Eruwa yield responses were

recorded at low levels of phosphorus application. He suggested that the response of maize to only low rates of phosphorus application in the savanna zone might be due to the fact that the phosphate adsorption capacity of the soils in this area is low thereby leaving most of the phosphorus in readily available form. It could also be due to the mineralisation of organic phosphorus which has been reported by many workers to supply substantial amounts of phosphorus to plants under tropical environment (Eid *et al.*, 1951; Bates and Baker, 1960; Enwezor and Moore, 1966; Adebayo and Akaeze, 1976; Adepetu and Corey, 1977). Uyovbisere and Lombin (1991) set up trials in the savanna zone to evaluate the agronomic potentials of four phosphorus fertilizer materials. They found that the response of maize to phosphorus in each year of the trial was highly significant up to phosphorus application of 26.2 kg P/ha irrespective of the phosphorus source. Their findings confirmed that only moderate amounts of phosphorus are required to overcome the deficiencies of phosphorus and satisfy crop needs in the soils of the savanna. Agboola and Obigbesan (1974) found that maize gave little or no response to phosphorus fertilization when the soil phosphorus was higher than 20 kg P/ha while rice showed little or no response at 15 kg P/ha. Bota crops responded well when the soil test value was less than 10 kg P/ha. They assumed that below 80% of the maximum yield, response to a given nutrient might be certain and that response was unlikely when it is above 95%. Responses of rice to phosphorus have also been reported by many workers. Sobulo (1982) found that the application of 25 kg P/ha on a rice cultivar gave response in soils of high phosphate fixing capacity at Ikenne, while in soils of low phosphate fixing capacity it depressed yield. Terman *et al.* (1970) conducted a series of greenhouse pot experiments with flooded rice on a silt loam of low available phosphorus in Alabama, United States of America. They found that rice responded very significantly to applied phosphorus.

Singh and Balasubramanian (1983) found that wheat and maize responded significantly to phosphorus application in some years of trial at Kadawa in the transition zone between the northern Guinea and Sudan savanna regions of Nigeria. A number of workers have reported responses of wheat and barley to phosphorus fertilization in soils of West Asia and North Africa. Amin *et al.* (1991) conducted two experiments on different soil series having low and medium soil test phosphorus values ($NaHCO_3$-extractable phosphorus values of 3 and 8 mg kg^{-1}, respectively) in rain-fed areas of Pakistan, and found that phosphorus rates increased grain and straw yields of wheat significantly over control treatments. Investigations carried out in Morocco using dryland wheat and barley showed that phosphorus response was generally consistent and significant. The soil test levels of the responsive sites determined by Olsen's method were lower than the critical level of 12 mg kg^{-1} (Moughli *et al*, 1991; Ryan *et al.*, 1991). Also, under dryland conditions in Turkey, significant yield responses of wheat to applied phosphorus fertilizer have been recorded as long as available phosphorus was below 55 kg P_2O_5/ha (Yurtsever, 1986; Yurtsever and Gedikoglu, 1991). In Jordan, responses of cereals, particularly wheat and barley, were inconsistent and varied between locations as a result of differences in soil type, moisture regime, level of $NaHCO_3$-extractable phosphorus and some other factors that affect the interaction of applied phosphorus with the soil, and therefore, its availability to plants (Khattari and Tell, 1988; 1989a; 1989b; Abu-Rub and Al-Ashhab, 1991).

A series of wheat fertilizer trials carried out across northern Syria by Pala *et al.* (1991) over four seasons showed that mean grain and straw yields were little affected by soil available phosphorus and responses to phosphorus were not statistically significant. Eskandanian and Sayyadian (1991) who worked on Western Iranian soils, also found no significant responses of wheat to P fertilization in most of the sites. The reason for this lack

of response was because most farmers use large amounts of phosphorus fertilizers every year.

Early fertilizer trials on tuber crops have also shown significant yield responses to phosphorus fertilization (Okonkwo and Ifenkwe, 1984; Ohiri *et al.*, 1987; Enwezor *et al.*, 1990). Response to as little as 15 kg P/ha has been recorded for yam grown on phosphorus deficient sandy soils of south-western Nigeria, while for cassava with a good phosphorus deficiency tolerance, as much as 35% of tuber yield response has been reported (Adepetu, 1983). Phosphorus application of 20 kg P/ha increased yam yield by 9.5% over the control on a silty loam soil of south-eastern Nigeria (Ohiri *et al.*, 1987).

Phosphorus has also been found to be the most critical nutrient for legumes. However, responses with these crops are usually obtained at low levels of phosphorus application (Greenwood, 1951; Heathcote, 1973).

Agbede (1987) who worked on Gambari and Sapoba soils in the rainforest zone of Nigeria found that when the initial phosphorus status is low, there is a rapid growth response to phosphorus application, while if the soil is high in initial phosphorus the response is low. Sobulo and Osiname (1981) found that with Bray-1 extractant, a soil containing less than 3 mg kg^{-1} phosphorus is considered low, between 4 and 6 mg kg^{-1} is medium, response is unlikely above 10 mg kg^{-1} phosphorus. When Bray-1 soil phosphorus test gives less than 5 mg kg^{-1} phosphorus, rice, maize and cowpea will respond to phosphorus application particularly in the rainforest soils.

2.4 Concept of Soil Testing

Soil testing is concerned with the relationship between the quantity and chemical form of essential nutrients in the soil and the resulting plant growth (Melsted and Peck,

1980a). It involves the process of quantitatively relating all fertility information influencing plant growth to soil properties that can be measured in the laboratory. It also involves the consideration of the response of crops to fertilizer materials and how this response is influenced by method and time of application with respect to various soil properties (Rouse, 1968).

Agboola (1982) described soil testing as the chemical and physical measurement of soil properties in order to make predictions on its agricultural use. Sobulo and Adepetu (1987) broadly defined soil testing as the assessment of chemical properties of a soil for predicting accurately its fertilizer requirement. Soil testing, therefore, aims at relating crop yields to soil nutrient levels and fertilizer needs (Enwezor, 1982). Melsted and Peck (1980b) summarised the term "soil testing" as follows:

> *"Through common usage the term 'soil testing' has been given both a more restricted and a much broader meaning. The term is restricted in the sense that it has come to mean rapid chemical analysis to assess the available nutrient status of a soil, and broadened to include interpretations, evaluations, and fertilizer recommendations based on results of chemical analysis and on several other considerations...*
>
> *...Soil Testing while traditionally has involved the evaluation of nutrient deficiencies in soils, today, soil tests are logical tools to determine areas where adequate or excessive fertilization has taken place. It is just as important to determine where fertilizers should not be used as it is to determine fertilizer need."*

These workers went on to summarise the objectives of soil testing thus:

> *"To us the objectives of soil testing are to accurately determine the available nutrient status of soils, to clearly indicate to the farmer the seriousness of any deficiency or excess that may exist in terms of various crops, to form the basis on which fertilizer needs are determined, and to express the results in such a way that they permit an economic evaluation of the suggested fertilizer recommendations."*

In a nutshell, the objective of soil testing is to obtain a value that will help to predict the amount of nutrients needed to supplement the supply in the soil (Tisdale and Nelson, 1975).

In building up the fertility and lime levels of agricultural soils from soil test results, one or the other of two concepts is usually relied upon as a basis for making recommendations of the amounts of amendments to apply (McLean *et al.*, 1983). These two concepts are:

(a) Sufficiency level of available nutrients (SLAN), and

(b) Basic cation saturation ratios (BCSR).

Both concepts are based on valid principles and they recognise that there is a fraction of a given plant nutrient measured by soil tests which is readily available to plants, and that the level of available nutrient measured may range from low to high in a given soil.

The SLAN concept grew out of Bray's development of soil tests (Bray, 1944; 1945) and application of soil test values to Mitscherlich's law of diminishing returns where increases in yield of a crop per unit of available nutrient decrease as the level of available nutrient approaches sufficiency. It resulted from research on crop response to addition of an element otherwise insufficient for maximum crop yields (Bray, 1944; 1945). The response was observed to be progressively smaller with each succeeding increment of the growth limiting element until further response was zero or negative with additional increments of the element. The concept focuses on the adjustment of one or more elements known to be at less-than-sufficiency levels for a given crop.

According to McLean (1980), the SLAN concept implies:

(a) that levels of available nutrients range in a group of soils from insufficiency to sufficiency for optimum growth of plants,

(b) that amounts of nutrients removed by suitable extractants will be inversely proportional to yield increases from added nutrients, and

(c) that calibrations have been made for changing the levels of available nutrients in the soil by adding fertilizer or lime.

He believed that the SLAN concept assumes little, if any, effect on the level of availability of one ion on that of another. However, it does recognise that an addition of the most limiting element may cause more efficient utilisation of a less limiting one. The concept is based on Mitscherlich's equation:

$$\frac{dy}{dx} = (A - y)\ c$$

which says, in effect, that yield increases (dy) per unit of available nutrient (dx) decrease as the current yield (y) approaches a maximum yield (A), c being a proportionality constant (Bray, 1944).

The SLAN concept seems to work best as a basis for soil test interpretation in soils of generally high, well-balanced fertility, but most deficient in one essential element (McLean, 1980; McLean *et al.*, 1983).

The Basic Cation Saturation Ratio deals with the nutrients which exist as basic cations particularly calcium (Ca), magnesium (Mg) and potassium (K). Its validity rests on the assumption that, for most crops, there is an optimum saturation of the soil cation exchange capacity (CEC) for each basic cation at which maximum yields occur (McLean, 1980; McLean *et al.*, 1983). The BCSR concept embraces only the CEC and adsorption of the basic cations. Also the concept deals with only one of the major fertilizer elements, potassium.

As stated by McLean (1980), the BCSR concept in soil test interpretation is based on an "idealised" procedure for providing an ionic environment with optimum conditions for plant growth. A plant toferates a considerable range:

(a) in level of available nutrients, or

(b) in level of toxic substances without appreciable effect on yield or quality of harvested product. However, the BCSR concept seeks to attain optimum conditions for a wide range of crops. It implies that for optimum growth of crops both a best ratio of basic cations and a best total base saturation exist in a soil.

The BCSR concept seems to work best as a basis for soil test interpretation in highly weathered soils of low pH requiring relatively major adjustments in fertility.

2.5 Basic Soil Testing Steps

The development of a soil testing programme which leads to the establishment of a rational basis for fertilizer recommendation to crops based on soil analysis involves five basic steps, namely:

1. Soil sampling - collecting composite soil samples from a number of sites over the whole area under study: The development of a soil testing programme starts with soil sampling from the field. The soil samples should be representative of the whole area under study and should include all known soil types which could be put into agricultural production. The sampling should be in such a way that the results of chemical analyses of the collected samples will accurately reflect the true nutrient status of the soils of the whole area.
2. Soil analysis for the nutrient under investigation using a number of extractants: Many chemical methods are available for assessing the chemical form or forms of essential plant nutrients in soils whose variation in amount is reflected in variations in plant growth and yield (Melsted and Peck, 1980b). Over the years researchers have tried extracts with water, carbonic acid, organic acids, salt solutions, and

many combinations of acids and salts. None has been found to be superior for all soil and crop situations. Relationships involved in choosing and adapting chemical procedures for use in making fertilizer recommendations are complicated by many factors. These include differences among soils, crops, nutrients, extractants, fertilizer sources, yield levels and recommendation philosophies (Cope and Evans, 1985).

The chosen methods must be simple rapid chemical analytical procedures which can accurately measure the level of available soil nutrients. This means that the extractant must remove from the soil an amount of nutrient that is proportional to what a crop extracts during the growing season (Cope and Evans, 1985). Data from such method must always be reproducible for the method to be meaningful. The resulting data from the extraction with the chosen method must correlate very well with nutrient uptake and crop yields (Melsted and Peck, 1980b).

Selection of a solution and procedures for accomplishing this involve many considerations. Some of these include the nutrients to be extracted, chemistry of the extractant, soils to be extracted, soil to solution ratio, shaking time and speed, temperature, flask size and shape, and filtering procedure (Agboola, 1982; Cope and Evans, 1985).

3. Correlation of analytical data for the various methods with measured crop response and nutrient uptake in the greenhouse: The soil samples collected from the various sites within the area under study should also be used for the greenhouse study. The analytical results from the various soil test methods is then statistically related to the yield data generated from the greenhouse to determine the most satisfactory soil test method for the element tested against the soil-crop system of interest.

4. Calibration of the analytical data (soil test data) obtained by the selected method with yield data from experiments in the field: For effective soil test calibration, a good number of experiments should be set up at various locations throughout the area under study. This is because a good soil test calibration cannot be carried out unless experiments are designed in such a way that the results may be interpreted in terms of known crop response patterns (Melsted and Peck, 1980b). The results of the field experiments and the soil test data could be calibrated to obtain the following information:

   (a) Critical soil test levels for the nutrient element and the crop; and

   (b) Soil test ratings and fertility indices (per cent sufficiencies).

5. Establishment of economic fertilizer rates for the nutrients and crops based on soil test data through appropriate interpretation of fertilizer trial results:
For effective soil test interpretation, a good number of fertilizer rate studies must be carried out in the field. Responses of crops to different soil nutrient levels and to increasing increments of both broadcast and band-applied fertilizers must be known. Based on the amount of fertilizer needed for maximum crop yield for each soil test level and the economic considerations of the upper levels of fertilization obtained, appropriate fertilizer recommendation will be made.

2.6 The Need for a Soil Testing Programme in Nigeria

For long Nigerian soil scientists have stressed the need for a comprehensive soil testing programme as a means of combating the steady decline in the productivity of our soils (Sobulo, 1970; Agboola and Corey, 1972; 1975; Corey and Schulte, 1972; Ekpete, 1972; Anande, 1972; Adetunji, 1974; Enwezor, 1977b; 1982; 1985; Agboola, 1982; Sobulo

and Adepetu, 1987). They recognised the usefulness of soil testing as a guide for efficient fertilizer use.

The use of soil analysis in making fertilizer recommendations is not a common practice in Nigeria. Sobulo (1970) suggested that this may be due to one or more of the following reasons:

(a) inability to obtain a suitable method that can predict response on soils of various origins (Nye and Bertheux, 1957; Goldsworthy and Heathcote, 1966);

(b) difficulty in interpretation of soil analysis for advisory purpose; and

(c) errors in obtaining representative soil sample of a large area in the field.

Enwezor (1977a) also gave reasons why soil testing for phosphorus is particularly difficult in highly leached, phosphate-deficient soils of the humid tropics, namely:

(a) Many of these soils have been cropped for centuries without any external replacement of the phosphorus removed in the crop harvest and consequently available phosphorus levels become very low. It is, therefore, sometimes difficult to obtain accurate measures of the available phosphorus content of the soil using dilute chemical reagents, some of which may, on certain soil types, be incapable of extracting measurable quantities of phosphorus.

(b) Because of the degree of weathering and leaching, many of the soils have high phosphate fixing capacities, being high in iron and aluminium oxides. This high phosphate fixing capacity tends to complicate the interpretation of soil test data.

(c) In many soils of the rainforest region, a high proportion of the potentially available phosphorus in the surface is in the soil organic matter, and, its release, which can contribute significantly to available phosphorus pool during a growing season, cannot be predicted by any chemicals extraction method.

In spite of all these problems and drawbacks associated with soil testing much has been done to use soil analysis for diagnosing the phosphorus status of soils and recommending appropriate rates of fertilization. Sobulo and Adepetu (1987) enumerated some of the advantages of soil testing. They include:

(a) ensuring balanced nutrient applications;

(b) saving up to half the cost of fertilizers by testing the soil before deciding on the types of fertilizers and rates of application;

(c) guaranteeing high yields even under continuous cultivation since the productivity of the soil is preserved; and

(d) serving as a key vehicle of extension package by the inclusion of other recommended agronomic practices.

A soil test is, therefore, one of the helpful tools a Nigerian farmer can get since it helps to monitor soil fertility and helps with fertilizer needs when used along with other diagnostic aids and good management practices. Corey and Schulte (1972) agreed that reliable fertilizer recommendations could be achieved in Nigeria with soil testing programme.

2.7 Soil Test Methods for Phosphorus

Phosphorus exists in soils in varied quantities and forms. The estimation of phosphorus availability is, therefore, one of the difficult problems and relatively few studies have been attempted on tropical soils. Phosphate supply from soil to plant is a function of intensity, quantity and rate factors (Williams, 1962) and measurements that reflect to some extent all these variables have given significant correlations with plant

growth for contrasting soils (Williams and Knight, 1963; Gunary and Sutton, 1967; Bache and Rogers, 1970).

Many chemical reagents are currently available for the extraction of phosphorus in soils. The quantities and forms extracted by each reagent depend on the forms of phosphorus in the soil and a number of other soil factors like pH, and clay and organic matter contents. The relationship between the extracted phosphorus and the amount available for uptake by crops is also a function of the reagent, the crop and the soil. For the same soil, different reagents extract different amounts of phosphorus and these amounts extracted may correlate differently with crop responses. No single extractant is suitable for extracting available phosphorus from all soils.

A number of workers have used the fractionation procedure developed by Chang and Jackson (1957) to separate forms of soil phosphorus. A dilute acid solution has been known to extract soil phosphorus from mainly calcium phosphates, a dilute base solution extracts soil phosphorus from predominantly aluminium and iron phosphates, and a neutral fluoride solution extracts soil phosphorus from aluminium phosphates and, to a lesser extent, from iron phosphates (Chang and Jackson, 1957; Chai and Caldwell, 1959; Chang and Juo, 1963; Susuki *et al.*, 1963; Al-Abbas and Barber, 1964; Pratt and Garber, 1964; Halstead, 1967). Good but varying correlations have been found between these phosphate fractions and phosphorus uptake (Smith *et al.*, 1957; Bishop and Barber, 1958; Martens *et al.*, 1969). However, this procedure is tedious and time-consuming and cannot be adapted for routine soil testing.

A number of soil test methods are currently available for assessing and estimating available phosphorus in soils. These include chemical extraction (dilute acids, dilute bases, combination of dilute acids and bases, buffered salts and organic chelating agents), ion

exchange, electrodialysis and isotopic dilution. These methods have been found satisfactory under different conditions although some of them cannot be adapted for routine soil testing because they are either tedious or time-consuming. The most widely used soil test methods for phosphorus include:

(a) Truog - 0.002N H_2SO_4 (Truog, 1930).

(b) Morgan - 10% sodium acetate in 3% acetic acid (Morgan, 1935).

(c) Bray No. 1 - 0.03N NH_4F in 0.025N HCl (Bray and Kurtz, 1945). This method has been extensively used and is effective in acid soils with moderate cation exchange capacity (CEC), and organic soils. It dissolves iron and aluminium phosphates and, therefore, adsorbed phosphates.

(d) Bray No. 2 - 0.03N NH_4F in 0.1N HCl (Bray and Kurtz, 1945). This is not as widely used as the Bray No. 1. It is believed to dissolve more of rock phosphate which is an insoluble source of phosphorus. The usefulness of Bray reagents (both No.1 and 2) is based on the assumption that the acid will extract portions of all forms of phosphorus in the soils and the fluoride will increase the amount of aluminium phosphate, iron phosphate and mono- and di-calcium phosphates extracted (Smith *et al.*, 1957).

(e) Olsen's - 0.5M $NaHCO_3$ adjusted to pH 8.5 (Olsen *et al.*, 1954; and modified by Watanabe and Olsen, 1965). This method is very effective in calcareous soils, alkaline soils and neutral soils. The extraction was based on the principle that bicarbonate ions reduce calcium activity in calcareous soils. It was also observed that the extractant solubilises portions of aluminium and iron phosphates which makes it adaptable to some acid soils.

(f) Williams - 0.1N NaOH (Williams, 1950).

(g) Anion Exchange Resins (Amer *et al.*, 1955). The chlorinated form of the strong basic anion exchange resin has been widely used and is believed to extract exchangeable (available) phosphorus from soils.

(h) Mehlich No.1 (North Carolina) - Raleigh or Double Acid -0.025N H_2SO_4 in 0.05N HCl (Mehlich, 1953). This has been widely used. It is a good extractant for low CEC (less than 15 cmol kg^{-1}) soils and acid soils. It is not specific for any form of phosphorus. It extracts calcium phosphate and small amounts of aluminium and iron phosphates.

(i) Mehlich No. 2 - 0.2N AcOH in 0.015N NH_4F in 0.012N HCl in 0.2N NH_4Cl (Mehlich, 1978). This method has been found to extract available phosphorus from a wide range of soils.

(j) Isotopically Exchangeable Phosphorus (McAuliffe *et al.*, 1948). This has been extensively used to determine the amount of surface (available) phosphorus in soils through the equilibration of the soil with labelled phosphorus.

(k) Chelating Agents: Chelating agents like 0.01N Na_2-EDTA (Sahrawat, 1977) and NH_4HCO_3-DTPA (Soltampour and Schwabb, 1977) have been employed to extract phosphorus mainly from alkaline soils. These reagents form water-soluble chelates with metallic ions thereby releasing phosphorus which is considered available to plants.

2.8 Phosphorus Soil Test Correlation Studies

Oko and Agboola (1974) compared eight different extractants for soils from two ecological zones of Western Nigeria, forest and savanna, using rice as the test crop. Based on the results of correlation between extractable P by different reagents and phosphorus

uptake or cumulative yield, they suggested that different ecological zones may require different extractants, for example:

(a) Bray No. 2 (0.03N NH_4F + 0.1N HCl) proved the best for the poorly-drained soils (swamp group) from both Ilaro and Ikenne which belong to the suborders psammaquents and aquox (USDA, 1960), respectively.

(b) Bray No. 4 (0.5N NH_4F + 0.1N HCl) proved best for the well-drained Alfisols of the Ilaro group.

Sobulo *et al.* (1975) cited Halm (1965) who pointed out that the main disadvantage of soil analysis as a diagnostic tool for phosphorus is that it is sometimes difficult to find an extraction procedure that is suitable for a wide range of soil types that differ in their physical and chemical characteristics.

Bromfield (1967) showed that the Bray-1 extracts forms of phosphorus that correlate best with maize yield in two savanna sites in Western State of Nigeria. Jaiyebo (1969) also showed that out of the five extractants used in various temperate countries, phosphorus extractable by Bray-1 reagent correlated best with phosphorus uptake by maize in greenhouse experiments (Bray-1, r = 0.78; Sodium Acetate, r = 0.75; O.1N NaOH, r = 0.35). Sobulo (1970), using five soils from various depths and a range of pH of 5.4 to 6.1 from various parts of Western Nigeria carried out a greenhouse investigation to determine the form of soil phosphorus that best predicts crop yields. He employed the fractionation method of Chang and Jackson (1957) to characterise aluminium phosphate (Al-P) and iron phosphate (Fe-P). He also extracted available phosphorus using the Bray-1 method. Although the linear correlation coefficients between the various extractable forms of phosphorus and phosphorus uptake as well as the absolute yield of maize were all significant ($P < 0.001$), Al-P was superior to Bray-1 P in predicting the response of maize

on these soils. However, he concluded that Bray-1 is the most suitable soil test method for predicting the response of maize to phosphorus on these soils.

Oko and Agboola (1974), using rice as the test crop, compared eight extractants of available phosphorus for 90 forest and savanna soils of Western State of Nigeria. They observed that the importance of various extractants in predicting the response of rice varied from one ecological zone to another. For example, Bray-2 gave the best correlation ($r = 0.433$, $P < 0.05$) with P uptake for the swamp soils, and Bray-4 ($r = 0.383$, $P < 0.05$) for the Ilora soils. However, when all the soils were considered, Bray-1 gave the best prediction ($r = 0.372$; $P < 0.001$).

Adetunji (1974) compared eight different extractants, namely: Bray-1, Bray-2, Raleigh (North Carolina), modified Raleigh (0.05N HCl + 0.025N H_2SO_4 + 0.03N NH_4F), Miller and Axley, 0.03N HCl + 0.03N NH_4F, Morgan and Truog, using maize as test crop over 25 sites scattered in different fertilizer response zones of Western State of Nigeria. His results suggested a correlation with Bray-1 although both the modified and unmodified Raleigh methods showed better promise with yield of control plots, yield increase with the use of fertilizer, relative yield and the optimum return.

A number of other works carried out in soils of Western Nigeria confirm Bray-1 as the best extractant of forms of phosphorus that predict crop responses in these soils (Agboola and Obigbesan, 1974; Kang and Osiname, 1979). However, Agboola and Oko (1976), who considered that most chemical extractants including Bray-1 are not dependable for measuring phosphorus status where organic phosphorus forms a good proportion of total phosphorus because of the inability of these extractants to solubilise organic phosphorus, found a definite to slight superiority of $NH_4F.HF$ (0.1N, pH 5.0) over Bray-1 for these soils. From linear correlation analysis with phosphorus uptake, they showed that

Bray-1 has nearly identical r values as $NH_4F.HF$ which is equally good in predicting plant availability in the soils of south-western Nigeria. They recommended that both the reagents could be used interchangeably although NH4F.HF might be preferred for work involving large number of samples because of the shorter time employed for some of the steps (one minute shaking time is recommended for this extractant).

Sobulo (1970) and Agboola and Obigbesan (1974) evaluated Bray-1 reagent as an extractant for phosphorus in savanna soils of Western Nigeria and concluded that this reagent is very suitable for assessing phosphate status of savanna soils where pH is less than 7.0 but suggested that on alkaline and saline soils where a pH of 8.0 or more is recorded, Olsen's bicarbonate may be preferred. Sobulo (1981) considered Bray-1 extractant useful on soils with pH in the range of mildly acid to neutral (pH 5.5 - 6.9) in predicting phosphate status but appears unreliable for very acid soils having pH less than 5.0.

Enwezor (1977b) compared seven chemical extractants in predicting the phosphorus fertility of soils from south-eastern Nigeria. He used 30 surface (0-15 cm) soil samples pH values in the range of 4.7 to 6.0 from 30 locations covering the main agricultural soils of the region. Maize crop was grown on these soils in a greenhouse. All the reagents extracted forms of phosphorus which correlated well at $P < 0.001$ with percentage yield of maize. However, the phosphorus extracted by Bray and Kurtz-2 (0.03N NH_4F + 0.1N HCl) gave the highest correlation ($r = 0.74$) with percentage yield. He, therefore, recommended this method for routine soil testing for phosphorus in the acid soils of south-eastern Nigeria.

Audi (1987) using millet as a test crop considered the relationship between phosphorus extracted by Bray-1, Olsen's and Double Acid methods, and absolute yield and

phosphorus uptake. He worked on nine soil samples collected from nine sites, Sahel (one), Sudan Savanna (three), Northern Guinea Savanna (four) and Rainforest (one). He found that Olsen's method extracted phosphorus that correlated best with yield ($r = 0.93$, $P < 0.001$) and phosphorus uptake ($r = 0.94$, $P < 0.001$). This was followed by Bray-1 which extracted phosphorus that correlated with yield ($r = 0.78$) and phosphorus uptake ($r = 0.83$) at 5% and 1% probability level, respectively. The Double Acid extracted phosphorus that was not significantly correlated with yield and phosphorus uptake. The poor relationship of Bray-1 P and Double Acid P with yield of and phosphorus uptake by millet may have resulted from the fact that the soils were collected from zones that differ significantly in climate and soil characteristics. Seven of the soils had pH values above 6.0 and only two below this value. Bray-1 and Double Acid methods are known to work best in more acid soils while Olsen's method works best in slightly acid to alkaline soils (CSTPA, 1980).

In view of the foregoing, it may be concluded that no single extractant best predicts phosphate fertility for all the soils of Nigeria. However, what is important for any method to be adopted is that it should be rapid, fairly accurate and reproducible, inexpensive, easily adaptable for routine analysis, and correlate well with yield and crop responses to fertilizers (Sobulo, 1981).

2.9 Phosphorus Soil Test Calibration Studies

Usually plant availability of native and residual phosphorus is estimated by soil testing, and the rate of phosphate fertilization is based on soil test values in conjunction with calibration data for the test. For this procedure to be successful, the soil test employed must accurately estimate the plant availability of the native and residual phosphorus (Martens *et al.*, 1969).

With suitable extractants and analytically accurate methods of analysis, it is possible to relate soil chemical values to lime and fertilizer needs. To accomplish this, the soil test value must give a measure of two interrelated soil parameters, namely:

(a) the severity of the deficiency, that is, how much yield increase will be obtained if the deficiency of the nutrient is corrected; and

(b) the amount of fertilizer required to correct the deficiency (Bray, 1948). Extensive research is required to accurately relate soil test values to severity of deficiency and to the required addition of fertilizer. The experimental process whereby these two relationships are established and combined to provide the basis for fertilizer recommendation is termed "soil test calibration" (Rouse, 1968).

Agboola and Corey (1972) carried out soil test calibration studies for nitrogen, phosphorus and potassium for maize in soils derived from metamorphic and igneous rocks of Western State of Nigeria. They concluded that response to phosphorus fertilizer was unlikely when Bray-1 extractable phosphorus in the soil was 20 lb/A (22.4 kg/ha). Ten to 20 lb P/A (11.2 - 22.4 kg/ha) were in the probable response zones, and less than 10 lb P/A (11.2 kg/ha) was assured response zone.

Critical levels of phosphorus for maize have been determined by a number of workers. Studies in Samaru and Kano have shown that for optimum growth of maize, a soil-solution phosphorus level of 0.3 mg/l is required (Balasubramanian *et al.*, 1978). Kang and Osiname (1979) working with the soils belonging to the Alfisols of Southern Nigeria estimated the critical Bray-1 phosphorus test value to be about 14 mg kg^{-1}. Sobulo (1981) obtained Bray-1 critical phosphorus value of 8 mg kg^{-1} for maize in the field. He also cited a number of workers in the tropics (Lungu, 1965; Warmsley and Forde, 1976; Agboola and Obigbesan, 1974) who reported the critical level of phosphorus extracted by Bray-1 for

maize to be between 8 and 14 mg kg^{-1}. Sobulo (1981) was of the view that this wide range suggests that a single critical phosphorus value may not be a satisfactory method of predicting phosphorus requirements, and that it should at best be a rough guide in assessing phosphorus status. He indicated that while Bray-1 extraction is suitable for predicting phosphorus deficiency, it is not useful in predicting the amount of phosphorus required. He, therefore, proposed a combination of Bray-1 (to identify deficiency) and phosphate sorption capacity (to assess the optimum phosphorus) for soil testing in Alfisols in the sub-humid tropics of Nigeria.

The determination of critical levels of available phosphorus have also been the required initial step for soil test calibration in other countries. Obreza and Rhoads (1988) calculated the critical Mehlich-1 phosphorus soil test level for irrigated maize in the south-western United States of America to be 9 mg kg^{-1}. Eskandanian and Sayyadian (1991) found that the critical $NaHCO_3$-extractable phosphorus was 5 mg kg^{-1} for wheat in soils of western Iran. Moughli *et al.* (1991) also found that $NaHCO_3$-phosphorus critical level for wheat in the Tadla and Gharb regions of Morocco was 12 mg kg^{-1}.

The relationship between chemical soil test values and soil fertility levels are usually described in such terms as Low, Medium or High (Rouse, 1968). Additional terms may be desirable sometimes, e.g., Very Low, Low, Medium, High, Very High and Extremely High (Rouse, 1968; Cope *et al.*, 1981). These ratings are influenced by the soil and the requirements of the crop to be grown. They are based on the relative yield which may be expected without adding the nutrient and when all other elements are in adequate supply (Cope *et al.*, 1981). Fertilizer recommendations are based on these ratings.

Rouse (1968) defined the soil test rating terms as follows:

(a) "Extremely High (Very Very High)" means an excessive amount of the nutrient in the soil and further additions may be detrimental;

(b) "Very High" means the nutrient supply is adequate further additions should not be made until the soil test level is lowered;

(c) "High" means the nutrient supply is adequate for highest yields, but there might be some advantage for a starter application or a maintenance application of fertilizer to keep the soil fertility level high;

(d) "Medium" means the soil will produce 75 to 100% of the yield potential without addition of the element;

(e) "Low" means the soil will produce 50 to 75% of the yield potential; and

(f) "Very Low" means the soil will yield less than 50% of maximum.

Sobulo and Adepetu (1987) believed that it is possible to classify the fertility of a soil into these ratings provided the critical soil level of each nutrient has been determined. Soil fertility classes have been determined for a number of nutrient elements in south-western Nigeria. From these classes soil fertility maps have also been developed for nitrogen (N), phosphorus, potassium (K) and sulphur (S) in the zone (Adepetu, 1985; Sobulo and Adepetu, 1987). These maps resulted from concerted efforts of soil scientists and agronomists in this zone (Smyth and Amon, 1960). This type of map can be used as a basis for fertilizer recommendations for farmers who are unable to afford the cost of routine soil testing of their farms (Adepetu, 1986). However, the use of such maps has limitations since soil fertility is dynamic as a result of cropping, fertilization and other forces.

Agboola and Corey (1975) used the Mitscherlich - Bray growth function to calibrate soil test phosphorus using Bray-1 as extractant. The relationship is as follows:

$$Log\ (A - y) = Log\ A - C_l b,$$

where A is the maximum possible yield obtained by supplying all growth factors in optimum amounts, y is the yield obtained when b, which is the amount of a nutrient originally present in the soil, is less than adequate, and C_l is a proportionality constant, the correlation constant, which depends on the nature of the growth factor. They used this relationship to determine the average value of C_l for each of the 32 locations covering both the savanna and forest areas on soils derived from metamorphic and igneous rocks in western Nigeria. The average C_l, 0.053, was obtained for maize for all the locations. From correlation tests carried out between b (soil test value) and per cent yield ($r = 0.872$, $P < 0.01$) they showed that b (Bray-1 P) is a reasonable measure of actual available phosphorus in the soils. From the obtained Cl value (0.053) various phosphorus soil test values were calculated for the quantity of fertilizer phosphorus necessary to produce a yield which is 50% of the maximum possible yield (Baule units) using the expression:

$$Log\ (100\text{-}50) = Log\ 100 - 0.0536b$$

which gave a b value of 5.81 lb P/A (6.51 kg/ha) at 50% yield (1 Baule unit). From the calculated phosphorus soil test values they confirmed the findings of Agboola and Corey (1972) that once the soil test for phosphorus is above 20 lb P/A (22.4 kg/ha) using Bray-1 extractant there is little or no response to fertilizer phosphorus on maize.

2.10 Fertilizer Recommendation

In the south-western zone, fertilizer recommendations based on soil fertility ratings (classes) are now the practice. For example, for soils with Bray-1 extractable phosphorus rated low (0 - 8 mg kg^{-1}), medium (8 - 20 mg kg^{1}) and high (>20 mg kg^{1}), phosphorus

fertilizer recommended for maize are 120 - 70, 70 - 25 and nil, respectively (Adepetu, 1986; Sobulo and Adepetu, 1987).

Through the extension of the Mitscherlich-Bray growth function the amount of fertilizer needed to raise the per cent yield from any given starting level to any other desired upper level for which fertilization is desired can be achieved (Melsted and Peck, 1980a). The expression then takes the form:

$$Log\ (A - y) = Log\ A - C_1 b - Cx,$$

where C is the efficiency factor for the method of applying fertilizer, and x is the quantity of fertilizer that needs to be added. The factor C is determined experimentally through fertilizer rate studies.

With the Mitscherlich-Bray function a calibration curve or table relating soil nutrient levels (b) to per cent sufficiencies (A) for use in interpreting the soil test value to the farmer could be constructed (Melsted and Peck, 1980a).

Using the Mitscherlich-Bray equations, Rashid *et al.* (1991) successfully calibrated soil test phosphorus values extracted by the $NaHCO_3$, Ammonium Bicarbonate-Diethylene Triamine Penta-acetic Acid (AB-DTPA) and Mehlich No. 3 (0.02N CH_3COOH + 0.25N NH_4NO_3 + 0.015N NH_4F + 0.013N HNO_3 + 0.001M EDTA) methods and evolved phosphorus fertilizer recommendations for wheat in Islamabad area of Pakistan. Yurtsever and Gedikoglu (1991) also used this procedure to calibrate and interprete $NaHCO_3$-extractable phosphorus for wheat in the Central Anatolia region of Turkey.

Sobulo and Adepetu (1987) suggested the use of easy-to-use charts and graphs which can be generated through computer modelling for different crops and nutrient types based on results of soil-crop yield data generated over many years for a given crop (Adepetu and Olufokunbi, 1987).

From the above accounts, more field investigations should be carried out using many more crops and under varying cultural practices. This is because the method "best" qualified to assay the soil fertility level and develop profitable fertilizer recommendations is measured crop responses to fertilizers in field experiments on all appropriate soil types and under conditions of all different cultural practices (Jones, 1982). The soil test values should be adequately rated; the degree of sufficiencies should be evaluated and the amounts of phosphorus fertilizers recommended for soil test values should be tabulated. This is because for a soil test to serve as a reliable basis for fertilizer and lime recommendations, it should show the degree of deficiency of each nutrient and amount of fertilizer needed to produce maximum yield (Cope, 1973).

CHAPTER THREE

MATERIALS AND METHODS

3.1 A Brief Account of the Study Area

3.1.1 Location and Extent

The map of Nigeria showing the various ecological zones is shown in Fig 1. The zone under investigation is the Southern Guinea Savanna which includes the Derived Savanna. The Southern Guinea Savanna agro-ecological zone which is the largest single ecological zone in Nigeria lies approximately between Latitudes 6° 30'N and 10°N and Longitudes 3°20'E and 12°20'E. Because of the vastness of the zone, only two States, namely, Plateau and Benue (part of which is now in Kogi State), were selected as the study area. The factors that were considered in the choice of these States include their extent, the number of vegetation units in the area, their vast agricultural potentials, their geological formations and the divergence of the soil types identified.

About 80% of the study area falls within the Southern Guinea Savanna zone. The Jos Plateau ecotone, and the sub-Sudan which can conveniently be grouped with the Northern Guinea Savanna, occupy about 20% of the total area studied. The total land area covered is about 125,985 km^2 (Fig. 1).

3.1.2 Soils

In the Southern Guinea Savanna ecological zone which in the main occupies the middle-belt of Nigeria, the soils are formed from three main types of parent materials, namely:

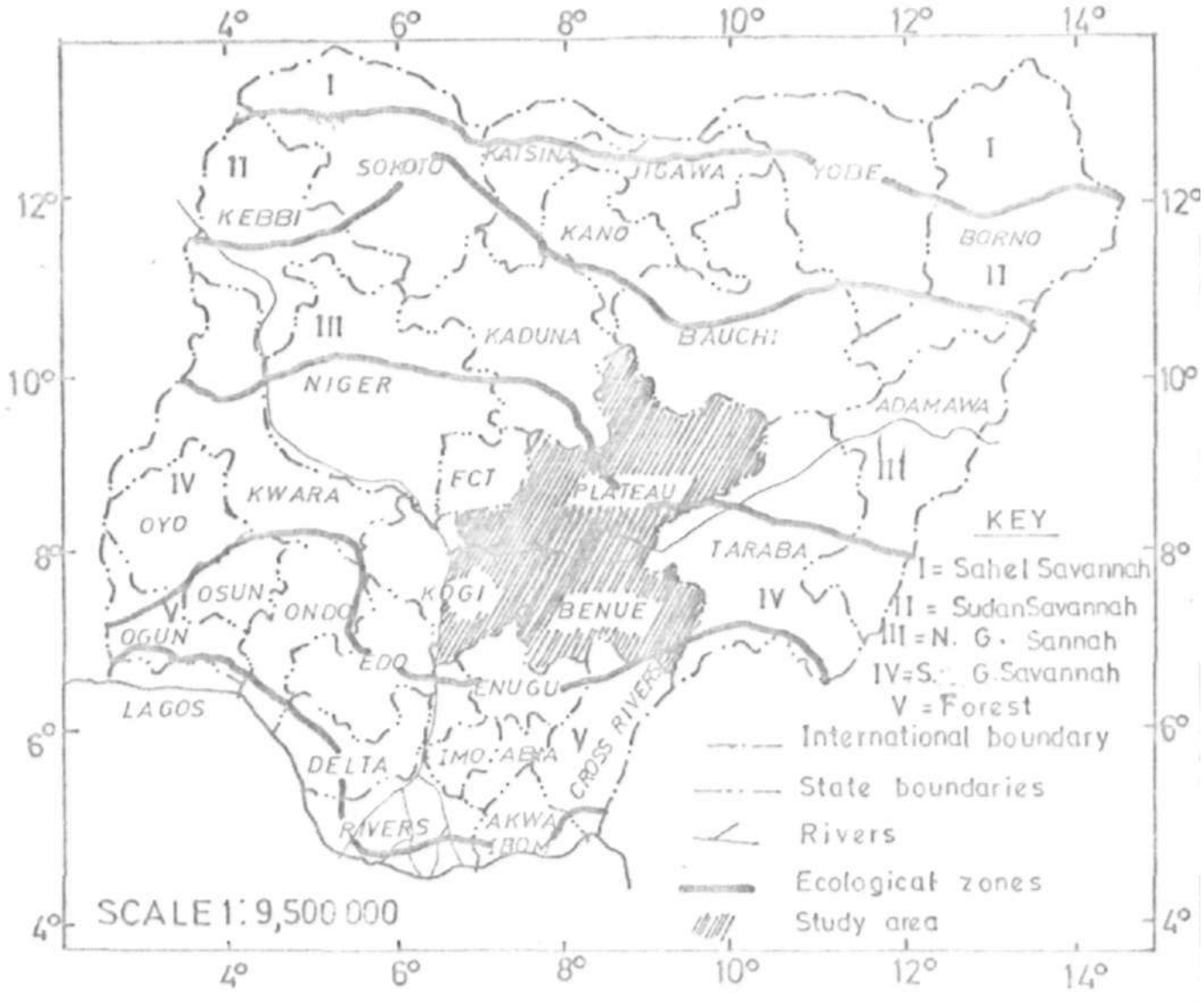


Fig. 1: Map of Nigeria showing the five ecological zones and the study area.

(a) Igneous and metamorphic rocks which are hard with a very large number of mineral components;

(b) Sedimentary rocks; and

(c) Alluvial stream deposit.

These three types of parent materials differ extensively from one another in their chemical and physical characteristics. Thus, they form different types of soils with varying chemical, physical and mineralogical characteristics.

Soils differ from location to location partly because of differences in parent materials and partly because of the influence of climate, organic matter and topography. For example, the various soil types around Minna in Niger State which are predominantly Alfisols differ from those around Makurdi in Benue State which are mainly Inceptisols. This is because the soils around Makurdi are derived from sedimentary parent material while those around Minna are derived from igneous/metamorphic parent materials. Even when the soils are formed from the same parent materials they could also differ in a number of ways. For example, the soil types commonly found around Bida in Niger State which are mainly Alfisols differ from those around Makurdi although both originated from sedimentary rocks. The difference in soils found at some areas around Niger and Benue States could be attributable to the differences in the sedimentary rocks. The sedimentary rock at Bida is sandstone while that at Makurdi is shale. Similarly, the soils around Abuja differ from those around Jos (Inceptisols) although both are formed from igneous/metamorphic rock. The volcanic rock at Jos differs chemically and physically from that at Abuja.

Soils over igneous/metamorphic parent materials dominate the Southern Guinea savanna zone. They occupy about 50% of Kogi State, 90% of Kwara State, 49% of Niger State, 60% of Plateau State (Jos Plateau and the surrounding lower plains), 20% of Benue State (Yandev-Katsina-Ala area) and 70% of the Federal Capital Territory, Abuja. The most extensive area is within the Kontagora-Wushishi-Nasarawa-Lafia-Shendam loop.

The soils of the study area are predominantly Alfisols and Inceptisols of various descriptions. From the Reconnaissance Soil Survey of the area (FDALR, 1985), Alfisols constituted about 43%, Inceptisols 32.8%, Ultisols 11.6% and Entisols 12.2% of the 189 soils described. Alfisols accounted for about 64% of the 75 soils described in Plateau State while Inceptisols accounted for about 32%. In Benue State 114 soils were described0. Inceptisols accounted for about 33.3%, Alfisols 29.8%, Ultisols 18.4% and Entisols 18.4% of the soils.

3.1.3 Climate

The southern Guinea savanna has a hot tropical climate. There are two major seasons in a year - the rainy season and the dry season. These correspond to the prevalence of the moisture- laden south-westerly maritime wind that originates from the South Atlantic and the dry continental north-easterly wind from the Sahara Desert, respectively. The rainy season lasts from April to October in most parts of the region while the dry season lasts from November to March.

The range of average rainfall within the wetter southern part (referred to as forest or derived savanna ecotone) of the region is 1200 to 1440 mm, with the high amounts in the extreme southern edge. On the other hand the range of average

rainfall within the drier northern part of the region (referred to as savanna grassland) is 1016 to 1200 mm. The general northward decrease in rainfall is interrupted in some places by topographical effect. Examples of this are the Jos Plateau and the area abutling the Plateau in the south-west which are more humid than the general surrounding. Wamba, Kafanchan and Jema'a are located in the latter area.

The temperature variations, like rainfall, are a result of changes in the prevailing wind as conditioned by altitude of the hills. Temperatures of about 27°C are typical in the rainy season in the lower parts of the region and 25°C on the Plateau. The highest temperatures occur around April and May before the rains. The lowest temperatures occur in December during the harmattan period.

The mean annual maximum temperature range is between 32° and 33°C while the mean annual minimum is between 21° and 22°C.

3.1.4 Vegetation (Alford and Tuley, 1974)

The vegetation is a product of the interaction between climate, soil, man, wildlife and plants. The area is covered by five vegetational zones, namely: the Jos Plateau, the southern Guinea savanna, the Northern Guinea savanna, the sub-Sudan, the forest savanna mosaic and the flood plain complexes.

The Forest Savanna Mosaic occurs mainly in the south-western parts of the area extending over Ankpa plateau and the southern parts of Itobi, Taraku and Aliade plains. The vegetation is characterised by a mosaic of secondary forest regrowth and relic patches of forests interspersed with savanna.

The southern Guinea savanna occupies most of the study area. In its original form which now exists in isolated areas, it is an open forest vegetation with deciduous and semi-deciduous trees and an underlay of herbaceous/shruby tangle. This has been reduced through cultivation and annual bush burning into a tree savanna or woodland with isolated fire resistant trees and perennial tussock grasses with remarkable regeneration abilities soon after burning.

On the Jos Plateau, due to prolonged cultivation, little or no original vegetation remains. The present day vegetation is mainly shrubs from short fallows.

The sub-Sudan zone comprises a southern extension of the Sudan zone that lies in the main shadow of the Jos Plateau. It has characteristics of the northern Guinea and Sudan savanna zones.

The northern Guinea savanna, which is at the northern fringes of the study area, has characteristics of the southern Guinea savanna except that the vegetation is much less dense as a result of lower intensity and duration of rainfall and other climatic factors.

3.2 Experiments

The project is divided into three parts, namely:

(a) Correlation Studies: This involved the establishment of a suitable extractant for soil phosphorus in the southern Guinea savanna ecological zone. This entailed greenhouse and laboratory studies using 36 composite soil samples collected from 36 locations evenly spread throughout the study area in Benue, Plateau and part of Kogi States (Fig. 1). Data generated from greenhouse and soil analysis using eight extractants were statistically analysed

using linear regression (correlation) analysis to determine the extractant that solubilised forms of soil phosphorus that "best" predicted the availability of phosphorus to maize in soils of the southern Guinea savanna agro-ecological zone.

(b) Calibration Studies: This involved field fertilizer experiments, and the use of data from these experiments and greenhouse and laboratory studies to:

- establish critical level of soil phosphorus for maize; and
- classify or group available soil phosphorus into "low", "medium" and "high".

(c) Interpretation of results leading to the establishment of economic phosphorus fertilizer recommendation for maize in the southern Guinea savanna ecological zone.

3.2.1 Greenhouse Studies

Soil Sampling

The sampling sites, as shown in Fig.2, were shared among the various vegetation zones in the study area according to the spread of each zone as follows:

- Southern Guinea savanna - 21
- Derived savanna - 7
- Jos Plateau - 4
- Sub-Sudan/Northern Guinea savanna - 4

The southern Guinea savanna has slightly more spread in Plateau than in Benue State. So, from this zone, 11 soil samples were collected in Plateau State as

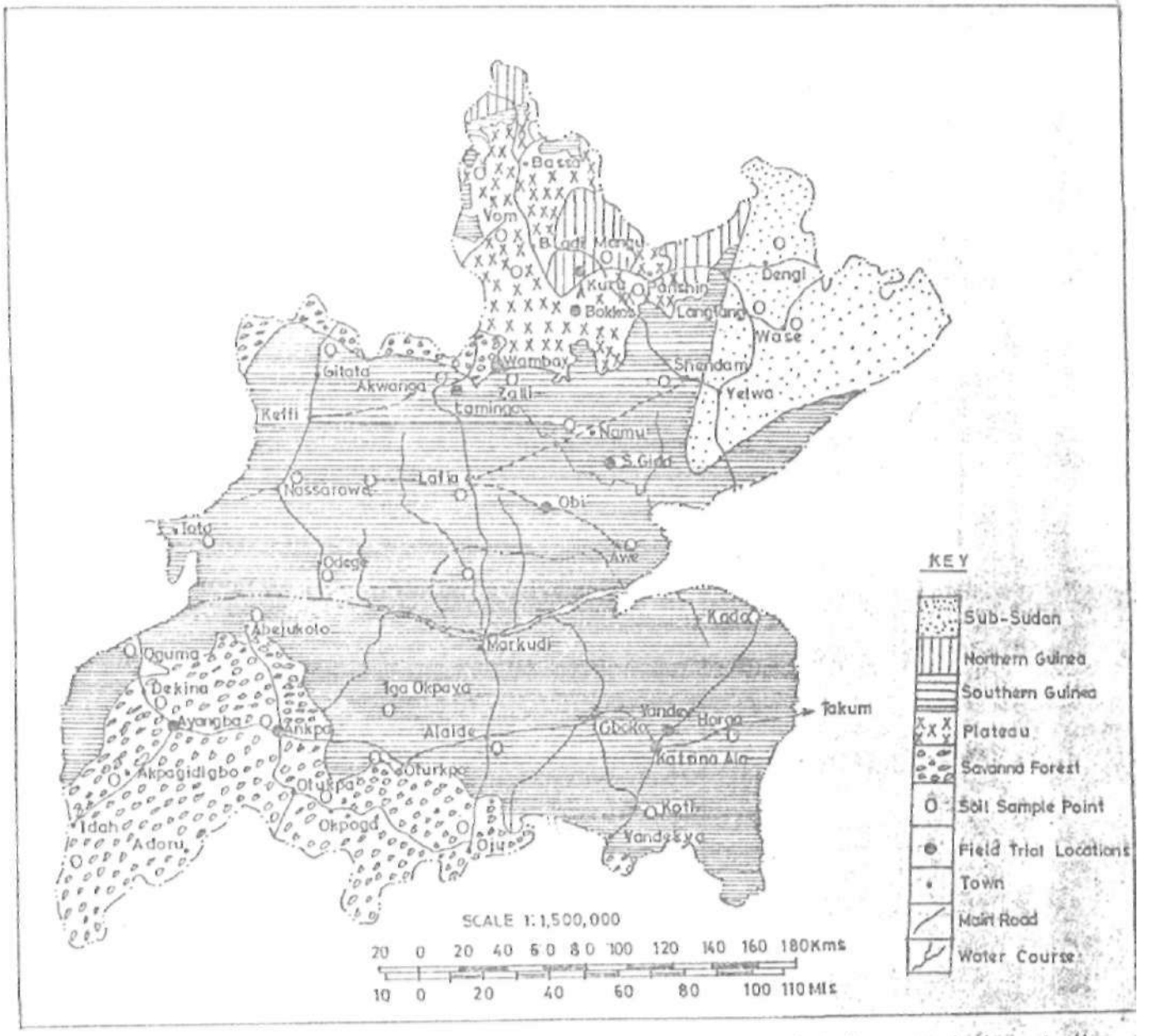


Fig. 2: Map of the study area showing soil sampling sites for correlation studies and locations for the field trials.

against 10 in Benue. In all, a total of 19 soil samples were collected in Plateau State and 17 in Benue and part of Kogi States.

The soil samples were collected to a depth of 20 cm using spades. At each sampling site 15 sub-samples were collected from a land area of 1 - 1.5 hectares. Equal volumes of the sub-samples were composited to form one soil sample. About 75 kg of soil were collected from each sampling site. Table 1 shows the locations where the soil samples were collected and the relevant information on the sites.

Soil Preparation and Potting

The soil samples were thoroughly mixed and air-dried. Life roots and other extraneous materials were hand-picked. The soils were then gently rolled over with wooden roller to break up larger peds. Each soil sample was sieved through 2- mm sieve. 2.5 kg of each sample were weighed out and potted in properly labelled 3-litre plastic pots with three drainage holes at the bottom and covered. Four pots were prepared per sample. Altogether 144 pots were prepared for the greenhouse studies.

Portions of the remaining soil samples were further air-dried, mixed thoroughly, passed again through 2-mm sieve and stored in plastic containers for physical and chemical analyses.

Test Crop

Maize was used as the test crop because it is a very popular and commonly grown crop in the study area. The variety used was TZSR - white maize which is the most popular improved variety in the zone.

Statistical Design

There were two treatments and two replicates. The treatments were:

Table 1: Location, soil classification, parent material, vegetation zone and history of the soil samples used for the greenhouse cropping.

S/No.	Soil Sample No.	Soil Classification (USDA)	Parent Geology	Town/Village	Local Government Area	State	Vegetation Zone	Fallow Length
1.	JP/BAS/01	Oxic Dystropept	Younger Granite	Angwar Granye,Bassa	Bassa	Plateau	Jos Plateau	2 years
2.	JP/KUR/02	Vertic Haplustalf	Younger Granite	Kuru	Jos South	"	"	5 years
3.	JP/BLA/03	Typic Eustropept	Younger Granite	Barkin Ladi	Barkin Ladi	"	"	>15 years
4.	NGS/MAN/04	Typic Dystropept	Basement Complex	Mangu	Mangu	"	NG Savanna	5 years
5.	JP/PAN/05	Typic Dystropept	Younger Granite	Pankshin	Pankshin	"	Jos Pleateau	>15 years
6.	SSS/DEN/06	Typic Haplustalf	Basement Complex	Samia Zaranda, Dengi	Kanam	"	S-S Savanna	2 years
7.	SSS/LAN/07	Typic Haplustalf	Basement Complex	Langtang	Langtang North	"	"	3 years
8.	SSS/WAS/08	Lithic Haplustalf	Cretaceous	Timshak, Wase	Wase	"	"	2 years
9.	SGS/SHE/09	Typic Eustropept	Basement Complex	Shendam	Shendam	"	SG Savanna	5 years
10.	SGS/NAM/10	Typic Haplustalf	Cretaceous	Namu	Quan Pan	"	"	>30 years
11.	SGS/ZAL/11	Oxic Dystropept	Basement Complex	Zalli	Akwanga	"	"	>15 years
12.	SGS/AKW/12	Oxic Haplustalf	Basement Complex	Akwanga	Akwanga	"	"	3 years
13.	SGS/GIT/13	Oxic Haplustalf	Basement Complex	Gitata	Keffi	"	"	6 years
14.	SGS/AMB/14	Oxic Haplustalf	Basement Complex	Amba	Keffi	"	"	5 years
15.	SGS/NAS/15	Typic Eustropept	Basement Complex	Nasarawa	Nasarawa	"	"	5 years
16.	SGS/TOT/16	Typic Haplustalf	Cretaceous	Majaga-Toto	Toto	"	"	6 years
17.	SGS/ODE/17	Typic Haplustalf	Cretaceous	Odege-Mbeki	Nasarawa	"	"	5 years
18.	SGS/LAF/18	Typic Haplustalf	Cretaceous	Mararaba Lafia	Lafia	"	"	>30 years

Table 1 (cont'd.)

S/No.	Soil Sample No.	Soil Classification (USDA)	Parent Geology	Town/Village	Local Government Area	State	Vegetation Zone	Fallow Length
19.	SGS/AWE/19	Typic Haplustalf	Creteaous	Awe	Awe	Plateau	SG savanna	3 years
20.	SGS/UDE/20	Ustic Dystropept	Creteaous	Udei	Makurdi	Benue	"	5 years
21.	SGS/MAK/21	Vertic Ustifluvent	Alluvium	Makurdi	Makurdi	"	"	1 year
22.	SGS/YAN/22	Typic Haplustalf	Basement Complex	Mbatuu, Yandev	Gboko	"	"	>10 years
23.	SGS/KYA/23	Oxic Haplustult	Basement Complex	Moga, Kyado	Katsina-Ala	"	"	>10 years
24.	SGS/HAR/24	Typic Tropaquept	Basement Complex	Harga	Katsina-Ala	"	"	2 years
25.	SGS/KOT/25	Typic Paleustalf	Basement Complex	Koti	Vandeikya	"	"	> 8 years
26.	SGS/ALI/26	Typic Paleustult	Cretaceous	Aliade	Gwer	"	"	3 years
27.	DS/OJU/27	Typic Paleustalf	Cretaceous	Ochodu Ukpa, Oju	Oju	"	D. savanna	>15 years
28.	SGS/IGA/28	Typic Paleustalf	Cretaceous	Iga-Okpanya	Apa	"	SG savanna	>10 years
29.	DS/OKP/29	Oxic Haplustalf	Cretaceous	Okpoga	Okpokwu	"	D. savanna	>10 years
30.	DS/ANK/30	Ustic Dystropept	Cretaceous	Ankpa	Ankpa	Kogi	"	5 years
31.	SGS/ABE/31	Lithic Eustropept	Cretaceous	Okpotala, Abejukolo	Ankpa	"	SG savanna	>10 years
32.	SGS/OGU/32	Oxic Dystropept	Cretaceous	Oguma	Bassa	"	"	5 years
33.	DS/DEK/33	Lithic Ustrothent	Cretaceous	Ajakagwu, Dekina	Dekina	"	D. savanna	>10 years
34.	DS/AKP/34	Oxic Haplustult	Cretaceous	Akpagidigbo	Ofu	"	"	>10 years
35.	DS/OGB/35	Typic Ustifluvent	Cretaceous	Ogbogbo	Idah	"	"	5 years
36.	DS/IDA/36	Vertic Tropaquept	Alluvium	Alokoyinna, Idah	Idah	"	"	2 years

NG = Northern Guinea savanna; SG = Southern Guinea savanna; S-S = Sub-Sudan savanna; D. = Derived savanna.

- Treatment 1 (T_1) - P_o = minus P (control)
- Treatment 2 (T_2) - P_x = plus P (125 mg P_2O_5 kg^{-1} soil)

The pots in each treatment were set up in a randomised complete block design.

Fertilizer Treatments

Table 2 shows the rates, sources and amounts of fertilizer nutrients used for the pot experiments. The amount of nutrients used have been considered by many workers as adequate for the plant population, and the period the plants were allowed to grow.

All the fertilizers required for each treatment replicates were weighed out. The weighed out fertilizers were dissolved in 2 litres of distilled water, 25 ml of the resultant homogeneous solution were added to each pot before planting. This supplied the amounts of all the nutrients required per pot.

The urea for top dressing was also dissolved in distilled water and added to all the pots 17 days after planting.

Cropping

The pots were placed on receivers and wetted to field capacity with de-ionised water for 24 hours before planting. Ten viable maize seeds (TZSR-White) were planted at almost equal spacing. The plants were thinned down to 8 stands per pot seven days after planting.

The soils were watered twice daily and maintained at field capacity. Any drained water in the receiver and any resultant residue were added back into the pot.

Table 2: Rates (soil equivalent bases), sources and amounts of fertilizer nutrients used in the greenhouse cropping.

S.No.	Nutrient	Rate (mg kg^{-1})	Fertilizer source (Analytical Grade)	Amount of fertilizer material added per pot at planting		Amount of urea required for top dressing 17 days after planting (mg)	
				P omitted	P added	P omitted	P added
1.	N	250	Urea-$(NH_2)_2CO$: DAP and KNO_3	605.32 mg Urea	-	541.03	541.03
2.	P	125	DAP-$(NH_4)_2HPO_4$-Diammonium phosphate	-	1.331 g		
3.	K	100	KNO_3 - Potassium nitrate	646.33 mg	646.33 mg		
4.	Magnesium, Mg	75	$Mg\ SO_4.7H_2O$ - Magnesium Sulphate	1.921 g	1.921 g		
5.	Sulphur, S	123	All Sulphates used				
6.	Manganese, Mn	25	$Mn\ SO_4.2H_2O$ - Manganese sulphate	212.51 mg	212.51 mg		
7.	Zinc, Zn	10	$Zn\ SO_4.7H_2O$ - Zinc sulphate	110.38 mg	110.38 mg		
8.	Copper, Cu	5	$Cu\ SO_4.5H_2O$ - Copper sulphate	49.12 mg	49.12 mg		
9.	Boron, B	0.5	H_3BO_3 - Boric Acid	7.05 mg	7.05 mg		
10.	Molybdenum, Mo	0.5	$Na_2MoO_4.2H_2O$ - Sodium molybdate	3.15 mg	3.15 mg		

Daily observations on the performance of plants were made and recorded. After 35 days of growth (21/4/91 to 27/5/91), all the above-ground parts of the maize plants were harvested using a new stainless steel razor blade. The plants were rinsed twice in de-ionised water and put inside well-labelled large envelopes. They were oven-dried at 60°C for 48 hours and allowed to cool down to laboratory temperature. The samples were weighed. The plants were then ground in a stainless steel mill and stored in small plastic bags for analysis.

Plant Analysis

Portions of the ground oven-dried plant samples were used for the determination of total phosphorus by the wet- digestion method as modified by IITA (1979). The phosphorus was determined colorimetrically by the vanado-molybdate method.

Soil Analysis

The 36 soil samples were analysed for total P by Jackson's (1958) method and for available (extractable) P by the following methods which were considered potentially suitable for the area of study:

(a) Mehlich-1-(Double Acid) - 0.05N HCl in 0.025N H_2SO_4 (Mehlich, 1953).

(b) Mehlich-2 - 0.2N AcOH in 0.015N NH_4F in 0.012N HCl in 0.2N NH_4Cl (Mehlich, 1978).

(c) Bray-1 - 0.03N NH_4F in 0.025N HCl (Bray and Kurtz, 1945).

(d) Bray-2 - 0.03N NH_4F in 0.1N HCl (Bray and Kurtz, 1945).

(e) Mississippi (Lancaster) - 1.5N AcOH in 0.06N Malonic Acid in 0.037N NH_4F in 0.012N $AlCl_3$ adjusted to pH 4.0 (Lancasler, 1970).

(f) Modified Mehlich-1 - 0.025N H_2SO_4 in 0.05N HCl in 0.03N NH_4F (Adetunji, 1974).

(g) Ammonium Bicarbonate - 1M NH_4HCO_3 in 0.005M DTPA at pH 7.6 (Soltanpour and Schwab, 1977).

(h) Olsen's method - 0.5M $NaHCO_3$ adjusted to pH 8.5 (Olsen *et al.*, 1954).

The samples were also analysed for pH, particle-size distribution by hydrometer method (Day, 1965), exchangeable cations leached by 1N NH_4OAc; the extracted K and Na were determined by flame photometry, and Ca and Mg by atomic absorption spectrophotometry (Heald, 1965, Pratt, 1965), exchangeable acidity by method of McLean (1965), total nitrogen by digestion-distillation method (Bremner, 1960) and organic carbon by Walkley and Black (1934) method as modified by Black (1965), the effective CEC was obtained by summation of exchangeable cations and exchange acidity.

Statistical Analysis

This involved analysis of variance and linear correlation analysis.

3.2.2 Field Fertilizer Trials

Location

The field fertilizer rate experiments were carried out in 10 sites spread through Plateau and Benue States. Six of the sites were in Plateau and four in Benue States (two in present Benue State and two in Kogi State). The sites which were chosen from farms owned by Government Agencies were carefully selected by considering the length of fallow and fertilizer history so that a good range of responses to phosphorus fertilization could be obtained.

In each site, one hectare parcel of land was mapped out. Half of the plot was used in 1988 while the other was used for the 1989 trial. The size of the farm was to ensure that large discards surrounded the experimental blocks as a protective measure.

The fertilizer rate experimental sites are shown in Fig.2. While the site information is given in Table 3, their locations are described here:

(a) Kuru (09°43'N; 08°49'E) — Federal Soil Conservation School, Kuru, Jos South Local Government Area, Plateau State (Jos Plateau ecotone).

(b) Bokkos (09°17'N; 08°59'E) — Plateau Agricultural Development Corporation (PADC), Bokkos Farm Project, Bokkos Local Government Area, Plateau State (Jos Plateau ecotone).

(c) Sabon Gida (08°40'N; 09°30'E) — PADC Upland Farm, Langtang South Local Government Area, Plateau State (Southern Guinea savanna).

(d) Wamba (08°56'N; 08°36'E) — PADC Wamba Farm Project, Akwanga Local Government Area, Plateau State (Southern Guinea savanna).

(e) Laminga (08°45'N; 07°50'E) — Plateau Agricultural Development Programme (PADP) Seed Farm, Nasarawa Local Government Area, Plateau State (Southern Guinea savanna).

(f) Obi (08°25'N; 08°40'E) — PADP Seed Farm, Obi Local Government Area, Plateau State (Southern Guinea savanna).

Table 3: History of the sites selected for the field fertilizer rate studies.

Site No.	Location	Soil Classification (USDA)	Local Government Area	State	Vegetation Zone	Land use,Fertilizer History	Length of fallow
KUR/01	Kuru - Inside campus of FSCS	Typic Haplustalf	Jos South	Plateau	Jos Plateau	Grassland: vegetation burnt annually: Has not been fertilized for more than 10 years	>10 years
BOK/02	Bokkos - Bokkas Farm Project	Typic Haplustalf	Bokkos	Plateau	"	Grassland: vegetation burnt annually; previously planted to maize: 15:15:15 used last.	5 years
SGI/03	Sabon Gida - PADC Upland Farm	Typic Haplustalf	Langtang South	Plateau	Southern Guinea	Under grass cover: previous vegetation recently burnt: previously cropped to maize: compound fertilizer 15:15:15 and CAN used last in 1984.	4 years
WAM/04	Wamba - PADC Farm	Typic haplustalf	Akwanga	Plateau	"	Patches of grass cover; much soil exposed due to recent burning' cropped last to maize; compound fertilizer 15:15:15 was used	2 years
LAM/05	Lamiinga - PADP Seed Farm	Ustic Dystropept	Nasarawa	Plateau	"	Dense vegetation with shrubs and trees; land cleared for the first time in many years, by PADP for cropping: has not been previously fertilized.	>15 years
OBI/06	Obi - PADP Seed Farm	Typic Haplustalf	Obi	Plateau	"	Vegetation completely burnt; much of the soil exposed as a result. Cropped last to maize. Compound fertilizer 15:15:15 and CAN used.	2 years
AYA/07	Ayangba - BNARDA Seed Farm	Ustic Dystropept	Dekina	Kogi	Derived Savanna	Under dense tall grass cover: few sprouting shrubs after burning of previous vegetation. Cropped last to maize. 15:15:15 and CAN used.	3 years
ANK/08	Ankpa - Farm Service Centre, Ejoka	Typic Haplustalf	Ankpa	"	"	Semi-forest with dense shrub under-growth and few scattered trees; land cleared for cropping; planted last to cassava; No fertilizer ever used.	13 years
YAN/09	Yandev - Farm Service Centre	Typic Haplustalf	Gboko	Benue	Southern Guinea	Under dense grass cover; burnt annually; has been continuously cropped; last cropped to maize and yam; 15:15:15 and CAN used.	3 years
KAL/10	Katsina-Ala - LBRDA Farm Ugbema	Typic Tropaquept	Buruku	Benue	"	Under dense grass cover; burnt annually: continuously cropped: planted last to soyabeans; 54 kg P_2O_5 as SSP broadcast in 1986.	2 years

57(g) Ayangba (07°30'N; 07°15'E)	Benue State Agricultural and Rural Development Authority (BNARDA) Seed Farm, Dekina Local Government Area, Kogi State (Derived savanna).
(h) Ankpa (07°40'N; 07°20'E)	Farm Service Centre, Ejoka, Ankpa Local Government Area, Kogi State (Derived savanna).
(i) Katsina-Ala (07°20'N; 09°20'E)	Lower Benue River and Rural Development Authority Farm, Ugbema, Buruku Local Government Area, Benue State (Southern Guinea savanna).
(j) Yandev (07°30'N; 09°E)	Farm Centre, Gboko Local Government Area, Benue State (Southern Guinea savanna).

Duration

The trials which were rainfed were carried out in the same locations for two successive cropping seasons.

Plot Size

Each treatment (plot) was made up of six rows of ridges 14.81 m long. The width of each plot was 4.5 m. Thus, the area of each plot was 66.65 m^2 or $1/_{150}$ ha. Out of this, 13.33 m by 3.0 m or 39.99 m^2 ($1/_{250}$ ha) was harvested for the calibration studies.

Treatments

There were six levels of phosphorus, 0, 20, 40, 60, 80 and 100 kg P_2O_5/ha. Basal applications of nitrogen, potassium and zinc in the forms of urea, muriate of potash and zinc sulphate, respectively, were made. The treatments were laid in a randomised complete block design and replicated three times. Table 4 includes the amount of N, P, K and zinc applied per treatment.

Table 4: Amounts of various nutrient elements applied per treatment.

Treatment No.	*Nitrogen* kg N/ha	*Phosphorus* kg P_2O_5/ha	*Potassium* kg K_2O/ha	*Zinc* kg Zn/ha
1	120	0	45	10
2	120	20	45	10
3	120	40	45	10
4	120	60	45	10
5	120	80	45	10
6	120	100	45	10

Test Crop

The test crop was maize (*Zea mays* L.). The variety used was TZSR-White.

Seed Bed Preparation

The half a hectare site selected each year for the fertilizer rate experiments was ploughed, harrowed and ridged by a tractor. The ridges were 75 cm apart. They were arranged in groups of six. Each group of six ridges was separated from the next by a gap of 1.5 m which is equivalent to the space occupied by two ridges. There were a total of six groups of six ridges in each block.

The length of each ridge per block was 14.81 m. Since the ridges were prepared in lengths measuring 50 m or more, lengths equal to 14.81 m were marked out. These were followed by gaps of 1.5 m. There were three blocks per experimental site. Each block contained six plots of six ridges each. Fig. 3 shows the arrangement of the plots.

Soil Sampling

Soil samples composited from 18 sub-samples (three sub-samples per plot) collected from depths of 0 - 20 cm were taken in each block. The samples were thoroughly mixed and put in well labelled soil sample bags. Meanwhile equal volumes of soil samples from the three blocks in each site were thoroughly mixed and put in labelled soil sample bags. Thus, four soil samples were collected per site, one for each block and the fourth for the entire site.

The soil samples were air-dried, passed through 2-mm sieves and put in well labelled plastic containers for necessary laboratory determinations.

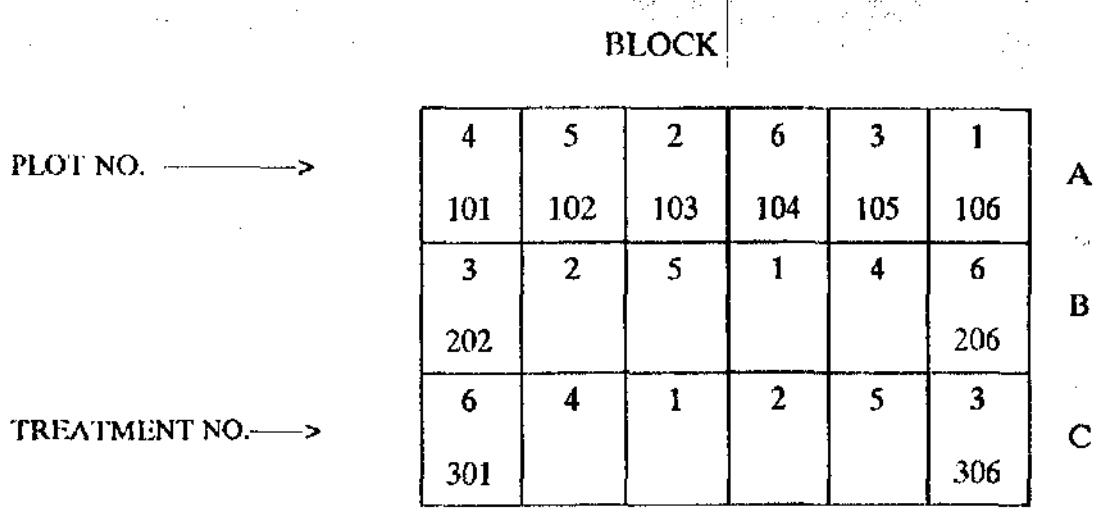


Fig. 3: Plot arrangement

Planting

Maize seeds were planted at a spacing of 25 cm within the ridges. Two seeds were planted per hole. The plants were thinned down to one stand per hole a week after planting. The plant population was 59 stands per ridge or 354 stands per plot or 53,100 stands per hectare.

Fertilizer Application

All of the phosphorus, potassium and zinc and half of the required dose of nitrogen were applied at planting. Grooves some 8 cm away from and 5 cm below the seeds were made on one side of and along the 14.81 m long ridges. The amount of each of the straight fertilizers required for each treatment was weighed out. These were separately divided into six equal portions corresponding to the number of ridges in each plot. The cups containing the fertilizers were put against the ridges. The fertilizers were applied evenly along the grooves. The order of application was phosphorus, followed by potassium, then nitrogen and finally zinc. The grooves were properly covered.

The second half of the required amount of nitrogen was applied as side-dressing six weeks after planting in holes 5 cm deep drilled 8 cm away from the stands. Table 5 includes the amount of the various fertilizers required per treatment.

Weeding

Weeding was done by hand-hoeing. The operation was carried out two or three times depending on the frequency of weed emergence. It was ensured that the farms were free of weeds in the first 10 weeks.

Observations

Each site was monitored at intervals of two weeks up to the tasselling stage. Guards were recruited to look after the farms. Recordings of visual observations were made.

Plant sampling

Index leaves were sampled from each of the treatments in two of the three blocks. Ten ear leaves, sampled from each plot before the silk turned brown, were collected, rinsed in distilled water, and put in well labelled large envelopes. They were oven-dried at 60°C for 48 hours, ground in stainless mill and put in small plastic bags for elemental analysis.

Harvesting

The maize was allowed to grow to maturity. Harvesting was carried out when the maize cobs had dried sufficiently.

In each plot (treatment) the two border ridges and the first two maize stands at both ends of each of the four middle ridges were discarded. The rest of the maize

Table 5: Field fertilizer studies: Amount of fertilizers needed per treatment (plot size: 14.81 m by 4.5 m = 66.65 m² = 1/150 ha).

Treatment No.	AT PLANTING								NITROGEN SIDE DRESSING	
	Urea 46% N		Single Superphosphate 18% P_2O_5		Muriate of Potash 60% K_2O		Zinc sulphate 22% Zn		Urea 46% N	
	kg/ha	kg/plot	kg/ha	kg/plot	kg/ha	kg/plot	kg/ha	kg/plot	kg/ha	kg/plot
1	130.84	0.87	0	0	75.0	0.50	45.45	0.30	130.84	0.87
2	130.84	0.87	111.11	0.74	75.0	0.50	45.45	0.30	130.84	0.87
3	130.84	0.87	222.22	1.48	75.0	0.50	45.45	0.30	130.84	0.87
4	130.84	0.87	333.33	2.22	75.0	0.50	45.45	0.30	130.84	0.87
5	130.84	0.87	444.44	2.96	75.0	0.50	45.45	0.30	130.84	0.87
6	130.84	0.87	555.56	3.70	75.0	0.50	45.45	0.30	130.84	0.87

plants were harvested. The area harvested was 13.33 m by 3.0 m or 39.99 m^2 or $1/_{250}$ ha.

Before harvesting was carried out, the stands in each harvested plot were counted and recorded. There should be 212 harvested stands per plot. In plots where fewer stands were recorded corrections were made to ensure equalisation of the stands per plot before the final grain yields were recorded.

The maize cobs were removed from the stands and put in well-labelled 50 kg capacity plastic bags. The bags were carried to base and the cobs dehusked, shredded, cleaned and weighed in an electronic sensitive balance. The weights were recorded.

A small quantity of maize grains from each treatment was collected, weighed and oven-dried at 80°C to constant weight. The moisture content was then recorded. The weights of the maize grains in all the treatments were than corrected for moisture and expressed in kilogrammes per hectare.

Post-Harvest Soil Sampling

After the harvesting of maize, three sub-samples were collected from a depth of 0-20 cm from each of the three replicates per treatment and composited. Six soil samples were, therefore, collected from each site - one from each treatment. The soil samples were put in well labelled soil sample bags. The soils were air-dried, passed through 2-mm sieves and put in well labelled plastic containers for necessary laboratory analysis.

Soil Analysis

The following determinations were carried out on the soil samples:

(a) Extractable (available) phosphorus using the methods developed in the correlation studies;

(b) Soil pH;

(c) Particle-size analysis;

(d) Total nitrogen;

(e) Organic carbon;

(f) Effective cation exchange capacity (ECEC);

(g) Percentage base saturation (% BS); and

(h) Residual phosphorus from post-harvest soil samples.

The analytical methods were as described earlier under section 3.2.1 Soil Analysis.

Plant Analysis

Total nitrogen was determined by digestion-distillation method, and phosphorus, potassium, magnesium, calcium and zinc were determined by the wet-digestion method as modified by IITA (1979) using atomic absorption spectrophotometer.

Statistical Analysis

Analysis of variance was carried out for the grain yields. Critical levels and soil test classes were determined using the Cate-Nelson graphical method (Cate and Nelson, 1965) and Cate-Nelson Analysis of Variance method (Cate and Nelson, 1971, as modified by Nelson and Anderson, 1980). Interpretations leading to fertilizer recommendations were carried out graphically and by the use of the Mitschelich-Bray equation and its expanded form (Melsted and Peck, 1980a).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Correlation Studies

4.1.1 Physical and Chemical Properties of the Soils

The sampling sites were freely drained except those derived from Alluvium (Makurdi and Idah) and those with high water table (Ogbogbo).

Table 6 includes data on the particle-size distribution and textural classes of the soils. The soils were generally coarse-textured with sandy loam and sandy clay loam being the dominant texture. Esu (1987) and Lombin (1987) reported that the soils of the savanna region are generally coarse-textured.

The data on chemical properties are given in Table 7. The pH of soils in water ranged from 4.0 to 6.0 with an average of 5.3. The soils from Jos Plateau and Derived savanna where the rainfall is more intense were extremely to very strongly acid with pH values between 4.0 and 5.0. All the soils from the southern Guinea savanna zone, which constitute about 60% of the soils studied, were strongly to moderately acid with pH values ranging from 5.1 to 6.0. These results are typical of the soils of this agro-ecological zone (Jones and Wild, 1975; Ojanuga and Awujoola, 1981).

The organic carbon contents of the soils ranged from 2.4 to 18.0 g kg^{-1} with an average of 7.2 g kg^{-1}. Three soils from Bassa (3.8 g kg^{-1} - sandy clay loam with scanty grass cover), Dengi (2.4 g kg^{-1} - gravelly sandy clay loam farmland) and Awe

Table 6: Particle-size distribution of the soils used for the correlation studies (USDA System).

Soil Sample No.	Location	Particle-size distribution (%)			Textural Class
		Clay	Silt	Sand	
BAS/01	Bassa	20	14	66	Sandy clay loam
KUR/02	Kuru	38	46	16	Silty clay loam
BLA/03	Barkin Ladi	42	16	42	Clay
MAN/04	Mangu	32	16	52	Sandy clay loam
PAN/05	Pankshin	46	18	36	Clay
DEN/06	Dengi	20	12	68	Sandy clay loam
LAN/07	Langtang	14	10	76	Sandy loam
WAS/08	Wase	20	18	62	Sandy clay loam
SHE/09	Shendam	12	12	76	Sandy clay loam
NAM/10	Namu	10	10	80	Loamy Sand
ZAL/11	Zalli	26	10	64	Sandy Clay Loam
AKW/12	Akwanga	16	6	78	Sandy Loam
GIT/13	Gitata	26	10	64	Sandy Clay Loam
AMB/14	Amba	14	12	74	Sandy Loam
NAS/15	Nassarawa	14	10	76	Sandy Loam
TOT/16	Toto	14	8	78	Sandy Loam
ODE/17	Odege	14	12	74	Sandy Loam
LAF/18	Lafia	18	36	46	Loam
AWE/19	Awe	12	16	72	Sandy Loam
UDE/20	Udei	30	42	28	Clay Loam
MAK/21	Makurdi	14	20	66	Sandy Loam
YAN/22	Yandev	12	20	68	Sandy Loam
KYA/23	Kyado	12	14	74	Sandy Loam
HAR/24	Harga	12	12	76	Sandy Loam
KOT/25	Koti	14	8	78	Sandy Loam
ALI/26	Aliade	20	16	64	Sandy Clay Loam
OJU/27	Oju	16	20	64	Sandy Loam
IGA/28	Iga Okpanya	36	28	36	Clay Loam
OKP/29	Okpoga	16	38	46	Loam
ANK/30	Ankpa	14	2	84	Loamy sand
ABE/31	Abejukolo	20	24	56	Sandy Clay Loam
OGU/32	Oguma	18	24	58	Sandy Loam
DEK/33	Dekina	12	2	86	Loamy Sand
AKP/34	Akpagidigbo	12	2	86	Loamy Sand
OGB/35	Ogbogbo	26	36	38	Loam
IDA/36	Idah	32	50	18	Silty Clay Loam

Table 7: Chemical characteristics of the soils used for the correlation studies

Soil Sample No.	Soil pH (1:2.5)	Organic Carbon (g/kg)	Total nitrogen (g/kg)	Total Phosphorus (mg/kg)	Exchangeable Bases (cmol(±) kg^{-1}				Total Exch. Acidity cmol(±) kg^{-1}	Effective cation Exch. Capacity cmol(±) kg^{-1}	Base Saturation (%)
					Ca	Mg	K	Na			
BAS/01	4.9	3.8	0.42	250	0.70	0.32	0.10	0.08	0.02	1.22	98.36
KUR/02	4.0	15.2	1.40	500	1.84	0.74	0.19	0.09	0.22	3.08	92.86
BLA/03	4.5	8.4	0.98	625	1.0	0.45	0.12	0.06	0.18	1.81	90.06
MAN/04	4.6	5.8	0.56	500	0.52	0.15	0.12	0.05	0.12	0.96	87.50
PAN/05	4.2	7.6	0.84	250	0.60	0.33	0.10	0.05	0.22	1.30	83.08
DEN/06	5.7	2.4	0.56	500	2.54	0.83	0.14	0.01	0.02	3.54	99.44
LAN/07	5.8	5.4	0.84	1000	2.31	0.72	0.1[illegible]	0.07	0.02	3.22	99.38
WAS/08	5.9	6.8	0.56	125	3.39	1.63	0.19	0.10	0.02	5.33	99.62
SHE/09	5.6	4.0	0.70	125	0.98	0.36	0.05	0.04	0.02	1.45	98.62
NAM/10	5.6	5.6	0.56	125	1.52	0.39	0.07	0.06	0.02	2.06	99.03
ZAL/11	5.4	6.4	0.84	250	0.75	0.53	0.11	0.04	0.02	1.45	98.62
AKW/12	5.3	6.6	0.56	125	0.69	0.28	0.06	0.03	0.02	1.08	98.14
GIT/13	5.7	11.0	0.84	125	2.18	1.73	0.19	0.06	0.02	4.18	99.52
AMB/14	5.8	4.8	0.84	125	0.82	0.43	0.07	0.05	0.02	1.39	98.56
NAS/15	5.7	5.8	0.70	125	1.07	0.66	0.09	0.03	0.02	1.87	98.93
TOT/16	5.8	5.0	0.42	375	0.95	0.47	0.03	0.03	0.02	1.50	98.67
ODE/17	5.5	7.2	0.42	125	1.34	0.54	0.10	0.04	0.02	2.04	99.02
LAF/18	5.3	7.8	0.56	500	1.02	0.92	0.11	0.05	0.02	2.12	99.06
AWE/19	5.8	3.8	0.56	875	1.85	0.54	0.10	0.04	0.01	2.54	99.61

Table 7 (continued).

Soil Sample No.	Soil pH (1:2.5)	Organic Carbon (g/kg)	Total nitrogen (g/kg)	Total Phosphorus (mg/kg)	Exchangeable Bases (cmol(±) kg^{-1})				Total Exch. Acidity cmol(±) kg^{-1}	Effective cation Exch. Capacity cmol(±) kg^{-1}	Base Saturation (%)
					Ca	Mg	K	Na			
UDE/20	5.4	17.4	1.12	875	3.18	2.30	0.13	0.10	0.02	5.73	99.65
MAK/21	5.2	4.8	0.56	125	1.02	0.24	0.08	0.08	0.01	1.43	99.30
YAN/22	5.9	5.2	0.56	625	1.51	0.39	0.07	0.04	0.01	2.02	99.50
KYA/23	6.0	4.4	0.56	250	1.37	0.41	0.07	0.04	0.01	1.90	99.47
HAR/24	5.8	5.6	0.56	375	1.85	0.56	0.10	0.05	0.02	2.58	99.22
KOT/25	5.4	8.8	0.98	250	1.17	0.59	0.04	0.04	0.02	1.86	98.92
ALI/26	5.5	4.6	0.70	500	1.13	0.50	0.06	0.03	0.02	1.74	98.85
OJU/27	4.7	18.0	0.42	500	1.45	1.11	0.21	0.05	0.16	2.98	94.63
IGA/28	5.5	6.4	0.98	125	1.38	0.73	0.12	0.04	0.01	2.28	99.56
OKP/29	5.3	8.8	0.84	125	1.50	0.89	0.14	0.05	0.01	2.59	99.61
ANK/30	4.5	4.2	0.56	375	0.15	0.10	0.02	0.03	0.04	0.34	88.24
ABE/31	4.7	6.4	0.84	125	0.59	0.28	0.05	0.03	0.01	0.96	98.96
OGU/32	4.8	7.2	0.84	250	1.15	0.47	0.05	0.05	0.02	1.74	98.85
DEK/33	4.7	5.4	0.70	125	0.33	0.12	0.02	0.03	0.09	0.59	84.75
AKP/34	4.7	4.2	0.70	125	0.27	0.12	0.02	0.02	0.02	0.45	95.56
OGB/35	5.0	10.0	0.84	250	1.38	1.65	0.11	0.08	0.03	3.25	99.08
IDA/36	5.1	15.6	1.12	500	4.39	2.47	0.26	0.22	0.04	7.38	99.46
MEAN	5.3	7.2	0.72	336.81	1.39	0.69	0.10	0.05		2.28	

(3.8 g kg^{-1} - sandy loam one year fallow on cassava) had very low organic carbon contents. Twenty-seven of the soils which constitute 75% of the soils studied were, according to FDALR (1990), rated low in organic carbon (4.0 to 8.8 g kg^{-1}). Two of the soils, Gitata (11.0 g kg^{-1} - bush fallow of many years) and Ogbogbo (10.0g kg^{-1} - bush fallow with high water table), were rated moderate while four, Kuru (15.2 g kg^{-1} - silty clay loam with vertic properties), Udei (17.4 g kg^{-1} - clay loam bush fallow for many years), Oju (18.0 g kg^{-1} - sandy loam forest), and Idah (15.6 g kg^{-1} - alluvium) had high organic carbon contents.

From these results, it can be concluded that the soils of the southern Guinea savanna are generally low in organic carbon. This agrees with the results of several studies on the organic carbon contents of savanna soils (Ojanuga, 1971; Jones, 1973; Esu, 1987; Lombin, 1987). Jones (1973) carried out a study of organic carbon contents of 605 well drained surface soils of the West African savanna. He found that the soils had an average organic carbon content of 6.8 g kg^{-1}. From his results he concluded that the organic carbon contents of the surface soils of this region are low.

The total nitrogen ranged from 0.42 to 1.4 g kg^{-1} with a mean value of 0.72 g kg^{-1}. Only the soils at Kuru (submerged grassland), Udei (wet forest) and Idah (alluvium) had total nitrogen contents above 1.0 g kg^{-1}. These results show that the total nitrogen contents of the soils of this zone are very low. This is in agreement with several reports on the total nitrogen contents of soils of the savanna region (Heathcote and Stockinger, 1970; Singh *et al.*, 1983; Sobulo and Osiname, 1985; Esu, 1987).

The soils studied were very low in total phosphorus with values between 125 and 1000 mg kg^{-1} and a mean of 336.81 mg kg^{-1}. Only three soils, Langtang, Awe and Udei, had total phosphorus contents above 625 mg kg^{-1}. Several workers have reported that the soils of the savanna region are generally low in total phosphorus (Enwezor and Moore, 1966; Heathcote and Stockinger, 1970; Jones, 1974b; Udo, 1985; Ayodele, 1986). It has been shown that the humid tropical soils of Africa, most of which are highly acid, are generally considered low in total and available phosphorus (Bouyer, 1971; Ayodele, 1986; Loganathan and Sutton, 1987). The low total phosphorus content of the savanna soils have been attributed to the low content in the parent material from which the soils were formed (Udo, 1985; Esu, 1987).

The cation exchange capacity (CEC) of the soils ranged from 0.34 to 7.38 cmol(±) kg^{-1} with an average of 2.28 cmol(±) kg^{-1}. The soils were, therefore, very low in CEC except Idah, with CEC of 7.38 cmol(±) kg^{-1}, that could be rated low. This confirms reports that the soils of the tropical savanna are characteristically low in cation exchange capacity (Singh *et al.*, 1983; Esu, 1987; Lombin, 1987).

Exchangeable calcium and magnesium dominate the exchange complex and accounted for 60.96% and 30.26% of the cation exchange capacity, respectively. The exchangeable calcium which varied from 0.15 to 4.39 cmol(±) kg^{-1} with a mean of 1.39 cmol(±) kg^{-1} is very low. Both exchangeable magnesium (0.10 to 2.47 cmol(±) kg^{-1}) and exchangeable potassium (0.02 to 0.26 cmol(±) kg^{-1}) are also rated very low in these soils.

The low contents of exchangeable bases in the soils could be explained on the basis of the fairly high rainfall regime of the southern Guinea savanna and the low organic matter and clay contents.

4.1.2 Amount of Phosphorus Solubilised by the Extractants

The available P extracted from the soils by the methods studied are in Table 8. The range of phosphorus extracted by the various soil test methods is as follows:

(a) Mehlich No.1 (Mehlich 1) - 0.72 to 21.07 mg kg^{-1}, mean 2.86 mg kg^{-1}.

(b) Mehlich No.2 (Mehlich 2) - 1.44 to 20.92 mg kg^{-1}, mean 4.50 mg kg^{-1}.

(c) Bray No.1 (Bray 1) - 0.48 to 19.42 mg kg^{-1}, mean 3.57 mg kg^{-1}.

(d) Bray No.2 (Bray 2) - 0.96 to 33.86 mg kg^{-1}, mean 5.54 mg kg^{-1}.

(e) Olsen's - 2.45 to 19.92 mg kg^{-1}, mean 5.47 mg kg^{-1}.

(f) Modified Mehlich 1 - 0.72 to 20.22 mg kg^{-1}, mean 4.0 mg kg^{-1}.

(g) Mississippi - 0.48 to 6.83 mg kg^{-1}, mean 1.22 mg kg^{-1}.

(h) Ammonium Bicarbonate-Diethylene Triamine Penta Acetic Acid (AB-DTPA) - 0.99 to 4.48 mg kg^{-1}, mean 1.74 mg kg^{-1}.

All the methods extracted a wide range of phosphorus from the soils. The results show that the soils varied widely in their extractable phosphorus contents. Bray 1 was the most effective in separating the soils, the largest amount of phosphorus extracted being 40.46 times the least. This is followed by Bray 2 (35.27 times), Mehlich 1 (29.26 times), Modified Mechlich 1 (27.78 times), Mehlich 2 (14.53 times), and Mississippi (14.23 times). Olsen's and AB-DTPA methods extracted the lowest range of 8.13 and 4.53 times, respectively. The relatively narrow range of extractable phosphorus obtained with Olsen's ($NaHCO_3$) and AB-DTPA

Table 8: Phosphorus extractable by various reagents (mg/kg).

Soil Sample Number	Mehlich No.1	Mehlich No.2	Bray No.1	Bray No.2	Olsen's	Modified Mehlich No.1	Mississippi	Ammonium Bicarbonate-DTPA
BAS/01	0.74	1.47	1.27	0.98	2.94	1.72	0.49	1.96
KUR/02	1.68	3.84	2.50	0.96	6.72	1.66	1.25	1.0
BLA/03	0.74	1.45	0.48	0.96	13.44	0.72	0.50	1.0
MAN/04	1.72	3.92	1.28	0.98	6.86	1.72	0.98	1.02
PAN/05	0.75	1.47	1.28	0.99	2.96	1.72	0.50	1.02
DEN/06	2.55	3.92	1.28	3.92	6.86	2.46	0.99	1.02
LAN/07	2.55	3.92	1.29	5.19	10.19	3.19	0.99	1.02
WAS/08	1.69	1.44	0.48	2.31	6.74	6.24	0.49	1.0
SHE/09	0.73	3.84	1.25	2.30	2.89	2.40	0.48	1.0
NAM/10	2.44	7.33	4.89	8.46	2.82	6.11	1.69	2.59
ZAL/11	0.72	1.44	1.25	2.66	2.88	2.40	0.48	1.92
AKW/12	1.72	3.93	1.28	3.92	2.94	3.92	1.0	1.02
GIT/13	1.72	3.92	1.28	2.35	2.94	2.45	0.98	1.02
AMB/14	1.72	3.92	0.49	2.35	2.95	2.45	0.49	1.96
NAS/15	0.75	1.49	1.29	2.39	2.99	1.74	0.50	2.75
TOT/16	2.58	3.97	2.59	3.97	2.99	2.48	1.0	1.98
ODE/17	1.74	3.97	1.29	5.26	2.98	3.22	0.99	1.98
LAF/18	2.58	5.77	2.58	5.27	6.96	3.98	1.29	1.03

Table 8 (continued).

Soil Sample Number	Mehlich No.1	Mehlich No.2	Bray No.1	Bray No.2	Olsen's	Modified Mehlich No.1	Mississippi	Ammonium Bicarbonate-DTPA
AWE/19	2.57	3.94	3.94	3.94	2.97	3.94	0.49	1.97
UDE/20	0.74	1.48	2.56	0.99	6.90	1.73	0.99	1.03
MAK/21	3.43	5.68	6.86	6.27	6.87	3.92	1.27	2.70
YAN/22	5.89	7.66	10.31	11.59	6.67	10.80	2.55	1.96
KYA/23	3.44	3.94	1.28	5.22	6.89	3.94	0.99	1.02
HAR/24	21.07	20.92	19.42	33.86	19.92	20.22	1.39	4.48
KOT/25	2.56	3.94	2.57	2.37	2.96	2.46	0.49	1.97
ALI/26	2.58	3.97	3.98	3.97	2.98	3.22	0.50	1.98
OJU/27	1.73	1.48	3.94	3.95	2.97	1.73	1.77	1.97
IGA/28	3.46	5.74	5.15	5.25	2.97	3.96	0.99	1.98
OKP/29	1.75	3.98	5.18	3.99	3.0	3.98	1.0	1.04
ANK/30	1.74	5.78	5.18	3.98	2.99	4.98	0.50	1.99
ABE/31	2.56	5.71	1.28	3.94	2.95	3.20	0.98	1.97
OGU/32	6.90	5.72	10.35	18.24	16.56	10.85	3.94	2.72
DEK/33	3.46	5.73	6.92	6.32	6.92	5.58	1.78	1.98
AKP/34	4.14	5.79	5.19	5.29	6.99	3.99	1.30	2.0
OGB/35	2.49	5.54	2.49	3.94	2.87	3.11	1.24	0.99
IDA/36	3.42	3.90	3.90	0.98	2.45	1.71	6.83	2.69
MEAN	2.86	4.50	3.57	5.54	5.47	4.0	1.22	1.74

methods is because the reagents are more effective in alkaline or high pH soils with high CEC and containing relatively large amounts of free $CaCO_3$.

The effectiveness of the extractants to solubilise phosphorus was in the order: Bray 2 > Olsen's > Mehlich 2 > Modified Mehlich 1 > Bray 1 > Mehlich 1 > AB-DTPA > Mississippi.

The superior effectiveness of Olsen's 1 over Bray 1 in extracting phosphorus from these soils is not in agreement with reports that the Bray 1 method usually extracts more phosphorus than the Olsen's method (Enwezor, 1977b; Varvel *et al.*, 1981; Udo, 1985). Sodium Bicarbonate ($NaHCO_3$) extractant is widely used for high CEC soils that have high percentage base saturation, that are alkaline, or that have relatively large amounts of free calcium carbonate (Jackson, 1958; Cope and Evans, 1985). Bray 1 is a good extractant for low to medium CEC soils. It is a rather strong extractant for aluminium-bound phosphorus (Al-P) and also extracts calcium-bound phosphorus (Ca-P) because of the acid included in the solution (Swenson *et al.*, 1949; Cope and Evans, 1985). The superiority of Olsen's method over Bray 1 in extracting quantities of phosphorus from the soils studied may be due to the fact that, in spite of the low CEC, the soils have high percentage base saturation with calcium dominating the exchange complex. Since the soils were coarse-textured and Pratt and Garber (1964) had found that Bray 1 method had extraction problems on sandy and high clay soils while Terman *et al.* (1958) had indicated similar problems with the $NaHCO_3$ method on acid soils, the results obtained could be explained on the basis of these. Also, since the soils of the savanna have been reported to have relatively low phosphate retention capacity (Osiname, 1974; Juo and Fox, 1977; Mokwunye, 1977) it is possible that they contain low levels of aluminium and iron

oxides and oxyhydroxides. This means that most of the phosphorus in the soils may not be aluminium- or iron-bound and may, therefore, be in forms that may not be easily available for extraction by Bray 1.

It should, however, be noted that the results obtained using these two extractants may depend on the varied nature of the soil characteristics (Vervel *et al.*, 1981) and climatic conditions. Widjaja-Adhi and Silva (1986) working on Indonesian and Hawaii soils found that the range of values of phosphorus extracted from these soils by Bray 1 and Olsen's was narrow. In the present study, as one moves towards the rainforest zone, Bray 1 proves more effective. From the central part of the southern Guinea savanna (Lafia) down to the Derived savanna, the range of values becomes narrow as Bray 1 and Olsen's methods extracted amount of phosphorus that averaged 5.42 and 5.99 mg kg^{-1}, respectively. In the Derived savanna, Bray 1 was more effective than Olsen's. The average amount of phosphorus extracted by the Bray 1 method was 4.99 mg kg^{-1} as against 4.88 mg kg^{-1} extracted by Olsen's.

The more effectiveness of Bray 2 over Bray 1 in extracting phosphorus is because of the increased strength of the acid (HCl). The more concentrated the acid the higher the amount of phosphorus extracted by the acid/fluoride solution (Enwezor, 1977b).

4.1.3 Relationships between the Extractants

Table 9 shows the matrix of linear correlation coefficients, r, among the quantities of phosphorus extractable by the methods used in this study. The extracts from all the methods except Mississippi were closely related as shown by the linear correlation coefficients which are significant at the 0.1% probability level. The best

Table 9: Matrix of linear correlation coefficients, r, among phosphorus extractants and selected soil properties.

	Mehlich No.1	Mehlich No. 2	Bray No.1	Bray No.2	Olsen's	Modified Mehlich No.1	Mississippi	AB-DTPA	% Clay	Soil pH	% Organic carbon	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	ECEC
Mehlich No. 1																
Mehlich No. 2	0.931															
Bray No.1	0.889	0.852														
Bray No. 2	0.799	0.723	0.760													
Olsen's	0.700	0.552	0.608	0.593												
Modified Mehlich No. 1	0.912	0.871	0.900	0.821	0.667											
Mississippi	0.250	0.171	0.347	0.146	0.174	0.212										
AB-DTPA	0.688	0.639	0.729	0.641	0.303	0.624	0.340									
% Clay	-0.256	-0.328	-0.292	-0.267	0.004	-0.373	0.066	-0.366								
Soil pH	0.199	0.179	0.066	0.221	-0.040	0.256	-0.104	0.141	-0.535							
% Organic Carbon	-0.133	-0.222	-0.075	-0.195	-0.064	-0.234	0.387	-0.142	0.449	-0.326						
Exch. Ca	0.093	-0.032	0.004	-0.066	0.095	0.040	0.474	-0.035	0.173	0.364	0.486					
Exch. Mg	-0.083	-0.179	-0.133	-0.186	-0.095	-0.153	0.410	-0.170	0.314	0.179	0.712	0.842				
Exch. K	-0.097	-0.220	-0.168	-0.171	-0.050	-0.204	0.353	-0.184	0.497	-0.048	0.676	0.733	0.744			
Exch. Na	-0.031	-0.112	-0.038	-0.173	-0.005	-0.117	0.650	0.046	0.371	-0.099	0.585	0.715	0.714	0.672		
ECEC	0.012	-0.110	-0.063	-0.132	0.022	-0.056	0.474	-0.164	0.280	0.256	0.628	0.972	0.940	0.799	0.764	
% BS	0.156	0.132	0.058	0.195	-0.054	0.160	0.112	0.183	-0.411	0.737	-0.026	0.439	0.354	0.128	0.131	0.381

n = 36

P < 0.05 = r ≥ 0.325; P < 0.01 = r ≥ 0.418; P < 0.001 = r ≥ 0.519.

relationships were between Mehlich 1 and Mehlich 2 (r = 0.931), Mehlich 1 and Modified Mehlich 1 (r = 0.912), Modified Mehlich 1 and Bray 1 (r = 0.900), Mehlich 1 and Bray 1 (r = 0.889), Mehlich 2 and Modified Mehlich 1 (r = 0.871), Bray 1 and Mehlich 2 (r = 0.852) and Modified Mehlich 1 and Bray 2 (r = 0.821).

The close relationship between phosphorus extracted by Mehlich 1, Mehlich 2, Modified Mehlich 1 and Bray 1 methods stems from the fact that the reagents are known to extract phosphorus from similar sources. In all these methods dilute HCl is a component reagent. It has been found that dilute acids extract portions of all forms of phosphorus in the soils. The fluoride in Bray 1, Modified Mehlich 1 and Mehlich 2 accounts for their closeness since this reagent is known to increase the amount of Al-P, Fe-P and mono- and di-calcium P extracted (Smith *et al.*, 1957; Chang and Jackson, 1957; Chai and Caldwell, 1959; Chang and Juo, 1963).

The quantities of phosphorus extracted by the Mississippi method are not significantly correlated with phosphorus extracted by the other methods except with Bray 1 (r = 0.347), and AB-DTPA (r = 0.340) where the linear correlation coefficients were significant at the 5% level. NH_4F of similar strength is employed by both the Mississippi and Bray 1 methods and these methods have been known to be successful on acid and low CEC soils (Cope and Evans, 1985). The Mississippi and AB-DTPA methods have also been employed for the extraction of phosphorus from alkaline and calcareous clay soils (Soltanpour and Schwabb, 1977; Cope and Evans, 1985).

Olsen's and AB-DTPA methods extracted quantities of phosphorus that vary widely and which are not significantly correlated. This is contrary to expectation since these methods have been shown to extract phosphorus from alkaline and high

CEC soils. However, since the soils studied are strongly to moderately acid, the reagents may be selective and rather specific in the solubilisation of phosphorus.

4.1.4 Dry Matter Yield

Herbage dry matter yields, relative yields and actual yield increases of maize from the greenhouse cropping are in Table 10. The yields for the treatments that received all the essential nutrients except phosphorus (P_o) were especially low and varied among soils, and ranged from 1.03 to 13.72 g/pot. This is confirmed by the analysis of variance (Appendix 2) which shows that the variation in yields were significant at the 0.1% probability level with a high coefficient of variation of 21.1%. The variation in dry matter yields when all the essential nutrients including phosphorus were added in sufficient quantities (P_1) was narrow and ranged from 23.48 to 39.09 g/pot. Although the analysis of variance (Appendix 3) shows that the soils varied significantly in their yields, the coefficient of variation was low (6.6%).

These results show that the soils:

(a) were highly deficient in phosphorus and the deficiency was widespread;

(b) varied in their phosphate fertility; and

(c) responded significantly to phosphorus additions as reflected in the analysis of variance between yields at P_o and P_1.

Visual observations of crops (Table 11) confirm that all the soils were deficient in phosphorus as there were:

Table 10: Greenhouse cropping herbage: dry matter yield of maize, relative yield and yield increase.

Soil Sample No.	Yield with phosphorus omitted, P_o (g/pot)	Yield with phosphorus added, P_1 (g/pot)	Relative yield (%)	Yield increase, $\triangle Y$ (g/pot)
BAS/01	1.65	34.01	4.85	32.36
KUR/02	1.86	36.15	5.15	34.29
BLA/03	2.07	23.69	8.74	21.62
MAN/04	1.74	28.72	6.06	26.98
PAN/05	1.76	26.77	6.57	25.01
DEN/06	2.19	34.31	6.38	32.12
LAN/07	2.94	36.47	8.06	33.53
WAS/08	2.69	33.24	8.09	30.55
SHE/09	1.93	33.57	5.75	31.64
NAM/10	5.83	33.41	17.45	27.58
ZAL/11	1.89	35.85	5.27	33.96
AKW/12	2.22	33.07	6.71	30.85
GIT/13	1.81	33.85	5.35	32.04
AMB/14	1.95	34.79	5.61	32.84
NAS/15	2.20	33.65	6.54	31.45
TOT/16	2.12	29.09	7.29	26.97
ODE/17	1.91	38.80	4.92	36.89
LAF/18	2.02	33.50	6.03	31.48
AWE/19	3.87	37.43	10.34	33.56
UDE/20	1.51	34.22	4.41	32.71
MAK/21	2.41	36.53	6.60	34.12
YAN/22	7.89	33.20	23.77	25.31
KYA/23	2.67	36.40	7.34	33.73
HAR/24	13.72	36.05	38.06	22.33
KOT/25	1.82	30.30	6.01	28.48
ALI/26	2.38	33.67	7.07	31.29
OJU/27	2.11	31.40	6.72	29.29
IGA/28	2.54	36.83	6.90	34.29
OKP/29	2.51	34.54	7.27	32.03
ANK/30	1.03	30.07	3.43	28.97
ABE/31	1.63	31.57	5.16	29.94
OGU/32	5.75	30.52	18.84	24.77
DEK/33	1.28	23.69	5.40	22.41
AKP/34	1.25	23.48	5.32	22.23
OGB/35	1.91	31.62	6.04	29.71
IDA/36	8.92	39.09	22.82	30.17

Table 11: Visual observations.

Treatment	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6 (harvest)
P omitted (P_o)	Normal development of all stands in all pots	Severe purpling of older leaves. Purpling spreading to younger leaves in some pots except Zalli, Akwanga, Makurdi, Yandev, Harga, Koti, Oguma and Ogbogbo where slight purpling is noticed only in few older leaves.	Severe purpling. Normal green colour of most younger leaves	Severe stunting, slender stems and narrow leaves except Harga which is fairly normal. General purpling of older leaves in all pots. Light green younger leaves in all pots. Slight purpling of youngest leaves in all pots except Yandev and Harga. Older leaves scorching from tips and edges	Severe stunting. Plants spindly. Severe purpling of plants. Oldest leaves dead. Development is average in Harga, Namu, Yandev and Idah	All pots severely stunted except Namu, Yandev, Harga, Oguma and Idah which are average. All oldest leaves completely scorched. Few stands dead in most of the pots. However only 1 to 3 life plants in Bassa, Mangu, Zalli, Gitata, Lafia, Ankpa and Akpagidigbo.
Padded (P_x)	Normal development of all stands in all pots	Normal development. Normal green leaves except Oju and Ogbogbo where slight purpling was noticed in few older leaves	Normal development. Slight purpling of older leaves in few stands in very few pots.	Normal green, broad leaves and robust stems in all pots	Normal green, broad leaves and robust stems. Plants luxuriant except Ankpa and Dekina which are average.	Normal development in all pots. Oldest leaves yellowing or scorched.

(a) severe purplings and stunting of the plants in most of the pots that received no phosphorus; and,

(b) normal development of the plants in all the pots in treatments that received all the essential nutrients including phosphorus.

The results obtained from the greenhouse cropping are in agreement with several reports that phosphorus deficiency is widespread in the savanna and that many crops respond significantly to phosphorus additions (Goldsworthy and Heathcote, 1963; Goldsworthy, 1967; Amon and Adetunji, 1970; Bache and Rogers, 1970; Jones, 1974a; Mokwunye, 1974; Amon, 1965; Jones and Wild, 1975; Enwezor, 1977b; Kang and Juo, 1979; Osiname, 1979; Balasubramanian *et al.*, 1980; Bationo *et al.*, 1986; Lombin, 1987; Sobulo and Adepetu, 1987; Uyovbisere and Lombin, 1991).

4.1.5 Phosphorus Uptake

Phosphorus uptake by the maize plants is in Table 12. The phosphorus concentration at P_o varied significantly among the soils (Appendix 7) and ranged from 1.13 to 2.38 g kg^{-1} with a mean of 1.77 g kg^{-1}. The phosphorus concentration at P_1 varied from 1.13 to 4.38 g kg^{-1} with an average of 3.16 g kg^{-1}. For the individual soils, the phosphorus concentration at P_1 was higher than the phosphorus concentration at P_o in all but Kuru, Barkin Ladi, Mangu and Idah soils. On the average there was an increase of about 79% in phosphorus concentration in the aerial parts of the maize plants at P_1 over P_o.

Phosphorus uptake at P_o varied very significantly among the soils (Appendix 8) and ranged from 1.29 to 24.0 mg/pot with a mean of 5.46 mg/pot and a coefficient

Table 12: Greenhouse cropping: Phosphorus uptake by maize.

Soil Sample No.	Minus P		Plus P	
	Concentration g kg^{-1}	Uptake mg/pot	Concentration g kg^{-1}	Uptake mg/pot
BAS/01	1.38	2.247	2.75	92.538
KUR/02	2.13	3.910	1.50	54.225
BLA/03	1.38	2.809	1.50	35.666
MAN/04	1.50	2.603	1.13	32.394
PAN/05	1.13	1.940	2.75	72.423
DEN/06	1.50	3.285	3.75	128.644
LAN/07	1.25	4.669	4.0	145.768
WAS/08	1.88	5.005	3.63	118.970
SHE/09	1.88	3.553	4.25	141.598
NAM/10	1.88	10.819	3.63	121.193
ZAL/11	1.25	2.258	3.0	107.611
AKW/12	1.63	3.624	2.13	69.864
GIT/13	2.13	3.892	3.75	127.135
AMB/14	2.13	4.128	2.63	91.058
NAS/15	1.88	4.147	4.0	134.797
TOT/16	1.63	3.484	2.88	83.812
ODE/17	2.0	3.810	3.88	150.467
LAF/18	2.0	4.030	3.25	107.635
AWE/19	2.38	9.199	2.63	99.015
UDE/20	2.13	3.253	3.38	115.145
MAK/21	1.88	4.584	3.38	122.637
YAN/22	2.25	17.753	4.13	135.613
KYA/23	2.38	6.270	3.88	139.994
HAR/24	1.75	24.002	3.25	118.423
KOT/25	1.88	3.408	3.75	113.325
ALI/26	2.13	5.024	2.75	93.628
OJU/27	1.75	3.673	2.0	63.434
IGA/28	1.50	3.803	3.63	133.873
OKP/29	1.38	3.469	3.75	128.474
ANK/30	1.25	1.288	3.88	116.830
ABE/31	1.63	2.642	3.25	102.603
OGU/32	2.13	12.224	3.75	113.378
DEK/33	1.38	1.725	4.38	101.919
AKP/34	1.25	1.557	3.38	79.819
OGB/35	1.75	3.343	2.13	67.224
IDA/36	2.25	20.059	1.88	73.528
MEAN	1.87	5.458	3.16	103.738

of variation of 21.2%. Phosphorus uptake at P_1 ranged from 32.39 to 150.37 mg/pot. This amounts to a very significant increase over P_o in all the soils. The least increase of about 4 times was with Idah soil while the highest increase of about 48 times was with the Zalli soil. The variation in phosphorus uptake at P_1 was not statistically significant (Appendix 9) showing that all the plants absorbed satisfactory quantities of phosphorus for maximum development at that stage of growth.

From the phosphorus uptake data it can be concluded that:

(a) the soils under investigation were highly deficient in phosphorus; the low percentage of phosphorus in the dry matter at P_o confirms near exhaustion of phosphorus in the soils (Bache and Rogers, 1970);

(b) *phosphorus is a very serious yield limiting nutrient in these soils; and*

(c) the efficiency of phosphorus absorption by the plants varied from soil to soil although the variation was not statistically significant.

4.1.6 Relationship between Extractable Phosphorus, and Phosphorus Uptake as well as Maize Yield

The effectiveness of the eight extractants employed in this study to solubilise forms of phosphorus that influence herbage yields and phosphorus uptake by the aerial parts of maize grown in the greenhouse is determined by linear correlation coefficients, r. Three yield variables, namely, actual yield (yield at check pots, that is, at P_o), relative yield and yield increase, and phosphorus uptake at P_o, were considered. These yield related or derived variables and phosphorus uptake have often been used in correlation studies (Bray, 1948; Smith *et al.*, 1957; Williams and Knight, 1963; Bromfield, 1967; Bache, 1970; Bache and Rogers, 1970; Adetunji, 1974; Oko and Agboola, 1974; Enwezor, 1977a; Nelson and Anderson, 1980).

The linear correlation coefficient values between phosphorus extracted by the eight extractants and actual yield, relative yield, actual yield increase, and phosphorus uptake are given in Table 13. Phosphorus extracted by all the methods were highly significantly correlated ($P < 0.001$) with actual yield, relative yield and phosphorus uptake (except Olsen's). Figs. 4, 5 and 6 are the scatter diagrams of relative yield, actual yield and phosphorus uptake against phosphorus extractable by Bray 1, Mehlich 1 and Modified Mehlich 1, respectively, which had the best correlation coefficients. For all the extractants except Mississippi and AB-DTPA, relative yield was better correlated with extractable phosphorus than actual yield.

Actual yield increase was not significantly correlated with phosphorus extractable by Bray 2, Mississippi and AB-DTPA methods, while it was not as well correlated with phosphorus extracted by the other methods as the other indices of growth.

The effectiveness of the four indices of growth in predicting the variation in the phosphorus extractable by Mehlich 1, Mehlich 2, Bray 1, Bray 2, and Modified Mehlich 1 are in the order: Relative Yield > Actual Yield > Phosphorus Uptake > Actual Yield Increase. For the Olsen's method the order is: Relative Yield > Actual Yield > Actual Yield Increase > Phosphorus uptake. For the Mississippi method the order is: Phosphorus Uptake > Actual Yield > Relative Yield > Actual Yield Increase, while the order is: Actual Yield > Relative Yield > Phosphorus Uptake > Actual Yield Increase for the AB-DTPA method. Bache and Rogers (1970) indicated that the relationships between soil phosphorus values and plant indices depend to some extent on which plant index is chosen for Williams and

Table 13: Greenhouse cropping: Linear correlation coefficients, r, between phosphorus extractable by various methods and selected soil properties against some yield variables.

Method	Actual yield (yield at P_o)	Relative yield	Actual yield increase	Phosphorus uptake
Mehlich No. 1	0.825***	0.833***	-0.419**	0.744***
Mehlich No. 2	0.745***	0.749***	-0.371*	0.660***
Bray No. 1	0.772***	0.798***	-0.471**	0.720***
Bray No. 2	0.670***	0.686***	-0.280 ns	0.581***
Olsen's	0.522***	0.575***	-0.488**	0.447**
Modified Mehlich No.1	0.791***	0.819***	-0.426**	0.728***
Mississippi	0.562***	0.550***	-0.204 ns	0.644***
AB-DTPA	0.672***	0.667***	-0.273 ns	0.636***

n = 36.
*** = P < 0.001; ** = P < 0.01; * = P < 0.05; ns = non-significant.

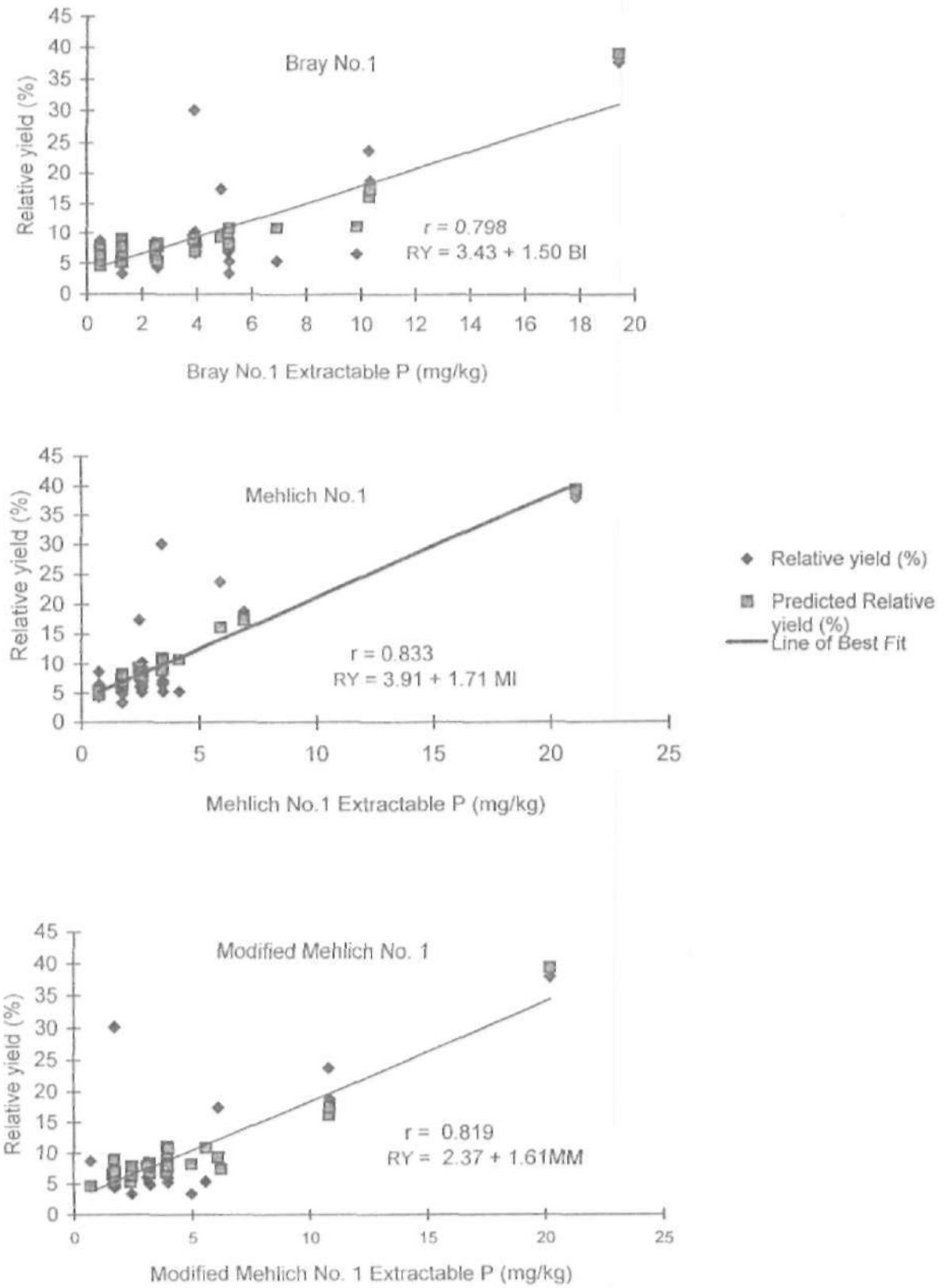
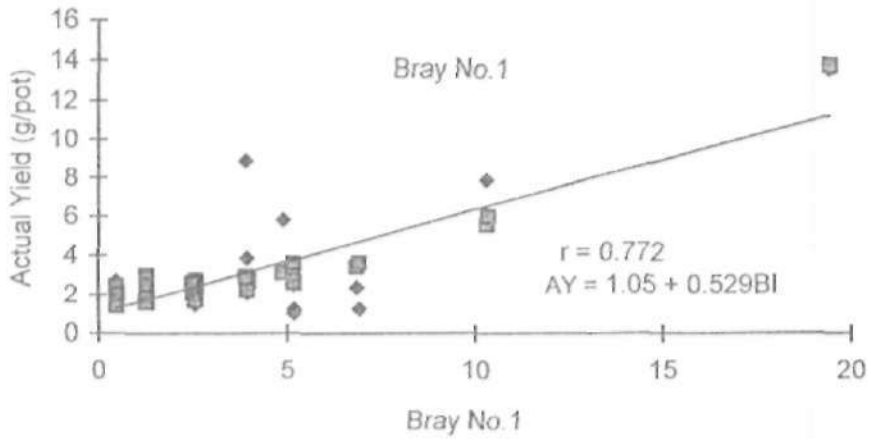
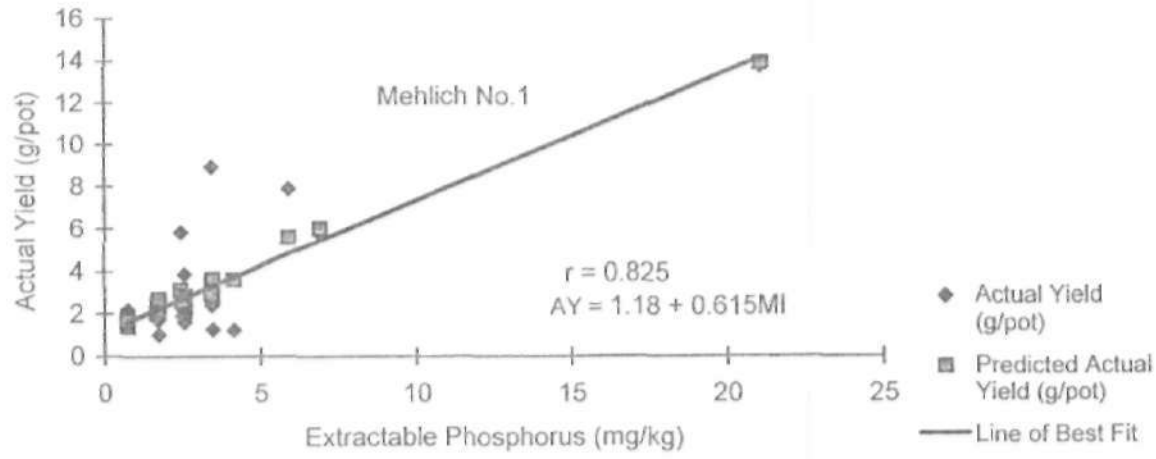


Fig. 4: Scatter diagram of percentage yield of maize versus soil test phosphorus.





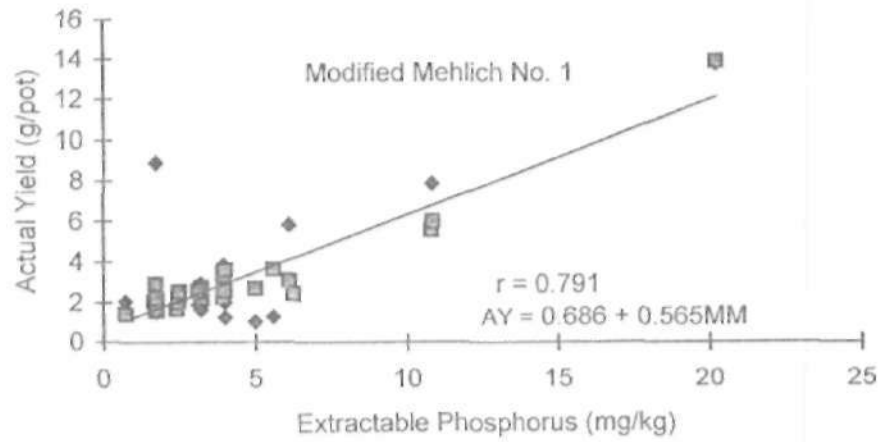


Fig. 5: Scatter diagram of actual yield (Yield at P_o) of maize versus soil test phosphorus.

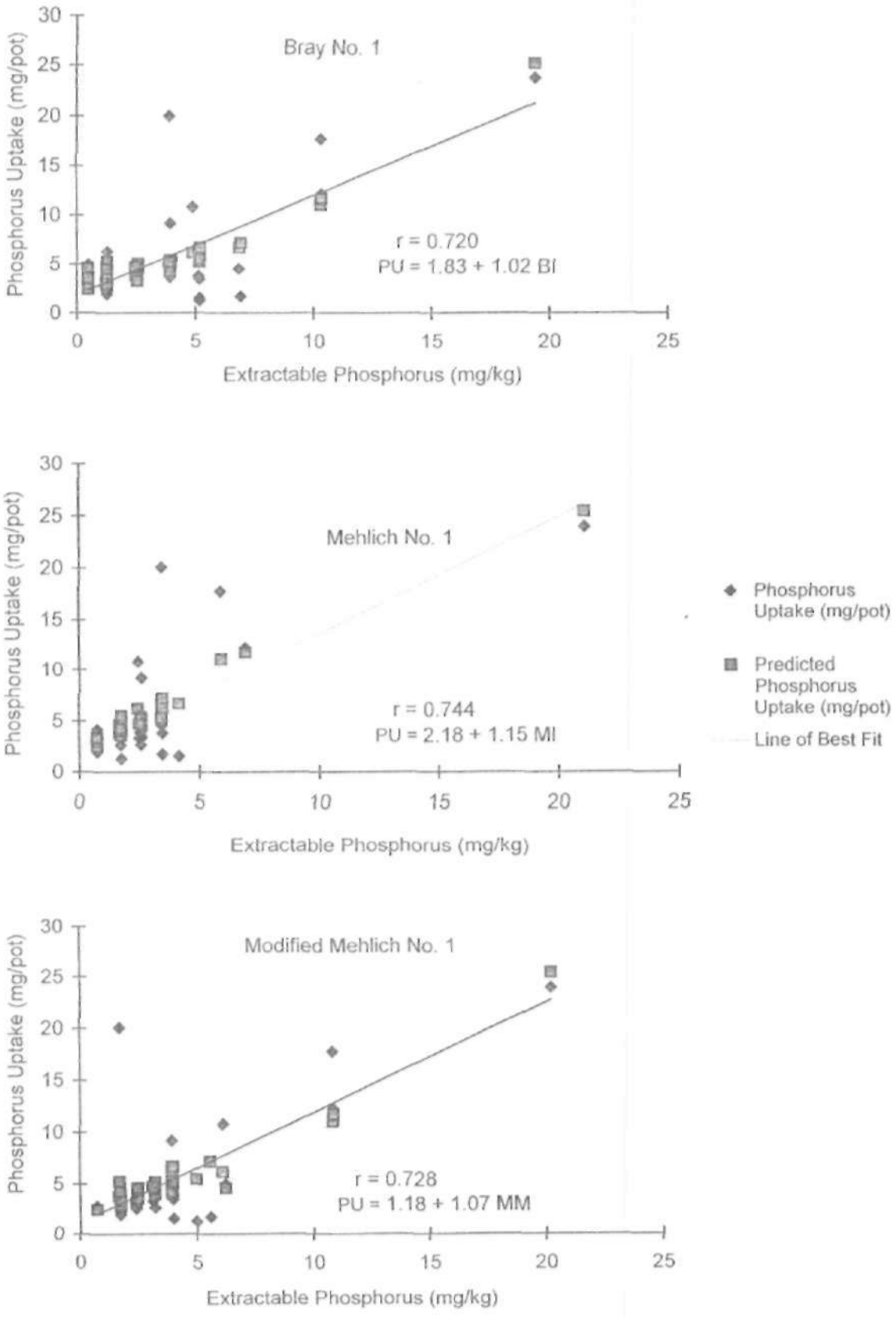


Fig. 6: Scatter diagram of phosphorus uptake by maize versus soil test phosphorus

Knight (1963) showed from oats grown in pots that quantity estimates correlated better with phosphorus uptake while intensity estimates correlated better with yield.

Relative Yield

Mehlich 1 gave the best correlation with relative yield (r = 0.833). This is followed by Modified Mehlich 1 (r = 0.819), Bray 1 (r = 0.798), Mehlich 2 (r = 0.749), Bray 2 (r = 0.686), AB-DTPA (r = 0.667), Olsen's (r = 0.575), and Mississippi (r = 0.550), in that order. Regression equations and coefficients of determination, R^2, for the yield variables and phosphorus uptake, against extractable phosphorus are in Tables 14 and 17, respectively. Mehlich 1, Modified Mehlich 1, Bray 1 and Mehlich 2, which had the best correlation coefficients had coefficients of determination, R^2, of 69.4, 67.0, 63.6 and 56%, respectively. This shows that these methods extracted phosphorus whose variations accounted for very significant variations in the relative yield of maize. Phosphorus extractable by all the eight methods combined accounted for 85.3% of the variation in relative yield.

Actual Yield

Actual Yield correlated highly significantly with phosphorus solubilised by all the eight extractants. Mehlich 1 gave the highest correlation with a linear correlation coefficient of 0.825. The order of effectiveness of the methods in predicting actual yield is Mehlich 1 > Modified Mehlich 1 > Bray 1 > Mehlich 2 > AB-DTPA > Bray 2 > Mississippi > Olsen's. The prediction of the variation in actual yield was 68.0, 62.5, 59.6, 55.5, 45.1, 44.9, 31.6, and 27.3%, respectively. Like relative yield, the

Table 14: Greenhouse cropping: Regression equations for some yield parameters against phosphorus extractable by various methods.

Method	Actual yield (AY) Equation	Relative Yield (RY) Equation	Actual Yield Increase (AYI) Equation	Phosphorus Uptake (PU) Equation
Mehlich No.1	AY = 1.18 + 0.615 MI	RY = 3.91 + 1.71 MI	AYI = 31.3 - 0.487 MI	PU = 2.18 + 1.15 MI
Mehlich No.2	AY = 0.362 + 0.574 MII	RY = 1.66 + 1.58 MII	AYI = 31.9 - 0.446 MII	PU = 0.75 + 1.05 MII
Bray No.1	AY = 1.05 + 0.529 BI	RY = 3.43 + 1.50 BI	AYI = 31.7 - 0.503 BI	PU = 1.83 + 1.02 BI
Bray No.2	AY = 1.52 + 0.257 BII	RY = 4.79 + 0.722 BII	AYI = 30.9 - 0.167 BII	PU = 2.92 + 0.458 BII
Olsen's	AY = 1.15 + 0.327 OL	RY = 3.38 + 0.989 OL	AYI = 32.5 - 0.476 OL	PU = 2.31 + 0.576 OL
Modified Mehlich No.1	AY = 0.686 + 0.565 MMI	RY = 2.37 + 1.61 MMI	AYI = 31.5 - 0.422 MMI	PU = 1.18 + 1.07 MMI
Mississippi	AY = 1.46 + 1.21 MIS	RY = 4.80 + 3.26 MIS	AYI = 30.8 - 0.686 MIS	PU = 1.96 + 2.86 MIS
AB-DTPA	AY = -0.919 + 2.22 AD	RY = -1.74 + 6.04 AD	AYI = 32.4 - 1.41 AD	PU = -2.07 + 4.32 AD

Multiple regression equations:

1. AY = 0.053 + 0.510 MI - 0.075 MII - 0.205 BI - 0.002 BII - 0.079 OL + 0.331 MMI + 0.870 MIS + 0.319 AD
   R^2 = 84.9%.

2. RY = 0.13 + 1.04 MI - 0.209 MII - 0.413 BI - 0.024 BII - 0.057 OL + 1.05 MMI + 2.23 MIS + 0.92 AD
   R^2 = 85.3%.

3. AYI = 33.5 + 0.215 MI - 0.117 MII - 0.559 BI + 0.145 BII - 0.459 OL + 0.174 MMI - 0.016 MIS - 0.33 AD
   R^2 = 33.1%.

4. PU = -0.25 + 1.0 MI - 0.322 MII - 0.423 BI - 0.077 BII - 0.237 OL - 0.901 MMI + 2.23 MIS + 0.680AD
   R^2 = 82.9%.

variation in phosphorus extractable by all the methods combined accounted for a very high percentage (84.9%) of the variation in actual yield.

From the above results it could be seen that actual yield was almost as good as relative yield in comparing soil test values. For the Mississippi and AB-DTPA methods, actual yield really correlated better with extractable phosphorus ($r = 0.562$ and 0.672) than relative yield ($r = 0.550$ and 0.667). Rouse (1968) indicated that since other environmental conditions vary from site to site, actual yields cannot be used as a basis of comparison. Nelson and Anderson (1980) pointed out that actual yields do not correlate well with soil test results because they contain variation among locations attributable to climatic variables and also contain variations in soil texture, structure, CEC, source of charge, and organic matter content. The effectiveness of actual yield in this study may have resulted from the fact that the levels of phosphorus in these soils were low, most of them falling within a certain narrow range. This, more than any other site or environmental factors which were identical for the soils studied, probably influenced the variations in yields. Bromfield (1967) working with savanna soils of Western Nigeria had found a very good correlation between phosphorus extracted by a number of methods and yield of control plots (actual yield). Bache and Rogers (1970) successfully used phosphorus uptake, dry matter yield from unfertilized plots (actual yield) and relative yield of Rhodes grass as plant indices of phosphorus supply from 24 soil samples from long term manural trials across the savanna region. Adetunji (1974) working on surface soils sampled across Western Nigeria also found significant correlations between the yield of maize from control plots and phosphorus extractable by Bray 1 method.

Phosphorus Uptake

The order of effectiveness of the extractants in solubilisng forms of phosphorus that relate to phosphorus uptake is Mehlich 1 ($r = 0.744$; $R^2 = 55.3\%$) > Modified Mehlich 1 ($r = 0.728$; $R^2 = 53\%$) > Bray 1 ($r = 0.720$; $R^2 = 51.8\%$) > Mehlich 2 ($r = 0.660$; $R^2 = 43.6\%$) > Mississippi ($r = 0.644$; $R^2 = 41.4\%$) > AB-DTPA ($r = 0.636$; $R^2 = 40.5\%$) > Bray 2 ($r = 0.581$; $R^2 = 33.7\%$) > Olsen's ($r = 0.447$; $R^2 = 20\%$). The phosphorus extractable by all the reagents in a multiple regression accounted for 82.9% of the variation in phosphorus uptake.

Actual Yield Increase

The correlations between phosphorus extracted by the various methods and actual yield increase were negative and not as high as those with relative yield, actual yield and phosphorus uptake. Olsen's method extracted phosphorus that correlated best with yield increase. This is followed by Bray 1, Modified Mehlich 1 and Mehlich 1 which had linear correlation coefficients of -0.488, -0.471, -0.426 and -0.419, respectively, which are significant at $P < 0.01$. Mehlich 2 had a linear correlation coefficient of -0.371 which is significant at $P < 0.05$. Phosphorus extractable by Bray 2, Mississippi and AB-DTPA were not significantly correlated with yield increase.

Nelson and Anderson (1980) and Bache (1970) had indicated preference of yield increase for soil test correlation. Nelson and Anderson (1980) reasoned that data based on actual yield increase have a definite advantage in that direct economic interpretations can be made from the results of soil test correlation studies. Adetunji (1974) successfully used, among other indices, yield increase in comparing

phosphorus extracted by various methods. In the present study, actual yield increase, although correlated well with phosphorus extractable by five of the eight methods, is not as suitable as relative yield, actual yield and phosphorus uptake for soil test correlation.

4.1.7 The Relationships between Soil Properties and Extractable Phosphorus

The relationships among phosphorus extractable by the various soil test methods and clay content, soil pH, organic carbon content, exchangeable Ca, Mg, K and Na, ECEC and percent Base Saturation (%BS) are in Table 9. All the soil properties except soil pH and %BS had negative influence on phosphorus extractable by all the methods except Mississippi. Clay content had a significant relationship with phosphorus extractable by only Mehlich 2 ($r = -0.328$), Modified Mehlich 1 ($r = -0.373$), and AB-DTPA ($r = -0.366$). The r values are significant at $P < 0.05$. These reagents may have extracted portions of phosphorus retained by clay minerals which are predominantly kaolinite. All the other soil properties except soil pH and % BS were significantly correlated at varying levels of significance with phosphorus extractable by only the Mississippi. Exchangeable Na ($r = 0.650$) was correlated with Mississippi phosphorus at $P < 0.001$. Exchangeable Ca ($r = 0.474$) and ECEC ($r = 0.474$) were correlated with Mississippi phosphorus at $P < 0.01$, while organic carbon content ($r = 0.387$), exchangeable Mg ($r = 0.410$) and exchangeable K ($r = 0.353$) were correlated with Mississippi phosphorus at $P < 0.05$.

The Mississippi extractant has been employed for the extraction of available phosphorus from soils of varying reactions including calcareous soils (Cope and

Evans, 1985). Exchangeable Ca, Mg, K and Na which are free ions in soil solutions cannot exist in reasonable concentrations in soils of pH values encountered in this study. It is, therefore, expected that the phosphorus associated with them will be negligible. Since the Mississippi phosphorus was not significantly correlated with soil pH, its significant relationship with these exchangeable bases and organic carbon may be directly related to the solubilisation of phosphorus associated with these soil constituents by this method. This is confirmed by the fact that the Mississippi extracted the least amounts of phosphorus from the soils which were strongly to moderately acid. So, the relationship between the soil properties and Mississippi extractable phosphorus may be a causal one which must be taken into consideration when recommending this method for soil testing.

A linear correlation analysis shows that only exchangeable Ca and Na had significant effects on actual yield, relative yield and phosphorus uptake (Table 15). Exchangeable Ca was significantly correlated with actual yield ($r = 0.403$) and relative yield ($r = 0.340$) at $P < 0.05$, and phosphorus uptake ($r = 0.457$) at $P < 0.01$. Exchangeable Na did not influence relative yield significantly but predicted actual yield ($r = 0.328$) and phosphorus uptake ($r = 0.391$) at $P < 0.05$. This relationship may be connected with the direct relationship between these soil properties and available phosphorus.

A multiple regression analysis involving all the selected soil properties plus phosphorus solubilised by each of the eight soil test methods against actual yield, relative yield and phosphorus uptake was carried out to determine the effect of these soil properties. The regression equations for the most promising extractants are given in Table 16. It was found that the inclusion of all the soil properties

Table 15: Greenhouse cropping: Linear correlation coefficients between selected soil properties and some yield parameters.

Method	Actual yield (*yield at* P_o)	Relative *yield*	Actual yield increase	Phosphorus uptake
% Clay	-0.155 ns	-0.149 ns		-0.164 ns
Soil pH	0.290 ns	0.246 ns		0.311 ns
% Organic carbon	0.028 ns	0.005 ns		0.075 ns
Exch Ca	0.403*	0.340*		0.457 **
Exch Mg	0.153 ns	0.098 ns		0.213 ns
Exch K	0.174 ns	0.115 ns		0.203 ns
Exch Na	0.328*	0.271 ns		0.391*
ECEC	0.311 ns	0.249 ns		0.369*
% BS	0.272 ns	0.214 ns		0.315 ns

n = 36.
** = P < 0.01; * = P < 0.05; ns = non-significant.

Table 16: Multiple regression equations involving extractable phosphorus and soil properties.

1. AY = -5.65 + 0.57 MI + 0.01 CL + 1.25 pH + 0.98 OC + 1.8 ExCa - 0.89 ExMg + 3.5 ExK + 31.4 ExNa - 1.2 CEC - 0.02 BS
2. AY = -10.7 + 0.57 MII - 0.02 CL + 1.41 pH + 1.06 OC - 2.5 ExCa - 5.6 ExMg - 1.5 ExK + 25.4 ExNa + 3.4 CEC + 0.01 BS
3. AY = -18.1 + 0.54 BI + 0.02 CL + 1.68 pH - 0.85 OC - 11.5 ExCa - 12.9 ExMg - 9.5 ExK + 17.6 ExNa + 11.9 CEC + 0.09 BS
4. AY = -3.6 + + 0.26 BII - 0.03 CL + 0.73 pH + 0.03 OC - 6.4 ExCa - 9.4 ExMg - 12.7 ExK + 24.8 ExNa + 7.8 CEC - 0.01 BS
5. AY = -13.4 + 0.57 MMI + 0.03 CL + 1.26 pH + 0.84 OC - 3.9 ExCa - 6.1 ExMg - 1.2 ExK + 29.2 ExNa + 4.3 CEC + 0.05 BS
6. RY = -15.9 + 1.6 MI + 0.03 CL + 3.03 pH + 1.94 OC - 7.8 ExCa - 14.1 ExMg - 15.3 ExK + 65.2 ExNa + 9.5 CEC - 0.01 BS
7. RY = -29.7 + 1.58 MII + 0.04 CL + 3.45 pH + 2.2 OC - 19.3 ExCa - 27.1 ExMg - 29.2 ExK + 48.7 ExNa + 22.0 CEC + 0.07 BS
8. RY = -53.6 + 1.55 BI + 0.09 CL + 4.27 pH - 3.37 OC - 46.3 ExCa - 48.8 ExMg - 52.7 ExK + 25.5 ExNa + 47.3 CEC + 0.31 BS
9. RY = -10.1 + 0.75 BII - 0.05 CL + 1.55 pH - 0.83 OC - 31.6 ExCa - 38.6ExMg - 61.8 ExK + 46.3 ExNa + 35.4 CEC + 0.03 BS
10. RY = -38.6 + 1.66 MMI 0.07 CL + 3.05 pH + 1.45 OC - 24.9 ExCa - 29.5 ExMg - 29.3 ExK + 58.6 ExNa + 25.7 CEC + 0.19 BS
11. PU = -15.3 + 1.02 MI + 0.004 CL + 2.66 pH + 2.76 OC + 4.1 ExCa - 2.0 ExMg + 1.9 ExK + 74.1 ExNa - 2.5 CEC - 0.01 BS
12. PU = -24.2 + 1.01 MII + 0.01 CL + 2.94 pH + 2.91 OC - 3.3 ExCa - 10.4 ExMg - 7.1 ExK + 63.4 ExNa + 5.5 CEC + 0.04 BS
13. PU = -40.0 + 1.01 BI + 0.02 CL + 3.47 pH - 0.74 OC - 21.2 ExCa - 24.7 ExMg - 22.6 ExK + 48.0 ExNa + 22.3 CEC + 0.19 BS
14. PU = -11.5 + 0.46 BII - 0.07 CL + 1.75 pH + 1.13 OC - 10.0 ExCa - 16.7ExMg - 26.5 ExK + 62.8 ExNa + 13.0 CEC + 0.01 BS
15. PU = -29.5 + 1.06 MMI + 0.03 CL + 2.68 pH + 2.45 OC - 6.8 ExCa - 11.8 ExMg - 7.1 ExK + 69.8 ExNa + 7.8 CEC + 0.12 BS

improved significantly the predictive ability of available phosphorus for actual yield, relative yield and phosphorus uptake (Table 17). This shows that there were either direct contributions of these soil properties on yield or the effects were indirect since soil properties have been shown to mask the relationship between nutrients and yield (Martens *et al.*, 1966). Results of t-tests showed that the degree of prediction of actual yield, relative yield and phosphorus uptake by extractable phosphorus alone against extractable phosphorus plus all the nine soil properties, differed significantly at the 1%, 5% and 0.1% levels, respectively. The degree of improvements on the predictive values, R^2, varied from extractant to extractant and from yield parameter to yield parameter (Table 18). The order of influence was phosphorus uptake > actual yield > relative yield. For actual yield, the improvement on R^2 was in the order Olsen's (109.52%) > Mississippi (68.99%) > Bray 2 (68.82%) > AB-DTPA (51.44%) > Mehlich 2 (48.11%) > Bray 1 (44.30%) > Modified Mehlich 1 (37.92%) > Mehlich 1 (26.91%). Table 17 shows that this is the reverse order of predictive values of extractable phosphorus on actual yield. This pattern was virtually the same for relative yield except that Olsen's exchanged position with Mississippi in the same order they predicted yield. For phosphorus uptake, the order was quite different. It was not exactly in the reverse order of the degree of prediction of the various soil test methods. However, Mehlich (44.85%) and Modified Mehlich 1 (55.47%) were still the least influenced. Olsen's (183.50%) was most highly improved followed by Bray 2 (110.98%). In general, the soil properties improved a lot more significantly the extractants that were less effective in predicting crop response.

Table 17: Coefficients of determination, R^2, of phosphorus extractable by the various soil test methods plus selected soil properties regressed against yield parameters.

Soil Test Methods	R^2 (%)								
	Actual Yield			Relative Yield			Phosphorus Uptake		
	Extractable P alone	Extractable P plus the nine soil properties	Extractable P plus soil properties in stepwise regression	Extractable P alone	Extractable P plus the nine soil properties	Extractable P plus soil properties in stepwise regression	Extractable P alone	Extractable P plus the nine soil properties	Extractable P plus soil properties in stepwise regression
	A	B	C	D	E	F	G	H	J
Mehlich No. 1	68.0	86.3	83.2 (ExNa + pH)+	69.4	82.7	78.2 (ExNa)	55.3	80.1	76.7 (ExNa + pH)
Mehlich No. 2	55.5	82.2	73.8 (ExCa)	56.0	77.0	69.3 (ExCa)	43.8	76.7	66.7 (ExCa)
Bray No. 1	59.6	86.0	75.7 (ExCa)	63.6	84.3	75.0 (ExCa)	51.8	83.3	72.5 (ExCa)
Bray No. 2	44.9	75.8	65.2 (ExNa)	47.0	72.9	62.7 (ExNa)	33.7	71.1	63.5 (ExNa + pH)
Olsen's	27.3	57.2	39.9 (ExCa)	33.1	55.5	41.3 (ExCa)	20.0	56.7	37.3 (ExCa)
Modified Mehlich No.1	62.5	86.2	80.4 (ExNa)	67.0	85.4	80.7 (ExNa)	53.0	82.4	78.6 (ExNa + pH)
Mississippi	31.6	53.4	43.9 (*pH*)	30.2	50.7	39.5 (*pH*)	41.4	64.0	55.9 (pH)
AB-DTPA	45.1	68.3	63.4 (ExCa)	44.4	63.5	57.7 (ExCa)	40.5	68.1	63.5 (ExCa)

n = 36

t - tests: A vs B = -3.580**
A vs C = -2.121ns
B vs C = -1.177ns
D vs E = -2.823*
D vs F = -1.510ns
E vs F = -1.146ns
G vs H = -5.710***
G vs J = -3.507**
H vs J = -1.467ns

\+ - Soil properties in parenthesis are those that made significant contributions to R^2 along with extractable P.

*** - $P < 0.00$ ** - $P < 0.01$ * - $P < 0.05$ ns - non-significant

Table 18: Degree of improvement of predictive values of extractable phosphorus on yields by soil properties.

Method	Degree of improvement (%)		
	Actual yield	Relative yield	Phosphorus uptake
Mehlich No. 1	26.91	19.16	44.85
Mehlich No. 2	48.11	37.50	75.11
Bray No. 1	44.30	32.55	60.81
Bray No. 2	68.82	55.11	110.98
Olsen's	109.52	67.67	183.50
Modified Mehlich No.1	37.92	27.46	55.47
Mississippi	68.99	67.88	54.59
AB-DTPA	51.44	43.02	68.15

From these results, phosphorus extractable by Mehlich 1, Modified Mehlich 1, and Bray 1 were the least influenced by soil properties. This shows that the interactions of soil properties did not significantly influence their uptake by growing crops.

A stepwise multiple regression analysis was carried out with each of the soil test methods and all the soil properties. This was to determine which of the soil properties significantly improved the predictive values of extractable phosphorus on yield parameters. The analysis was also intended to bring out the true relationships between the yield parameters and soil test values since interactions of soil properties not particularly involved will be eliminated.

It was shown that only exchangeable Ca and Na and soil pH made significant contributions to R^2 (Table 17). Exchangeable Na improved the prediction of Mehlich 1, Bray 2 and Modified Mehlich 1. Soil pH influenced Mehlich 1 and Mississippi while exchangeable Ca improved Mehlich 2, Bray 1, Olsen's and AB-DTPA. However, the improvement on R^2 was not significant with actual yield and relative yield. With phosphorus uptake the improvement was highly significant at $P < 0.01$. Daudu (1993) had reported that the inclusion of soil pH, exchangeable acidity, exchangeable bases and CEC improved the prediction of phosphorus uptake by Morgan solution, and Bray 1 + DTPA extractable phosphorus for the soils of north-western Nigeria.

From the results obtained in this study, it is necessary to consider some soil properties like exchangeable Ca and Na and soil pH while selecting extractants that effectively predict yield response in the southern Guinea savanna. These soil

properties could form the basis for grouping soils for purposes of fertility evaluation and fertilizer recommendation.

4.1.8 Greenhouse Critical Levels of Phosphorus Extractable by the various Soil Test Methods

The greenhouse critical levels of phosphorus extractable by the eight soil test methods were determined by the graphical method of Cate and Nelson (1965) as illustrated in Figs. 7, 8 and 9 for the three best extractants, Mehlich 1, Bray 1 and modified Mehlich 1. The critical levels of phosphorus for Bray 2, Mississippi and AB-DTPA soil tests which were 8.6, 1.9 and 2.6 mg kg^{-1}, respectively, were obtained at relative yield of about 18% (Table 19). Those for Mehlich 1, Mehlich 2, Bray 1, Olsen's and Modified Mehlich 1 which were above 6 mg kg^{-1} were obtained at about 24%. It should be noted that the highest relative yield of maize dry matter obtained from Harga soil was 38.06%.

Bray 1 is the only extractant whose greenhouse critical level has been reported for Nigerian soils. Sobulo (1981) obtained a value of 10.0 mg kg^{-1} for Bray 1 extractable phosphorus for the Alfisols from the various ecological zones of south-western Nigeria. This value compares favourably with the value of 10.6 mg kg^{-1} obtained in this study for the soils of the southern Guinea Savanna.

Since the best relative yield of maize dry matter recorded in this study was 38%, further studies involving soils of widely varying available phosphorus fertility will be very necessary for the confirmation of these results.

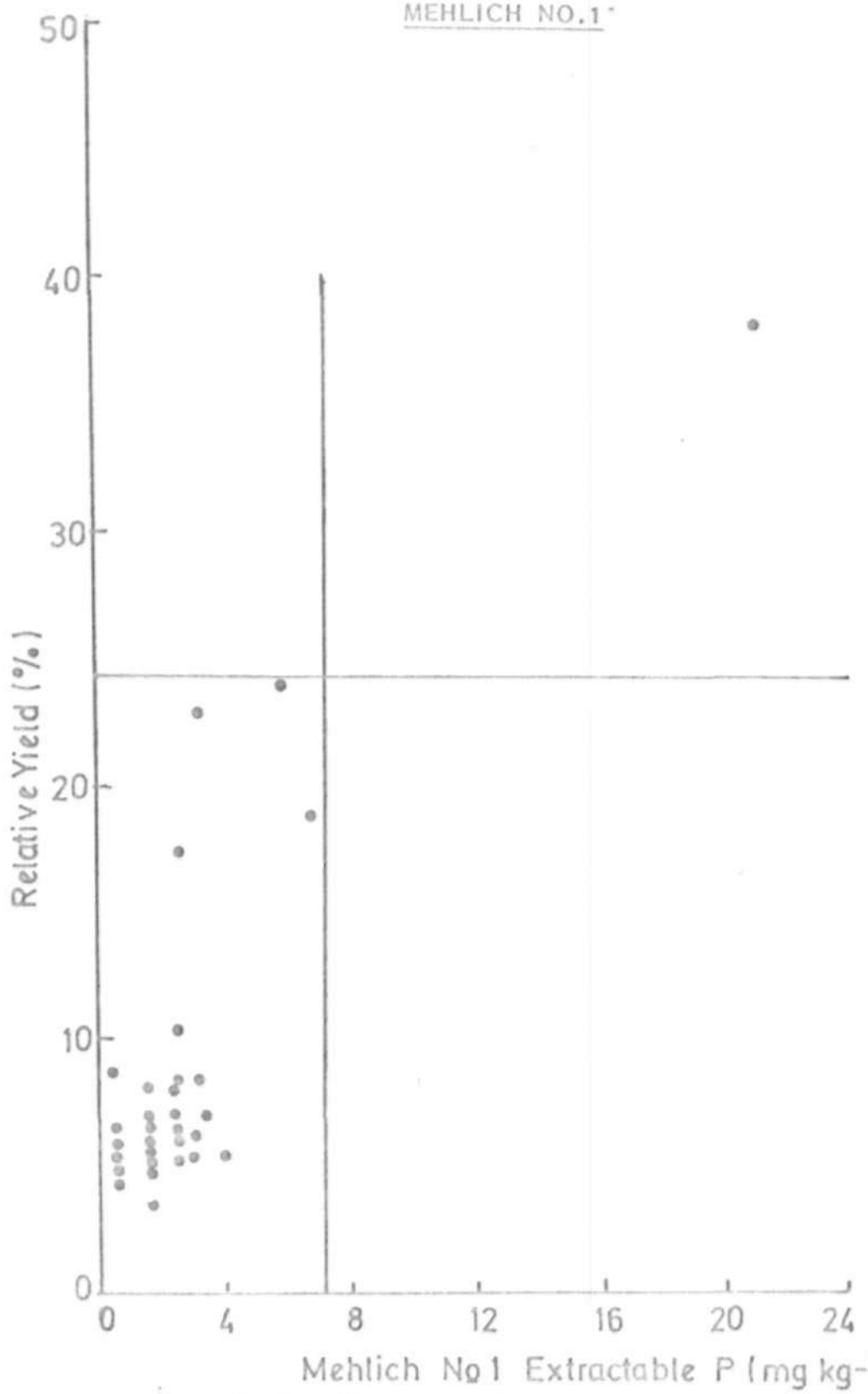


Fig. 7 : Scatter diagrams of Relative Yield of maize versus Mehlich No.1 Soil Test P for evaluation of green house critical level by the graphical method.

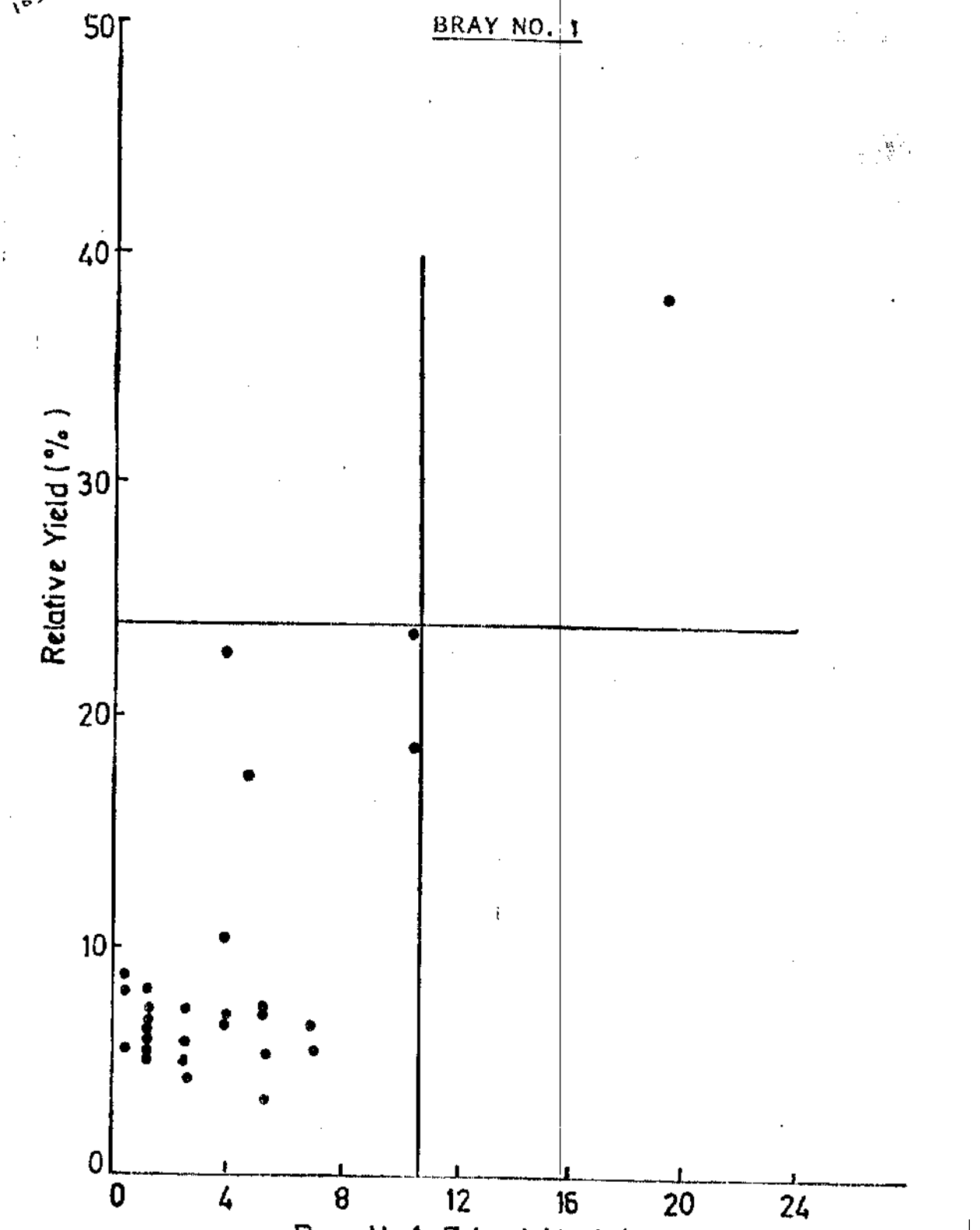


Fig. 8 : Scatter duagrams of Relative Yield of maize versus Bray No. Extractable P for evaluation of critical level by the graphical method.

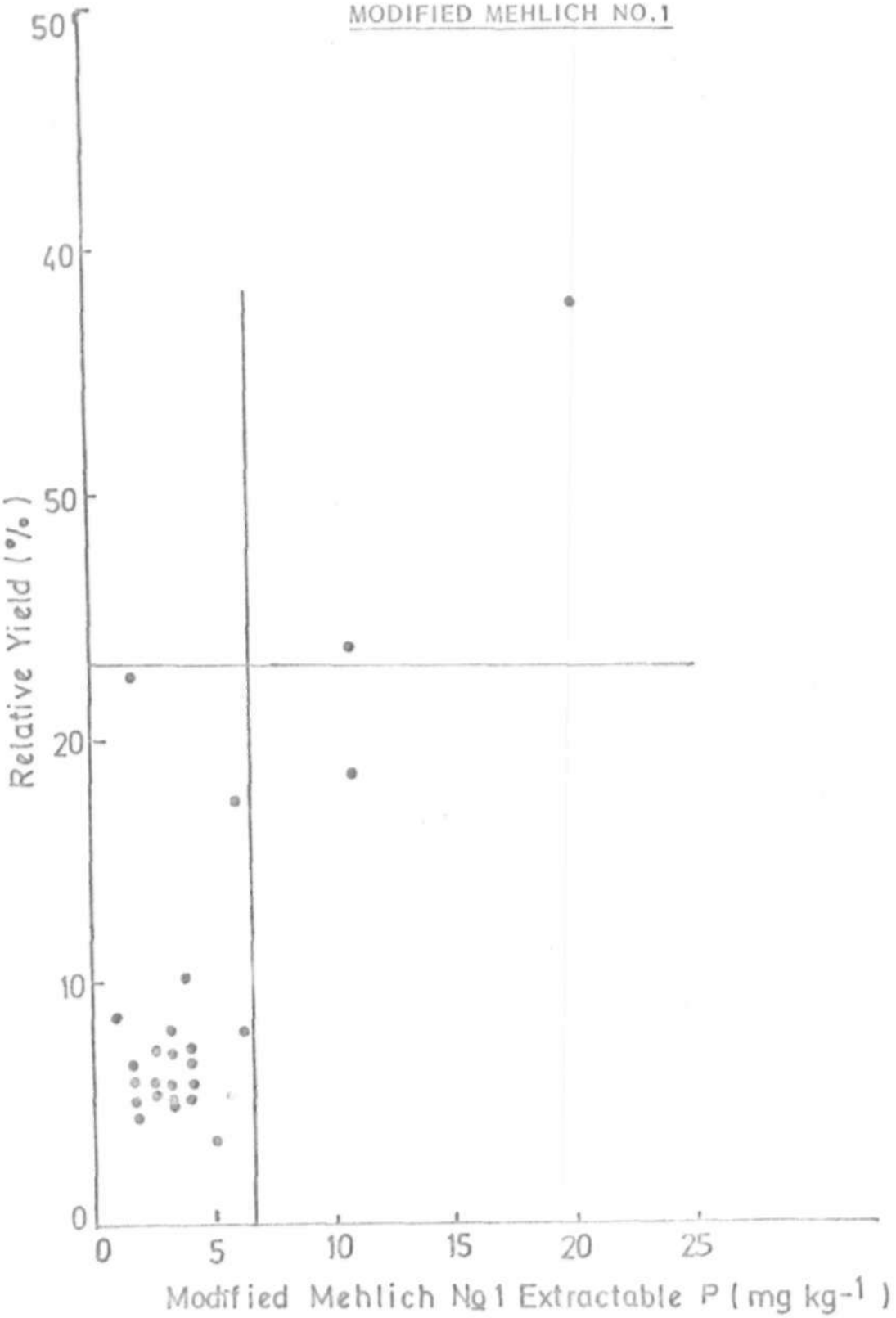


Fig. 9 Scatter diagrams of Relative Yield of maize versus Modified Mehlich No.1 Extractable P for evaluation of green house critical level by the graphical method.

Table 19: Greenhouse critical level of phosphorus in soils and critical phosphorus concentration in dry matter of maize.

Soil test method	Range of soil test values (mg kg^{-1})	Critical level (mg kg^{-1})	Relative yield at which P was critical (%)
Mehlich No. 1	0.72 - 21.07	7.2	24.0
Mehlich No. 2	1.44 - 20.92	8.0	24.0
Bray No. 1	0.48 - 19.42	10.6	24.0
Bray No. 2	0.96 - 33.86	8.6	18.0
Olsen's	2.45 - 19.92	13.6	24.0
Modified Mehlich No.1	0.72 - 20.22	6.5	23.0
Mississippi	0.48 - 6.83	1.9	18.25
AB-DTPA	0.99 - 4.48	2.6	18.25
	Critical P concentration (g kg^{-1}) Range (g kg^{-1})		
Phosphorus concentration	1.13 - 2.38	2.44	24.0

4.1.9 Critical Phosphorus Concentration in Maize Dry Matter

The critical phosphorus concentration in the dry matter of the aerial parts of maize grown in the greenhouse for 35 days was 2.44 g kg^{-1} (Fig. 10 and Table 19). This is close to the values obtained by several workers. Gallo *et al.* (1968) obtained a critical phosphorus concentration of 2.3 g kg^{-1} for maize at tasselling. At silking a value of 2.95 g kg^{-1} was obtained by Tyner (1946). The ear leaf critical phosphorus concentration at tasselling was found to be 2.5 g kg^{-1} by Melsted *et al.* (1969). However, Terman *et al.* (1972) obtained a much lower critical phosphorus concentration of 1.4 g kg^{-1} for maize grown in the greenhouse.

Plank (1979) documented the sufficiency ranges of phosphorus concentration in maize and other crops for the State of Georgia in the United States of America. For whole maize plants less than 12 inches tall, the value ranges from 3.0 to 5.0 g kg^{-1}. From this result it is evident that the critical phosphorus concentration obtained in this study is below the sufficiency range and may only represent that concentration below which yields decrease or deficiency symptoms appear (Jones and Eck, 1980). This is corroborated by the fact that the critical phosphorus concentration was obtained at a relative yield of 24% in this study. This yield level is within the range where available phosphorus is rated very low.

4.1.10 Recommended Soil Test Methods

From the linear correlation coefficients and using actual yield, relative yield and phosphorus uptake, all the eight methods, namely, Mehlich 1, Mehlich 2, Bray 1, Bray 2, Olsen's, Modified Mehlich 1, Mississippi, and AB-DTPA, are suitable for solubilising available phosphorus from the soils of southern Guinea savanna. It has

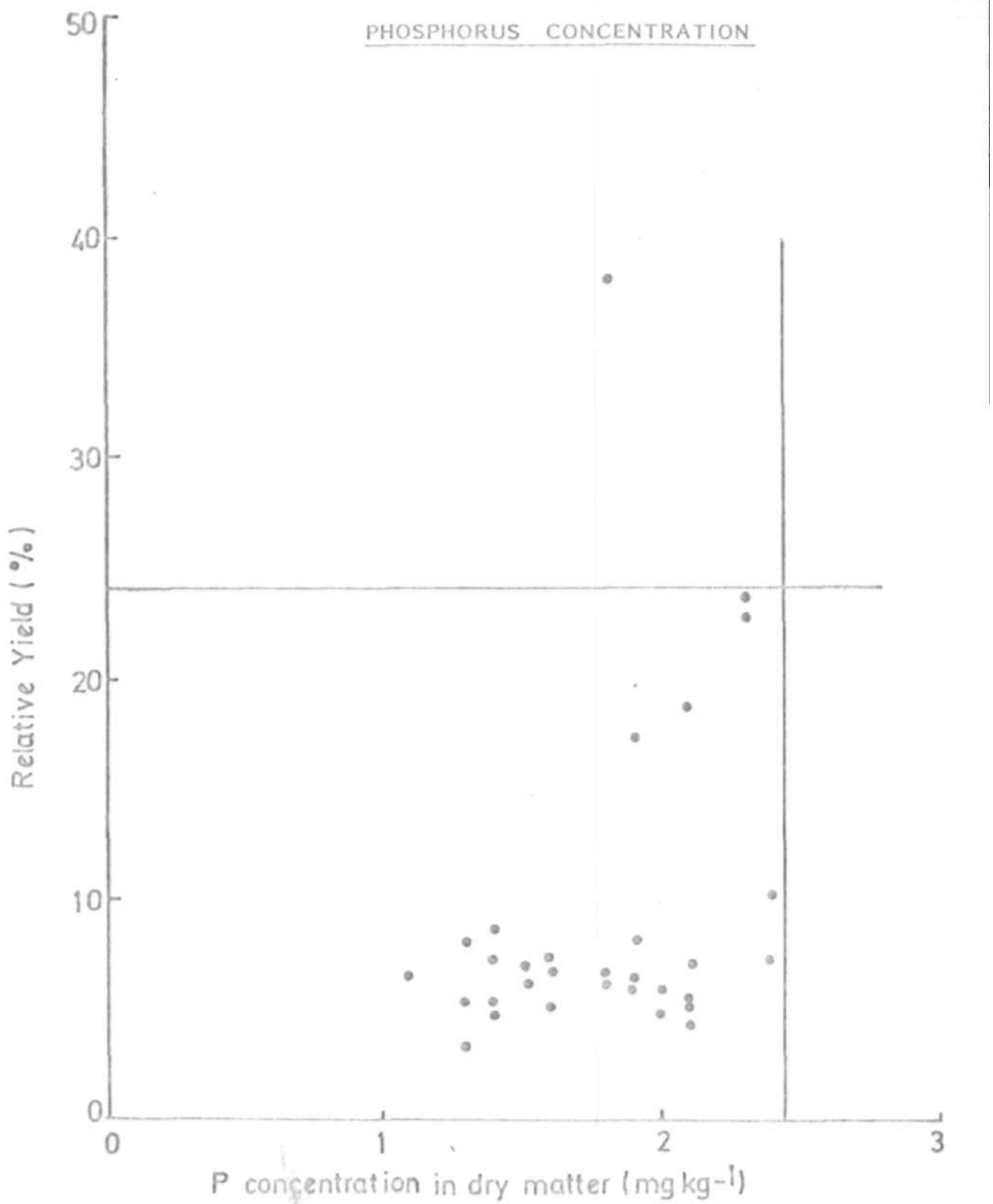


Fig. 10 Scatter diagram of Relative Yield of maize versus concentration of Phosphorus for evaluation of green house critial P concentratio in herbage dry matter.

been pointed out that phosphate supply from soil to plant is a function of intensity, quantity and rate factors (Williams, 1962), and measurements that reflect to some extent all these variables have given significant correlations with plant growth for contrasting soils (Williams and Knight, 1967, Gunary and Sutton, 1967). Bache and Rogers (1970) showed that quantity measurements correlated better with plant indices than intensity ones. The extracting solutions studied must have solubilised some quantity components as well as the intensity forms which are directly proportional to the ability of the soils to supply phosphorus to the growing maize plants.

The efficiency of a number of methods in extracting forms of soil phosphorus available to crops in the various agro-ecological zones of Nigeria has been assessed by a number of workers. It has been shown that no single extractant is of general applicability (Bache, 1970; Oko and Agboola, 1974; Sobulo *et al.*, 1975).

Extractants that have had some success in the tropics include those of Bray, Truog (dilute H_2SO_4), Saunder (NaOH solution) and of Olsen ($NaHCO_3$ solution). It has been widely reported that Bray 1 extractant shows greater promise for assessing the phosphorus status of some tropical soils (Lungu, 1965; Sobulo, 1970; Agboola and Obigbesan, 1974).

Many extractants of available phosphorus for the various ecological zones of western Nigeria have been extensively studied. These include Bray 1, Bray 2, Mehlich 1 (Raleigh or Double Acid), Modified Mehlich 1, Miller and Axley, Morgan, Truog, $NH_4F.HF$, Olsen's, Saunder and Calcium lactate. Bray 1 has been severally reported to be the most suitable for both the rainforest and savanna soils of this zone (Bromfield, 1967; Jaiyebo, 1969; Sobulo, 1970; Agboola and Obigbesan,

1974; Adetunji, 1974; Oko and Agboola, 1974; Kang and Osiname, 1979). However, Agboola and Oko (1976) and Agboola and Omueti (1980) proposed the use of $NH_4F.HF$ as a suitable alternative to Bray 1 for extracting available phosphorus from soils of western Nigeria. They concluded that the two reagents extract forms of soil phosphorus which relate to phosphorus response to the same degree but $NH_4F.HF$ employs shorter extraction time of one minute.

Sobulo (1970) and Agboola and Obigbesan (1974) have recommended Bray 1 for extracting available phosphorus from the savanna soils of western Nigeria. They also concluded that this method is very suitable for savanna soils with pH values below 7.0.

Enwezor (1977a) compared seven commonly used chemical reagents in predicting phosphorus availability in soils of southeastern Nigeria. He showed that all the methods, namely, Anion exchange resin, Bray 1, Bray 2, Morgan, Truog, Olsen's, William and NaOH (total phosphorus), extracted phosphorus which correlated with percentage yield of maize at the 0.1% probability level. He, however, recommended Bray 2 method, which extracted forms of phosphorus that had the most superior correlation coefficient, for routine soil testing for phosphorus in the acid soils of south-eastern Nigeria.

Although Bray 1 has been recommended for use in the south-western Nigeria, Mehlich 1 (Raleigh or North Carolina or Double Acid) and Modified Mehlich 1 have been found to be equally precise or even better in some soils or under some cropping conditions (Agboola, 1982; Adetunji, 1974; Oko and Agboola, 1974). In the savanna region of northern Nigeria, extensive soil test correlation studies using many extracting methods have not been carried out. The Mehlich 1

and Modified Mehlich 1 have not been considered as possible extractants of available phosphorus for these soils. Attention has always been on Bray 1 and Olsen's methods.

In the present study, Mehlich 1 was the most precise and effective in predicting phosphorus response. This is followed by the Modified Mehlich 1 and Bray 1. From the linear correlation coefficients, each of these three extractants could be satisfactorily used as a soil test method for phosphorus for the soils of the southern Guinea savanna. In terms of time, each method has a shaking time of five minutes. They have been known to be effective in acid soils with low to moderate CEC. Each of the methods is also known to extract quantities of aluminium-bound phosphorus, iron-bound phosphorus and calcium-bound phosphorus which are sources of available phosphorus. These methods are less influenced by soil properties like clay content, soil pH, organic matter content, exchangeable bases, ECEC and percent base saturation. In terms of availability of reagents, Mehlich 1 which employs H_2SO_4 and HCl has an advantage. From the point of view of the predictive value obtained in this study, precision, effectiveness, rapidity, cost of analysis, and minimal influence of other soil properties, Mehlich 1 (Double Acid - 0.025 N H_2SO_4 + 0.05 N HCl) appears to be the best soil test method for phosphorus for the soils of the southern Guinea savanna agro-ecological zone of Nigeria.

4.2 Calibration Studies

4.2.1 Physical and Chemical Properties of Soils

The particle-size distribution and textural classes of the soils are in Table 20. The soil texture varied from loamy sand to silty clay loam. Only Kuru, Bokkos, Sabon Gida and Obi had clay and silt contents above 20%. Wamba, Laminga, Ankpa, Ayangba, Yandev and Katsina-Ala were generally coarse-textured with sand fraction constituting over 70% of the particles.

Table 21 shows the chemical characteristics of the soils. The pH in water ranged from 4.8 to 6.4 with an average of 5.7.

The organic carbon contents were between 2.6 and 13.4g kg^{-1} with an average of 6.3g kg^{-1}. The soils, thus, were very low to low in organic carbon with only Bokkos (1989) and Obi being ranked moderate.

The total nitrogen contents of the surface soils were between 0.35 and 1.05g kg^{-1} with a mean of 0.61g kg^{-1}. The soils were, therefore, very low to low in their total nitrogen contents. Only Bokkos (1989) and Obi (1989) were moderate in total nitrogen.

The sites selected for the fertilizer rate studies were very low in total phosphorus. The values obtained were between 125 and 500 mg kg^{-1}. This is in line with several reports that the soils of the savanna are generally low in total phosphorus (Enwezor and Moore, 1966; Heathcote and Stockinger, 1970; Jones, 1974b; Udo, 1985; Ayodele, 1986).

Table 20: Particle-size distribution of surface soil samples from field experimental sites (USDA System).

Soil Sample No.	Location	Particle-size distribution (%)			
		Clay	Silt	Sand	Textural Class
1988 Experimental Sites					
KUR/01	Kuru	22	30	48	Loam
BOK/02	Bokkos	28	24	48	Sandy clay loam
SGI/03	Sabon-Gida	24	36	40	Loam
WAM/04	Wamba	12	14	74	Sandy loam
LAM/05	Laminga	14	8	78	Sandy loam
OBI/06	Obi	38	44	18	Silty clay loam
AYA/07	Ayangba	16	4	80	Sandy loam
ANK/08	Ankpa	12	4	84	Loamy sand
YAN/09	Yandev	14	14	72	Sandy loam
KAL/10	Katsina-Ala	10	8	82	Sandy loam
1989 Experimental Sites					
KUR/01	Kuru	24	40	36	Loam
BOK/02	Bokkos	28	16	56	Sandy clay loam
SGI/03	Sabon-Gida	24	36	40	Loam
WAM/04	Wamba	12	18	70	Sandy loam
LAM/05	Laminga	12	8	80	Sandy loam
OBI/06	Obi	34	44	22	Silty clay loam
ANK/08	Ankpa	10	4	86	Loamy sand
YAN/09	Yandev	14	12	74	Sandy loam
KAL/10	Katsina-Ala	10	10	80	Sandy loam

Table 21: Chemical characteristics of the soils from the experimental sites.

Soil Sample No.	Soil pH 1:2.5	Organic carbon (g/kg^{-1})	Total nitrogen (g/kg^{-1})	Total phosphorus (mg/kg)	Exchangeable Bases (emol(±) kg^{-1})				Total Exch. Acidity (emol(±) kg^{-1})	Effective cation Exch. capacity (emol(±) kg^{-1})	Base saturation (%)
					Ca	Mg	K	Na			
					1988						
KUR/01	5.4	6.4	0.91	250	1.37	0.68	0.30	0.11	0.40	2.86	86
BOK/02	4.8	8.8	0.91	500	2.33	1.18	0.42	0.11	1.20	5.24	78
SGI/03	4.9	7.6	0.49	125	1.19	0.57	0.31	0.14	0.60	2.81	78
WAM/04	5.9	3.6	0.35	250	1.55	0.33	0.26	0.09	0.10	2.33	96
LAM/05	6.1	5.6	0.49	250	1.89	0.86	0.26	0.09	0.10	3.20	97
OBI/06	4.8	1.0	0.77	250	3.30	1.58	0.40	0.15	0.40	5.83	93
AYA/07	6.1	5.2	0.49	125	1.73	0.64	0.16	0.08	0.10	2.71	96
ANK/08	6.0	4.0	0.35	125	1.07	0.54	0.16	0.08	0.10	1.95	95
YAN/09	5.9	4.4	0.49	125	1.05	0.36	0.23	0.08	0.10	1.82	95
KAL/10	6.1	2.6	0.49	125	0.94	0.29	0.12	0.07	0.10	1.52	93
					1989						
KUR/01	5.2	7.6	0.63	125	1.28	0.55	0.24	0.09	0.60	2.76	78
BOK/02	5.1	13.4	1.05	500	1.89	0.81	0.40	0.10	0.40	3.60	89
SGI/03	5.3	9.2	0.77	125	2.70	1.22	0.34	0.15	0.30	4.71	94
WAM/04	6.0	3.6	0.49	125	1.63	0.37	0.23	0.11	0.10	2.44	96
LAM/05	6.4	4.4	0.35	375	2.17	0.59	0.25	0.10	0.10	3.21	97
OBI/06	5.5	12.8	1.05	250	3.52	1.61	0.49	0.15	0.20	5.70	97
ANK/08	6.2	3.4	0.49	375	1.14	0.57	0.18	0.09	0.10	2.08	95
YAN/09	6.1	3.8	0.63	500	0.91	0.34	0.26	0.08	0.10	1.69	94
KAL/10	6.2	3.0	0.35	438	1.03	0.35	0.15	0.08	0.10	1.71	94

The cation exchange capacities (CEC) of the soils were very low and varied from 1.52 to 5.83 cmol(±)kg^{-1}. Exchangeable calcium is rated very low to low and varied from 0.91 to 3.52 cmol(±)kg^{-1} with a mean of 1.72 cmol(±)kg^{-1}. It dominated the exchange complex, constituting about 56.2% of the CEC. Exchangeable magnesium which accounted for about 23.10% of the CEC, was generally low and ranged from 0.29 to 1.61 cmol(±)kg^{-1} with an average of 0.71 cmol(±)kg^{-1}.

Data on extractable (available) phosphorus are in Table 22. The range of phosphorus extracted by Mehlich 1, Mehlich 2, Bray 1, Bray 2, Olsen's, Modified Mehlich 1, Mississippi and AB-DTPA were 2.56 - 19.46, 1.49 - 22.46, 1.23 - 15.67, 2.28 - 24.95, 2.84 - 19.96, 1.74 - 17.76, 0.48 - 6.18 and 1.03 - 3.39 mg kg^{-1}, respectively. The order of effectiveness in solubilising phosphorus was Mehlich 2 > Bray 2 > Olsen's > Modified Mehlich > Mehlich 1 > Bray 1 > AB-DTPA > Mississippi.

4.2.2 Yield Response of Maize to Phosphorus

Table 23 shows the mean grain yields and relative yields of maize in the 10 sites cropped in 1988 and 1989. Grain yields varied from treatment to treatment in each site, from site to site for each treatment, and from year to year for each site-treatment (Fig. 11).

Analysis of variance of maize grain yields for all the sites combined for each year of trial (1988 - Appendix 8; 1989 - Appendix 9) show that the sites differed significantly in their capacity to produce maize. For each year, there were highly significant yield differences between the treatments. Also, there were highly significant site-treatment interactions suggesting the peculiarities of each site in its

Table 22: Field fertilizer rate studies: Phosphorus extractable by various reagents from soil samples (0-20 cm) collected from the various experimental sites before planting (mg/kg).

Location / Method	Kuru		Bokkos		Sobon Gida		Wamba		Lamminga		Obi		Ankpa		Yandev		Katsina-Ala		Ayangba	Mean	
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1988	1989
Mehlich No. 1	2.58	3.47	2.56	13.45	3.46	3.48	19.46	9.92	5.78	16.47	3.32	2.56	3.85	4.96	11.73	12.52	5.94	7.0	7.57	6.63	8.20
Mehlich No. 2	5.75	5.75	5.71	1.49	5.74	5.75	22.46	13.39	13.01	11.28	7.39	5.72	9.09	5.76	20.96	14.85	11.19	9.78	14.19	11.55	8.29
Bray No. 1	1.29	1.29	5.12	15.64	1.29	2.58	15.67	7.94	7.71	7.98	1.23	2.56	4.83	3.97	13.47	15.54	5.15	3.99	7.57	6.33	6.83
Bray No. 2	3.97	3.97	7.68	23.51	5.25	2.38	24.95	11.71	6.17	13.97	2.28	0.99	5.94	7.74	18.46	11.68	7.72	3.99	7.35	8.98	8.88
Olsen's	2.98	2.98	13.78	32.87	6.93	2.98	19.96	6.94	2.89	10.38	2.84	2.96	2.78	2.98	13.97	13.86	2.97	2.99	2.84	7.20	8.77
Modified Mehlich No. 1	1.74	2.48	3.20	16.68	3.22	3.22	17.76	10.91	6.27	13.37	2.37	3.20	6.03	6.45	8.23	16.58	4.95	5.64	9.60	6.34	8.73
Mississippi	0.50	0.99	3.64	6.18	0.99	0.99	3.99	2.18	0.48	1.80	0.47	0.49	0.93	0.99	2.99	3.66	1.78	1.0	1.23	1.70	2.03
AB-DTPA	1.03	1.03	1.97	3.39	1.03	1.98	3.39	1.98	2.63	2.75	1.90	1.03	1.86	1.98	2.75	3.37	1.98	2.0	1.89	2.04	2.17

Table 23: Field fertilizer rate studies: Mean yield and relative yield of maize.

Rate (KgP_2O_5/ha)	1988		1989	
	Mean yield (kg/ha)	Relative yield (%)	Mean yield (kg/ha)	Relative yield (%)
		KURU		
1. 0	0	0	0	0
2. 20	584.26	26.73	173.43	13.99
3. 40	1097.95	50.22	454.87	36.69
4. 60	1407.23	64.37	858.55	69.25
5. 80	1955.56	89.45	1127.81	90.97
6. 100	2186.14	100.00	1239.78	100.00
TVR:	1988 - 139.753***	(LSD=5% .220.35)	1989 - 77.391***	(LSD=%183.14)
		BOKKOS		
1. 0	572.89	17.87	1088.65	46.53
2. 20	918.59	28.65	1724.32	73.69
3. 40	2037.99	63.55	2040.98	87.23
4. 60	2074.60	64.70	2162.27	92.41
5. 80	2043.70	63.73	2339.90	100.00
6. 100	3206.72	100.00	2014.77	86.10
TVR:	31.064***	(LSD = 533.38)	7.431***	(LSD = 512.89)
		SABON GIDA		
1. 0	676.66	19.86	756.75	20.78
2. 20	1912.50	56.13	2148.89	58.99
3. 40	3132.74	91.94	2958.98	81.23
4. 60	2170.62	63.71	3087.60	84.77
5. 80	3407.23	100.00	3481.11	95.57
6. 100	2982.27	87.53	3642.52	100.00
TVR:	20.388***	(LSD = 708.06)	462.879***	(LSD = 157.74)
		WAMBA		
1. 0	2749.11	71.41	2495.90	64.47
2. 20	3638.23	94.50	3248.27	83.90
3. 40	3849.79	100.00	3600.28	92.99
4. 60	3346.26	86.92	3462.80	89.44
5. 80	3828.89	99.46	3871.67	100.00
6. 100	3271.19	84.97	3609.84	93.24
TVR:	2.180^{ns}		14.291***	(LSD = 399.48)
		LAMINGA		
1. 0	1974.08	39.00	3159.89	83.11
2. 20	3285.59	64.91	3802.27	100.00
3. 40	3844.86	75.96	3461.80	91.05
4. 60	4388.79	86.70	3179.50	83.62
5. 80	5062.01	100.00	3243.41	85.30
6. 100	5022.33	99.22	3121.26	82.09
TVR:	513.0***	(LSD = 597.77)	1.46^{ns}	

Table 23 continued.

Rate (KgP_2O_5/ha)	1988 Mean yield (kg/ha)	1988 Relative yield (%)	1989 4Y Mean yield (kg/ha)	1989 4Y Relative yield (%)
		OBI		
1. 0	545.63	17.56	747.27	28.23
2. 20	1673.51	53.86	1605.53	60.66
3. 40	1572.68	50.61	1588.31	60.01
4. 60	2823.49	90.87	1852.20	69.98
5. 80	3107.17	100.00	1871.22	70.70
6. 100	2113.10	68.01	2646.64	100.00
TVR:	38.440***	(LSD = 472.11)	27.749***	(LSD = 380.32)
		ANKPA		
1. 0	1735.68	60.58	1055.42	50.25
2. 20	2054.17	71.70	1725.51	82.16
3. 40	2404.31	83.92	1883.22	89.67
4. 60	2449.03	85.48	1831.64	87.21
5. 80	2864.98	100.00	2100.28	100.00
6. 100	2826.64	98.66	1757.38	83.67
TVR:	9.505***	(LSD = 448.05)	4.840*	(LSD = 507.09)
		YANDEV		
1. 0	3982.41	83.68	2745.30	64.69
2. 20	3340.73	70.20	3489.43	82.23
3. 40	4294.46	90.24	4052.56	95.50
4. 60	4326.34	90.91	2985.40	70.35
5. 80	4223.15	88.74	4243.61	100.00
6. 100	4759.00	100.00	3936.90	92.77
TVR:	3.197ns		4.164*	(LSD = 939.10)
		KATSINA-ALA		
1. 0	1178.56	46.12	2288.86	46.88
2. 20	2555.33	100.00	4164.03	85.29
3. 40	2434.06	95.25	3811.26	78.06
4. 60	2354.07	92.12	4117.17	84.33
5. 80	2463.62	96.41	4882.17	100.00
6. 100	1649.11	64.54	4163.72	85.28
TVR:	23.653***	(LSD = 362.72)	8.633**	(LSD = 929.30)
		AYANGBA		
1. 0	1644.25	83.11		
2. 20	1978.33	100.00		
3. 40	1587.20	80.23		
4. 60	1650.13	83.41		
5. 80	1593.81	80.56		
6. 100	1969.01	99.53		
TVR:	0.60ns			

*** = P < 0.001; * = P < 0.05; ns = non-significant.

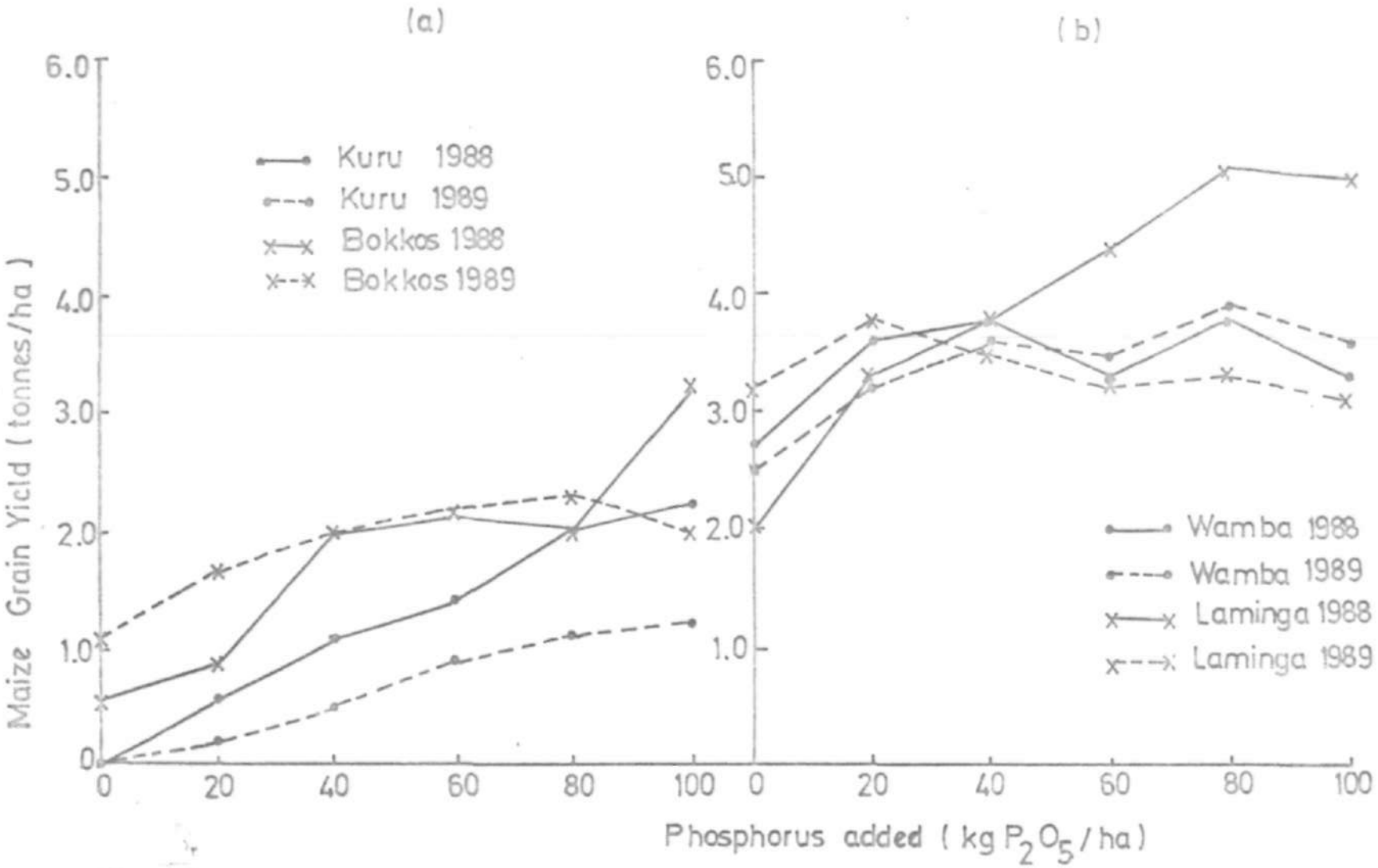


Fig. 11 Response Curve of maize grain yield aganist Padded for Kuru, Bokkos, Wamba and Laminga sites (1988 and 1989)

soil-phosphate-plant relationship. In general, the soils in all the 19 site-years responded significantly to phosphate fertilization. The degree of response varied from site to site, and for the same site, from year to year. It has been reported that the frequency and degree of phosphorus response largely depends on previous land use. Phosphorus response is common under continuous cultivation system or short fallow system or with highly acid soils, while little or no response is expected under long fallows with good residue management or in soils that had received phosphorus fertilizer applications in the past (Adetunji, 1974; Adepetu and Corey, 1977; Kang and Juo, 1979).

In all cases, yield increases were recorded in treatments 2 (P addition of 20 kg P_2O_5/ha) over the control plots (treatment 1 - plots that received no P addition). In some locations like Katsina-Ala where a yield increase of 1626 kg/ha was obtained, the increases were dramatic, while in a few like Yandev where a yield increase of 51 kg/ha was obtained, they were not significant (Table 24).

For the control plots, average maize yields for the two years of cropping (Table 24) varied from 0 kg/ha in Kuru to 3364 kg/ha in Yandev, representing 0 to 77% of the average maximum yield. Maximum yields for each site-year were obtained at varying treatments. For Kuru, Bokkos and Yandev sites, maximum yields were recorded at the maximum phosphorus addition of 100 kg P_2O_5/ha. For the other six sites where cropping was carried out for two years, namely, Sabon Gida, Wamba, Laminga, Obi, Ankpa and Katsina-Ala, maximum yields of between 2483 (Ankpa) and 4153 (Laminga) kg/ha, were recorded at 80 kg P_2O_5/ha. For these sites increase in phosphorus additions to 100 kg/ha resulted in yield depressions.

Table 24: Field fertilizer rate studies: Two-year average of maize grain yields for each of the treatments for each site.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry grain yield (kg/ha)								
		Kuru	Bokkos	Sabon Gida	Wamba	Laminga	Obi	Ankpa	Yandev	Katsina-Ala
1	0	0	831	717	2623	2567	646	1396	3364	1734
2	20	379	1321	2031	3443	3544	1640	1890	3415	3360
3	40	776	2039	3046	3725	3653	1580	2144	4175	3120
4	60	1133	2118	2629	3405	3784	2338	2140	3656	3236
5	80	1542	2192	3444	3850	4153	2489	2483	4233	3673
6	100	1713	2611	3312	3441	4072	2380	2292	4348	2906
	SED	88.80	220.90	221.70	330.30	268.80	177.10	199.60	447.60	333.80
	LSD (0.05)	228	568	570	849	691	455	573	1151	858

The maize grain yield data generated from the fertilizer rate studies reveal some significant characteristics of the soils/sites.

1. The soils were highly deficient in available phosphorus. It had been shown that because of its pronounced deficiency, phosphorus is an important yield limiting nutrient in the Nigerian savanna (Jones, 1974a; Bromfield, 1975; Mokwunye, 1977; Uyovbisere and Lombin, 1991). Phosphorus extractable from the soils by Bray 1 which has been confirmed to extract available phosphorus from savanna soils was very low, being between 1.29 and 7.98 mg kg^{-1} except for Wamba 1988 and Yandev where extractable phosphorus was rated medium (13.47 to 15.67 mg kg^{-1}). Phosphorus concentrations in the ear leaves of maize at silking for the control plots (Table 25) also showed that the soils were low in available phosphorus since they were in most cases below the critical phosphorus concentration. The critical phosphorus concentration of maize ear leaf at bloom stage has been put variously at 2.95 g kg^{-1} (Tyner, 1946), 2.5 g kg^{-1} (Melsted *et al.*, 1969; Agboola, 1972) and 2.3 g kg^{-1} (Gallo *et al.*, 1968). In this study the phosphorus concentration of maize ear leaves at silking for the control plots ranged from 1.3 g kg^{-1} in Katsina-Ala where the control plot gave a relative yield of 46%, to 3.8 g kg^{-1} in Laminga 1989 where the relative yield was 83%. Except for soils like Bokkos 1989, Wamba, Laminga 1989, Yandev, Katsina-Ala and Ayangba which had received phosphorus fertilization in the past, and those like Ankpa and Laminga 1988 which had been under long bush fallows with dense vegetation, none of the soils had available phosphorus levels that could make them attain up to 30% of their maximum potential in maize production without phosphorus fertilization.

Table 25: Field fertilizer rate studies: Nutrient concentration in index leaves.

Treatment	Total N g/kg	Total P g/kg	Total K g/kg	Total Ca g/kg	Total Mg g/kg	Total Zn g/kg
			KURU 1988			
1	26.9	2.0	18.6	2.4	1.4	0.08
2	31.9	3.5	18.9	1.9	1.0	0.08
3	29.1	1.8	17.8	2.3	1.1	0.08
4	33.3	2.3	18.6	2.4	1.0	0.08
5	28.6	2.0	16.7	2.4	1.1	0.09
6	30.9	2.3	16.2	2.3	1.2	0.07
			KURU 1989			
1	25.8	2.0	16.5	1.5	1.6	0.07
2	22.8	2.5	17.8	1.7	1.8	0.07
3	33.3	2.3	16.5	1.4	1.3	0.07
4	33.2	2.5	16.5	1.9	1.6	0.07
5	35.0	3.5	18.1	2.1	1.9	0.07
6	25.8	2.3	17.1	1.8	1.2	0.07
			BOKKOS 1988			
1	31.5	2.3	12.4	2.3	1.9	0.09
2	28.0	2.3	14.6	2.8	2.2	0.08
3	32.2	2.3	15.7	2.6	2.2	0.09
4	31.5	2.0	13.0	2.5	1.8	0.08
5	35.1	2.5	13.0	2.3	2.0	0.11
6	33.3	2.0	12.4	3.0	2.3	0.08
			BOKKOS 1989			
1	25.2	2.3	16.7	2.6	1.3	0.08
2	29.7	2.3	16.7	2.2	1.2	0.08
3	28.4	2.8	16.2	2.5	1.4	0.09
4	27.0	2.5	13.5	2.4	1.2	0.08
5	34.4	2.3	17.3	2.5	1.5	0.09
6	29.3	2.5	17.8	2.2	1.2	0.08
			SABON GIDA 1988			
1	26.3	1.5	16.0	1.8	1.9	0.06
2	28.1	2.0	14.9	1.7	1.8	0.06
3	29.7	2.3	14.9	1.6	1.7	0.06
4	30.8	2.3	14.1	1.8	1.9	0.06
5	32.8	2.3	15.1	1.8	2.0	0.05
6	31.9	2.0	14.6	1.6	1.8	0.07

Table 25 continued.

Treatment	Total N g/kg	Total P g/kg	Total K g/kg	Total Ca g/kg	Total Mg g/kg	Total Zn g/kg
			SABON GIDA 1989			
1	26.6	2.5	20.0	2.3	1.0	0.08
2	30.4	3.3	18.6	2.3	1.0	0.07
3	33.6	2.5	19.2	2.5	0.9	0.08
4	34.5	3.3	21.1	2.6	1.0	0.07
5	30.3	3.0	18.9	2.4	1.0	0.07
6	13.5	2.8	19.7	1.7	1.0	0.07
			WAMBA 1988			
1	31.4	2.3	16.8	2.6	1.0	0.07
2	30.4	2.5	14.6	2.3	1.0	0.06
3	32.4	2.0	16.5	2.7	0.9	0.07
4	33.4	2.3	16.5	2.6	1.1	0.07
5	29.8	2.0	16.2	3.3	1.2	0.07
6	22.1	2.3	16.5	3.5	1.5	0.07
			WAMBA 1989			
1	32.6	1.3	22.2	2.1	0.9	1.0
2	29.4	1.8	18.1	2.1	0.8	0.08
3	32.5	2.3	19.7	2.5	1.1	0.09
4	30.0	2.0	18.1	2.8	0.9	0.10
5	28.9	2.0	20.8	3.1	1.2	0.08
6	29.8	2.8	18.9	1.8	1.1	0.09
			LAMINGA 1988			
1	30.8	1.3	13.0	1.6	1.3	0.09
2	31.4	2.5	16.2	1.8	1.2	0.10
3	33.2	2.3	10.1	2.0	1.4	0.06
4	32.9	2.3	11.2	3.0	1.7	0.08
5	33.5	2.0	11.9	2.3	1.4	0.08
6	34.6	2.5	12.8	2.8	1.7	0.11
			LAMINGA 1989			
1	34.3	3.8	18.4	2.8	1.5	0.09
2	29.6	3.0	16.8	2.4	1.3	0.09
3	34.0	3.3	18.7	3.0	1.6	1.0
4	34.6	3.8	19.5	2.7	1.4	1.0
5	31.5	3.8	23.0	2.4	1.8	0.08
6	30.7	3.8	18.4	2.1	1.5	1.0

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Table 25 continued.

Treatment	Total N g/kg	Total P g/kg	Total K g/kg	Total Ca g/kg	Total Mg g/kg	Total Zn g/kg
			OBI 1988			
1	29.0	1.5	00.6	1.8	1.9	0.07
2	36.7	2.3	11.9	2.0	1.8	0.07
3	33.5	2.0	11.6	2.2	2.2	0.07
4	28.9	2.3	11.9	2.0	1.6	0.06
5	35.6	2.3	11.1	1.9	1.7	0.05
6	35.7	2.5	10.9	2.2	1.9	0.06
			OBI 1989			
1	30.0	2.0	22.1	1.3	1.7	0.09
2	30.0	2.3	22.7	1.7	2.0	0.09
3	31.8	2.0	22.2	1.7	1.8	0.09
4	35.2	2.0	21.6	1.6	1.5	0.08
5	31.8	1.8	20.8	1.6	1.6	0.08
6	33.2	1.8	20.0	1.5	2.0	0.08
			AYANGBA 1988			
1	37.5	2.3	9.5	1.7	1.5	0.05
2	34.3	2.8	13.5	1.6	1.6	0.07
3	28.9	2.5	12.7	2.0	1.9	0.06
4	29.4	2.8	12.7	2.2	1.9	0.05
5	32.4	2.3	10.8	2.5	2.2	0.06
6	33.3	2.3	11.1	2.1	2.6	0.05
			ANKPA 1988			
1	32.1	2.0	16.8	1.5	1.4	0.07
2	34.3	2.3	12.7	2.2	1.4	0.09
3	38.2	2.0	14.3	2.3	1.2	0.08
4	38.0	2.3	13.0	2.1	1.3	0.06
5	29.7	2.5	13.3	2.6	1.5	0.07
6	34.9	2.3	14.9	2.1	1.1	0.07
			ANKPA 1989			
1	32.6	2.8	17.0	2.6	1.4	0.06
2	31.9	2.5	16.2	2.5	1.3	0.07
3	32.7	3.3	17.3	2.8	1.5	0.07
4	29.1	2.5	17.0	2.8	1.5	0.07
5	28.3	3.3	16.8	3.0	1.6	0.06
6	23.1	3.0	17.0	3.6	1.7	0.07

Table 25 continued.

Treatment	Total N g/kg	Total P g/kg	Total K g/kg	Total Ca g/kg	Total Mg g/kg	Total Zn g/kg
			YANDEV 1988			
1	31.3	1.8	16.2	1.4	1.0	0.06
2	33.4	2.0	15.1	1.5	0.9	0.05
3	35.3	2.0	14.9	2.1	1.1	0.06
4	30.0	2.5	15.1	1.8	1.0	0.06
5	29.1	2.3	15.1	1.8	0.9	0.05
6	26.1	2.8	15.4	2.7	1.2	0.07
			YANDEV 1989			
1	33.3	3.5	15.7	2.9	2.5	0.06
2	27.1	3.8	15.7	2.9	2.2	0.06
3	34.6	3.5	16.5	2.6	2.4	0.06
4	23.4	3.0	16.2	3.3	2.5	0.06
5	33.7	3.5	16.8	3.3	2.2	0.06
6	27.9	2.3	17.6	3.0	2.5	0.05
			KATSINA-ALA 1988			
1	27.4	1.3	14.9	1.6	1.6	0.06
2	27.0	2.0	13.5	2.2	1.8	0.07
3	29.1	2.3	13.2	2.1	2.0	0.07
4	30.2	2.5	13.8	1.9	1.7	0.07
5	28.4	2.5	12.7	1.8	1.8	0.06
6	25.2	2.8	17.3	2.0	2.1	0.07
			KATSINA-ALA 1989			
1	28.1	2.0	16.2	1.7	1.8	0.07
2	25.4	2.4	17.0	1.9	1.8	0.08
3	24.1	2.5	16.8	2.2	1.5	0.07
4	26.7	2.8	15.9	2.0	1.8	0.07
5	27.3	2.5	17.6	2.7	2.0	0.06
6	22.2	2.5	17.6	2.3	2.0	0.07

2. Because of low levels of available phosphorus highly significant yield responses to phosphorus additions were recorded in most of the sites. The only sites where significant responses were not recorded or where the responses were low were those that had previously received phosphorus fertilizer additions like Wamba 1988, Laminga 1989, and Ayangba, and those newly opened up after long bush fallows like Ankpa 1989. Fertilizer trials conducted on food crops in humid West Africa have shown significant responses to phosphorus fertilization. Early trials in the Nigerian savanna indicated significant and economic responses to phosphorus (Goldsworthy, 1967; Goldsworthy and Heathcote, 1963). Singh and Balasubramanian (1983) recorded significant responses of wheat and maize to applied phosphorus when the initial value of available phosphorus dropped from 12.0 to 3.77 mg kg^{-1}. Uyovbisere and Lombin (1991) working on savanna soils recorded maize responses to phosphorus in each year of the trials irrespective of the phosphorus source. Amon and Adetunji (1973) using unimproved maize varieties recorded significant yield responses to phosphorus at three sites at Ilora, Fashola and Eruwa in south-western Nigeria. Osiname (1979) who used improved maize varieties also recorded responses to phosphorus additions in all the three fertility zones of south-western Nigeria. Lombin (1987) reported that responses to nitrogen and phosphorus have been most pronounced on cereals and that these nutrients have been identified as the most limiting to crop production in the savanna.

The frequency and degree of phosphorus response has been reported to depend largely on the type and length of fallow and fallow residue management. Kang and Juo (1979) reported that phosphorus response is common under continuous cultivation system or with highly acid soils. They pointed that instances

of lack of phosphorus response can partly be attributed to the fact that many of the trials were carried out on newly cleared land which generally have adequate phosphate status due to fallow residue burning and subsequent mineralisation of organic phosphorus (Adepetu and Corey, 1977). For short fallow system or on continuously cropped land consistent responses to phosphorus application should be expected. Adetunji (1974) also pointed out that responses to fertilizer application depended on whether the sites had just been cleared or had been cultivated for some time. Mineralisation of organic phosphorus particularly for newly cleared bush fallows may account for the lack of response to phosphorus application since it has been severally reported that the mineralisation of organic phosphorus supplies substantial amount of phosphorus to plants under tropical environment (Eid *et al.*, 1951; Bates and Baker, 1960; Enwezor and Moore, 1966; Adebayo and Akaeze, 1976; Agboola and Oko, 1976; Osiname, 1977; Sobulo and Osiname, 1981).

3. It was found that significant responses were recorded when the initial phosphate status was low, or when the yields of control plots were less than 70% of maximum yields. Little or no responses were obtained when the phosphorus status was medium or when the yields of control plots were above 70% of maximum yields. Agbede (1987), from studies carried out at Gambari and Sapoba in the rainforest zone of Nigeria reported that when the initial phosphorus status is low there is a rapid growth response to phosphorus application and when the soil is very high in initial phosphorus the response is low. Singh and Balasubramanian (1983) reported from studies carried out in the savanna that significant crop response to applied phosphorus will be obtained only when the initial phosphate status in available form is low. Sobulo and Osiname (1981) found that when Bray 1 soil test gives less than

5 mg kg^{-1}, rice, maize and cowpea will respond to phosphorus application particularly in the forest soils. Agboola and Obigbesan (1974), from results of their studies assumed that below 80% of maximum yield, response to a given nutrient was certain and that response was unlikely when it is above 95%.

4. Some of the soils, although highly deficient in available phosphorus, needed only 20 to 40 kg P_2O_5/ha to attain a high percentage of their yield potentials (Table 23). In most of the soils increases were obtained beyond phosphorus additions of 40 kg/ha. Such increases were, in some cases, not statistically significant. Balasubramanian *et al.*(1980), who worked on savanna soils, found that grain yields of maize increased significantly as the fertility level rose from 22.5 to 45 kg P_2O_5/ha. They suggested that this was because of the low inherent fertility status of the soil which responded very well to initial doses of phosphorus. However, their data showed that significant yield increases could be obtainable beyond phosphorus addition of 45 kg/ha. Uyovbisere and Lombin (1991) working on the response of maize to phosphorus from various sources found that statistically significant responses were obtained up to 26.2 kg P/ha. Osiname (1979) reported response of maize to small levels of phosphorus applications at Eruwa in the savanna zone of south-western Nigeria. He found that 10 kg P/ha was considered optimum for maize even when the soil tested low in phosphorus (Bray 1 P was 4.30 P/ha). The present studies showed that significant responses were obtained in most cases with moderate fertilizer additions although yield increases could still be recorded at higher additions. In some soils only moderate phosphorus additions were needed for the soils to attain their maximum yield potentials. This confirms numerous findings that although widespread phosphorus deficiencies occur in the savanna, only moderate phosphorus additions are required for maximum yields (Amon, 1965; Amon and

Adetunji, 1970; Bache and Rogers, 1970; Jones and Wild, 1975; Bationo *et al.*, 1986; Uyovbisere and Lombin, 1991). Osiname (1979) provided reasons for this trend:

(a) The low phosphate sorption capacity of the soils leaves most of the applied phosphorus in a readily available form.

(b) Most savanna soils are sandy to the depth of about 100 cm, and so, maize roots are probably able to extract phosphorus from an unrestricted soil volume.

5. Some of the sites recorded very poor yields relative to others. The reasons were multiple and varied. These include:

(a) Some of the soils like Kuru 1988 needed phosphorus additions in excess of 100 kg/ha to attain maximum yield. This is shown by the nature of the response curve (Fig. 11a). The soil was highly phosphate deficient. The control plot did not produce a single grain of maize. Much of the added phosphorus was probably utilised to saturate the sorption sites.

(b) Some of the sites like Kuru 1989 were waterlogged mid-way into the growing season. This affected the performance of the crops.

(c) Some of the sites like Obi 1989 were affected at the early developmental stages of the crops by drought. Since the soil had high clay content, the effect of inadequate rainfall was dramatic even on the soil. Crop yields have been shown to be highly correlated with measurements of climatic factors such as number of moisture stress days during the growing season (Runge and O'Dell, 1958; Engelstad and Doll, 1961; Dale and Shaw, 1965). Barber (1980) indicated that soil and climatic factors may be unfavourable for high crop yields and may result in situations where potential yield is severely limited

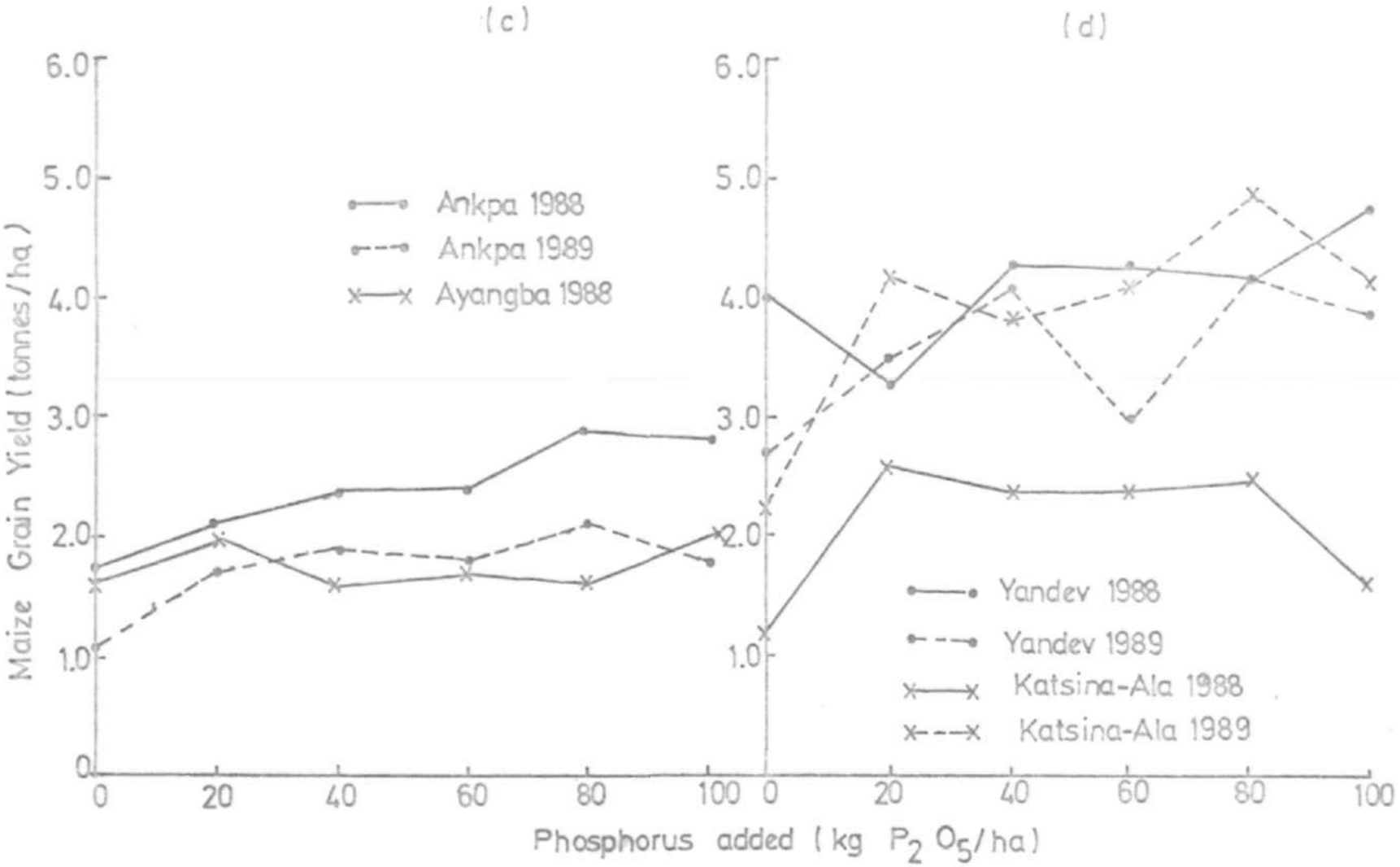


Fig.11a: Response Curve of maize grain yield against Padded for Ankpa, Ayangba, Yandev and Katsina-Ala sites (1988 and 1989).

and additional fertilizer additions may not lead to improvements or may lead to yield decreases.

(d) Some of the soils like Ankpa and Ayangba were very sandy. This probably resulted in excessive leaching of some essential nutrients.

(e) In some of the sites like Ankpa 1989 the crops were infested with stem borers. They had done a lot of damage before they were controlled with furadan.

(f) Some outstanding differences in soil properties may have influenced differences in yields. Cope and Rouse (1980) indicated that amounts of phosphorus and potassium absorbed by plants are affected by such soil factors as amount and type of clay, organic matter, total soil content of phosphorus and potassium and fertilizer and cropping history. The degree of response has also been found to be related to CEC (Volk, 1942; Winters, 1945; Cope and Rouse, 1980).

4.2.3 Soil Test Calibration

For soil tests to be meaningful they have to be calibrated against responses of crops to fertilizers in field experiments on all appropriate soil types and under the conditions of all different cultural practices (Cope and Rouse, 1980; Hanway, 1980; Melsted and Peck, 1980b; Thomas and Peaslee, 1980; Jones, 1982). Cope and Rouse (1980) had defined "soil test calibration" as the process of determining the crop-soil relationship in order to indicate the degree of deficiency of a nutrient and the amount of the nutrient to be applied as fertilizer to correct the deficiency.

However, in this study, the fertilizer recommendation step will be separated from "calibration" and treated under "interpretation of results."

Soil Test Methods

All the eight soil test methods studied extracted phosphorus that correlated highly significantly ($P < 0.001$) with yield of maize in the greenhouse. They also extracted amounts of phosphorus that varied widely. Each of the methods will, therefore, have a separate calibration, for Cope and Evans (1985), realising that several extractants could possibly be satisfactory, stressed that each would have a different calibration because of the wide variation in amounts of phosphorus removed.

Partitioning of Soil Test Data

Thomas and Peaslee (1980) indicated that to convert soil test values of phosphorus into fertilizer recommendations requires two sets of calibration information for each combination of crop-soil type-climate:

(a) the soil test level for phosphorus that produces the maximum net return per hectare for the overall input of production units, considering the individual farmer's economic risk situation; and

(b) the quantity of fertilizer phosphorus that is required to reach that test level.

The first component must be based on crop yield information from field studies and should indicate the soil test level of phosphorus beyond which no additional increments can be expected. Some form of partitioning or rating of soil test values are normally made.

Critical Levels

Two methods were employed to determine the critical level of phosphorus for maize for the soil test values.

(a) Cate-Nelson Graphical Method

Cate and Nelson (1965) developed a graphical method for partitioning percentage yield versus soil test level scatter into two fertility groups, namely:

1. those for which the probability of response to fertilizer is large, and
2. those for which the probability of response to added fertilizer is small.

The soil test value separating the two groups was termed the "critical level" by the authors (Nelson and Anderson, 1980).

Figures 12 to 19 are the scatter diagrams of phosphorus extractable by the various soil test methods versus relative yield of maize. From these graphs critical levels of phosphorus soil tests were evaluated.

(b) Cate-Nelson Analysis of Variance Method

Cate and Nelson (1971) reported an iterative statistical procedure for separating percentage yield data into two or more classes based upon maximization of the class sum of squares in a one-way analysis of variance. This method has been employed in determining critical levels based on the calculation of a series of coefficients of determination, R^2, for divisions made at various levels of soil test. The critical level of soil test is taken as that level of soil test division for which R^2 is maximum (Nelson and Anderson, 1980). Using this procedure as modified by Nelson and Anderson (1980) critical levels of phosphorus for each of the eight soil test methods were evaluated (Tables 26 to 33).

1. Mehlich No.1

Mehlich 1 phosphorus soil test critical levels of 7.25 and 7.29 mg kg^{-1} were evaluated for maize using the Cate-Nelson graphical method (Fig.12) and Cate-Nelson analysis of variance method (Table 26), respectively. It is seen from these results that the two methods produced values of critical level that were in perfect agreement.

Although Mehlich 1 has been shown in this study to be the best extractant of available phosphorus in soils of the southern Guinea savanna, the method has not been extensively studied as a soil test method in Nigeria. Because of this the critical level of Mehlich 1 phosphorus soil test had not been reported for any of the agro-ecological zones. However, from the work carried out in the south-eastern United States of America it was found that the critical level of Mehlich 1 soil test for irrigated corn is 9.0 mg kg^{1} (Obreza and Rhoades, 1988).

2. Modified Mehlich No. 1

Modified Mehlich 1 ranks second to Mehlich 1 as the most precise soil test method for phosphorus in the southern Guinea savanna. The phosphorus soil test critical level for maize determined by the Cate-Nelson graphical method is 6.75 mg kg^{-1} (Fig. 13) while the value obtained through the Cate-Nelson Analysis of Variance method (Table 27) is 6.36 mg kg^{-1}.

Like the Mehlich 1 soil test method, the critical level of soil test for this method has not been reported for Nigerian soils.

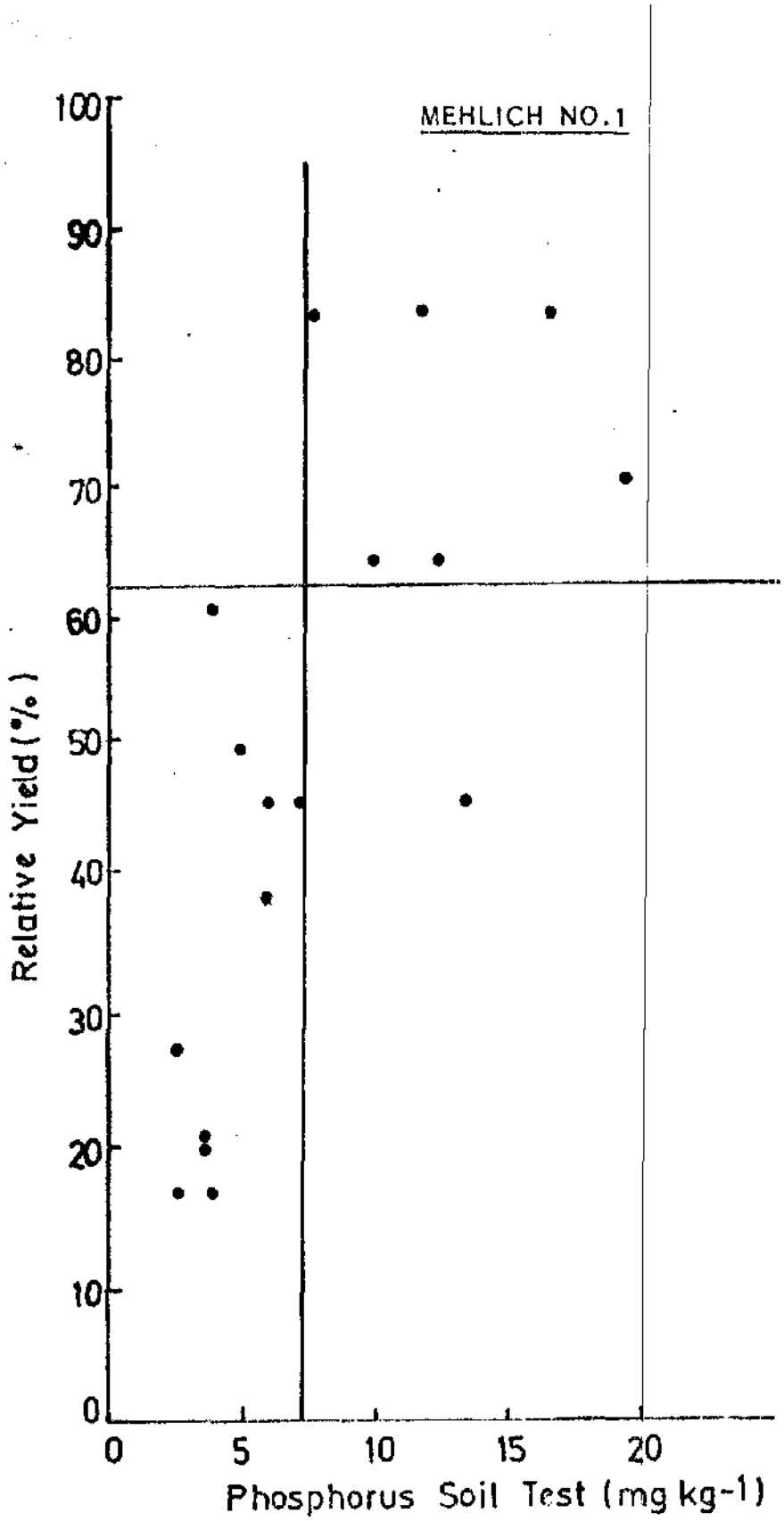


Fig. 12 Scatter diagram of Mehlich No.1 extractable Phosphorus against relative yield of maize for evaluation of critical level (field fertilizer rate studies)

Table 26: Data on maize grain yield, Mehlich No. 1 extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	±Ymax (kg/ha)	Mehlich No. 1 Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
3206.72	572.89	2633.83	2.56			82.13
2646.64	747.27	1899.37	2.56	0.71	0.06	71.77
2186.14	0	2186.14	2.58	1.03	0.08	100.00
3107.17	545.63	2561.54	3.32	1.93	0.15	82.44
3407.23	676.66	2730.57	3.46	3.32	0.26	80.14
1239.78	0	1239.78	3.47	2.24	0.18	100.0
3642.52	756.75	2885.77	3.48	4.03	0.32	79.22
2864.98	1735.68	1129.30	3.85	2.87	0.23	39.42
2100.28	1055.42	1044.86	4.96	1.88	0.15	49.75
5062.01	1974.08	3087.93	5.78	4.04	0.32	61.0
2555.33	1178.56	1376.77	5.94	3.55	0.28	53.88
4882.17	2288.86	2593.31	7.00	5.52	0.43	53.12
1978.33	1644.25	334.08	7.57	3.10	0.24	16.89
3871.67	2495.90	1375.77	9.92	2.85	0.22	35.53
4759.00	3982.41	776.59	11.73	1.71	0.13	16.32
4243.61	2745.30	1498.31	12.52	1.60	0.13	35.31
2339.90	1088.65	1251.25	13.45	1.55	0.12	53.47
3802.27	3159.89	642.38	16.47			16.89
3849.79	2749.11	1100.68	19.46			28.59

*Calculated after converting $\pm Y_{max}$ from kg/ha to tonnes/ha.

1. $R^2 = \frac{\text{Class sum of squares}}{\text{Total corrected sum of squaress}}$

2. $\text{Class sum of squares} = \frac{(\text{Total } \pm Y_{max} \text{ for class 1})^2}{n_1} + \frac{(\text{Total } \pm Y_{max} \text{ for class 2})^2}{n_2} - \frac{(\text{Total } \pm Y_{max} \text{ for both classes})^2}{n}$

3. $n = n_1 + n_2$

4. Total corrected sum of squares = $\sum \Delta Y_{max}^2 - \frac{(\sum \Delta Y_{max})^2}{n}$ 12.71

5. $\frac{(\sum \Delta Y_{max})^2}{n}$ = 55.08

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 3.67	20.86	85.10
2 = 3.67 - 7.29	48.57	51.43
3 = 7.29 - 14.96	68.50	31.50
4 = > 14.96	77.26	22.74

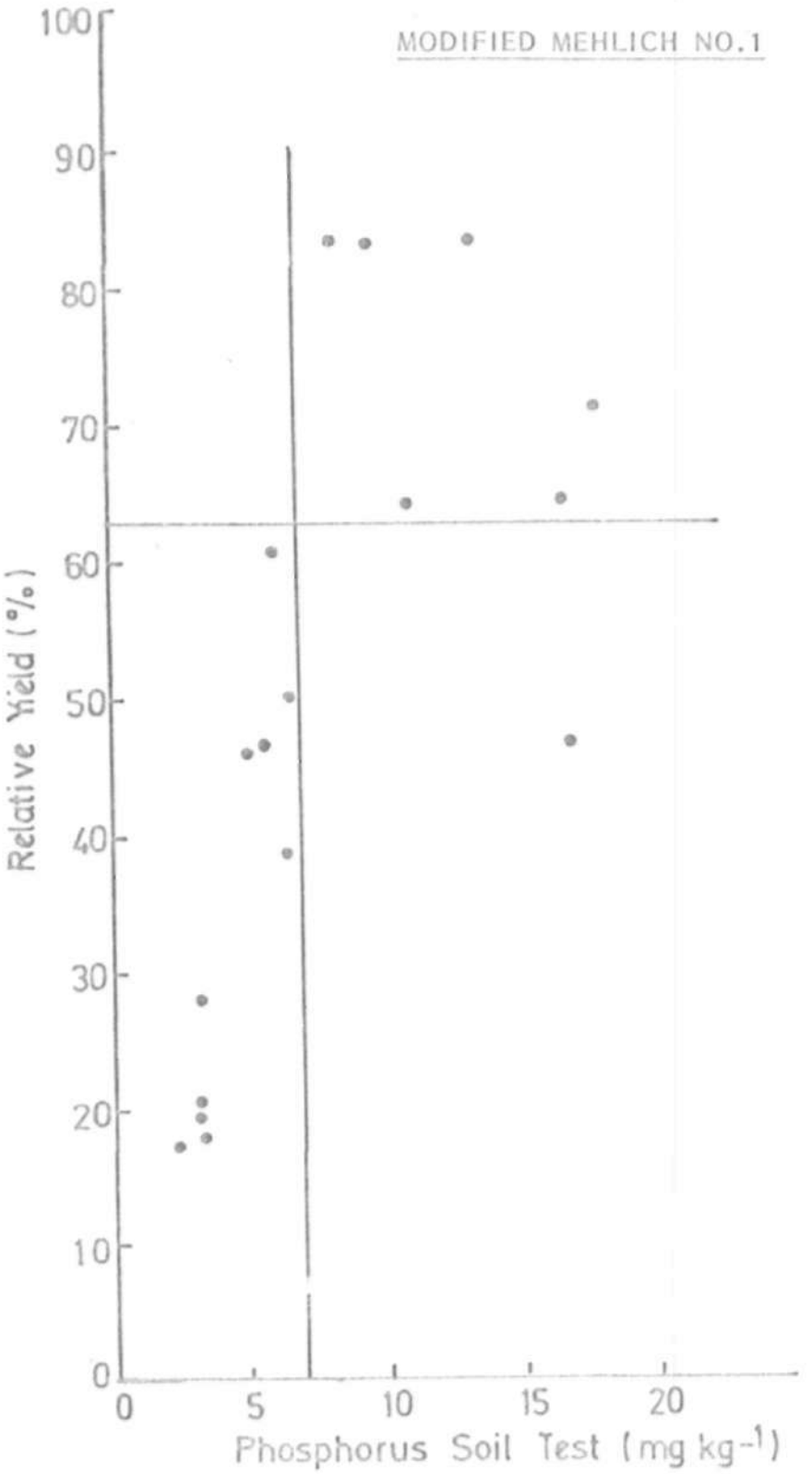


Fig. 13: Scatter diagram of Modified Mehlich No.1 Extractable Phosphorus against relative yield of maize for evaluation of critical level (field fertilizer rate studies).

Table 27: Data on maize grain yield, Modified Mehlich No. 1 extractable phosphorus and results of *Cate-Nelson Analysis of variance - 2 class model.*

Ymax (kg/ha)	Yo (kg/ha)	±Ymax (kg/ha)	Modified Mehlich No. 1 Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
2186.14	0	2186.14	1.74			100.00
3107.17	545.63	2561.54	2.37	1.01	0.08	82.44
1239.78	0	1239.78	2.48	0.31	0.02	100.00
3206.72	572.89	2633.83	3.20	1.04	0.08	82.13
2646.64	747.27	1899.37	3.20	1.09	0.09	71.77
3407.23	676.66	2730.57	3.22	2.24	0.18	80.14
3642.52	756.75	2885.77	3.22	4.03	0.32	79.22
2555.33	1178.56	1376.77	4.95	3.28	0.26	53.88
4882.17	2288.86	2593.31	5.64	4.83	0.38	53.12
2864.98	1735.68	1129.30	6.03	3.74	0.29	39.42
5062.01	1974.08	3087.93	6.27	6.77	0.53	61.00
2100.28	1055.42	1044.86	6.45	5.52	0.43	49.75
4759.00	3982.41	776.59	8.23	3.93	0.31	16.32
1978.33	1644.25	334.08	9.60	1.90	0.15	16.89
3871.67	2495.90	1375.77	10.91	1.71	0.13	35.53
3802.27	3159.89	642.38	13.37	0.63	0.05	16.89
4243.61	2745.30	1498.31	16.58	0.62	0.05	35.31
2339.90	1088.65	1251.25	16.68			53.47
3849.79	2749.11	1100.68	17.76			28.59

* Calculated after converting ±Ymax from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 4.09	20.86	85.10
2 = 4.09 - 6.36	48.15	51.86
3 = 6.36 - 12.14	70.38	29.62
4 = > 12.14	66.44	33.57

3. Bray No. 1

Figure 14 shows the scatter diagram of Bray 1 extractable phosphorus against relative yield of maize. From this scatter diagram and using the Cate-Nelson graphical method the critical level of phosphorus for maize in the soils of the southern Guinea savanna was found to be 8.0 mg kg^{-1}. With the Cate-Nelson Analysis of Variance method a critical level of 7.83 mg kg^{-1} was obtained (Table 28).

Extensive research has been carried out using this soil test method. Critical levels of phosphorus for various crops and ecological zones have been reported. Sobulo (1981), and Agboola and Obigbesan (1974) obtained Bray 1 critical level of 8.0 mg kg^{-1} for maize in soils of south western Nigeria. Agboola and Corey (1972), Ayodele (1986), Okeya (1977), Kang and Osiname (1979), Sobulo and Osiname (1981), and Adepetu *et al.* (1979) obtained critical levels of 10.0, 12.7, 17.0, 14.0, 10.0, and 15.0 mg kg^{-1}, respectively, for maize in the Alfisols and Ultisols of south-western Nigeria. Sobulo (1981) cited a number of workers in the tropics (Lungu, 1965; Agboola and Obigbesan, 1974; Warmsley and Forde, 1976; Kang and Osiname, 1979) who found that the critical level of phosphorus extracted by Bray 1 for maize is between 8.0 and 14.0 mg kg^{-1}.

Bray 1 critical level of phosphorus for maize has not been earlier reported for the soils of the southern Guinea savanna of Nigeria. However, from the results of this study there appears to be good agreement with results of earlier studies for the other ecological zones.

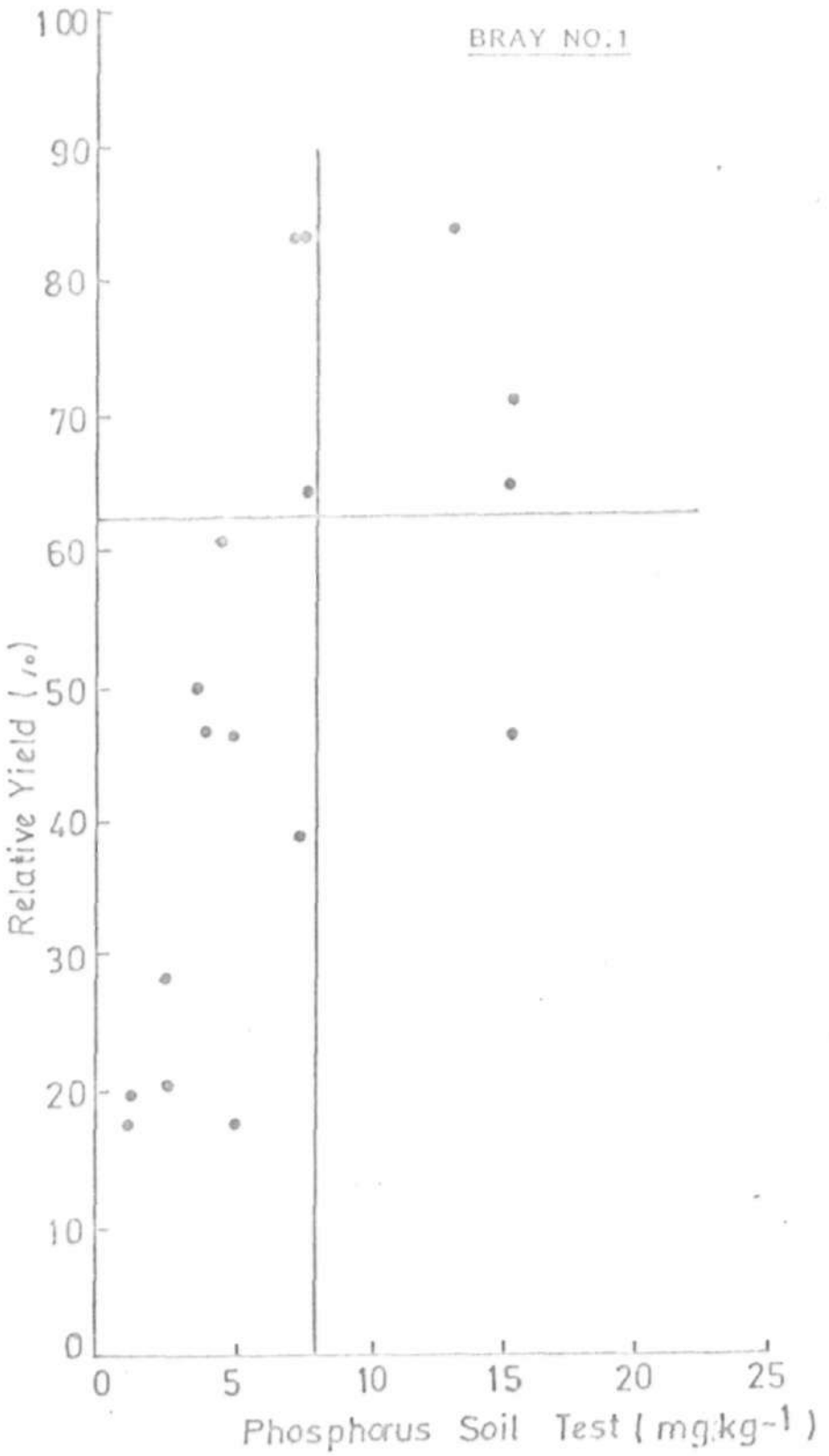


Fig. 14: Scatter diagram of Bray No.1 Extractable Phosphorus against relative yield of maize for evaluation of critical level (field fertilizer studies).

Table 28: Data on maize grain yield, Bray No. 1 extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	$_{z}$Ymax (kg/ha)	Bray No. 1 Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
3107.17	545.63	2561.54	1.23			82.44
2186.14	0	2186.14	1.29	1.01	0.08	100.00
1239.78	0	2139.78	1.29	0.31	0.02	100.00
3407.23	676.66	2730.57	1.29	1.16	0.09	80.14
2646.64	747.27	1899.37	2.56	1.21	0.10	71.77
3642.52	756.75	2885.77	2.58	2.64	0.21	79.22
2100.28	1055.42	1044.86	3.97	1.56	0.12	49.75
4882.17	2288.86	2593.31	3.99	2.67	0.21	53.12
2864.98	1735.68	1129.30	4.83	1.83	0.14	39.42
3206.72	572.89	2633.83	5.12	3.17	0.25	82.13
2555.33	1178.56	1376.77	5.15	2.73	0.21	53.88
1978.33	1644.25	334.08	7.57	1.07	0.08	16.89
5062.01	1974.08	3087.93	7.71	3.10	0.24	61.00
3871.67	2495.90	1375.77	7.94	2.85	0.22	35.53
3802.27	3159.89	642.38	7.98	1.51	0.12	16.89
4759.00	3982.41	776.59	13.47	0.63	0.05	16.32
4243.61	2745.30	1498.31	15.54	0.62	0.05	35.31
2339.90	1088.65	1251.25	15.64			53.47
3849.79	2749.11	1100.68	15.67			28.59

* Calculated after converting $_{z}Y_{max}$ from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 3.28	21.61	85.60
2 = 3.28 - 7.83	49.12	50.88
3 = > 7.83	68.89	31.02

4. Mehlich No. 2

Mehlich No. 2 phosphorus critical level for maize for the soils of the southern Guinea savanna determined by the graphical method of Cate and Nelson (1965) is 13.0 mg kg^{-1} (Fig. 15). A value of 13.20 mg kg^{-1} was also obtained with the Cate-Nelson Analysis of Variance method (Table 29).

The Mehlich 2 soil test method has not been extensively used in correlation studies in Nigeria. So, the critical level of phosphorus using this extractant had not been determined for any Nigerian soil or crop.

5. Bray No. 2

Figure 16 is the scatter diagram of Bray No. 2 phosphorus soil test against relative yield of maize. From this diagram the critical phosphorus level for this soil test method was evaluated for the soils of the southern Guinea savanna using the graphical method of Cate and Nelson (1965). A value of 8.0 mg kg^{-1} was obtained. Also with the Cate-Nelson Analysis of Variance method a soil test critical level of 6.76 mg kg^{-1} was obtained (Table 30).

Although Bray 2 has been reported to be the best extractant of available phosphorus for soils of south-eastern Nigeria, no serious calibration work on this method has been reported.

6. Olsen's Method

The critical level of phosphorus for maize for the Olsen's soil test method was evaluated using the Cate-Nelson graphical method (Fig. 17) and the Cate-Nelson Analysis of Variance method (Table 31). A value of 7.25 mg kg^{-1} was

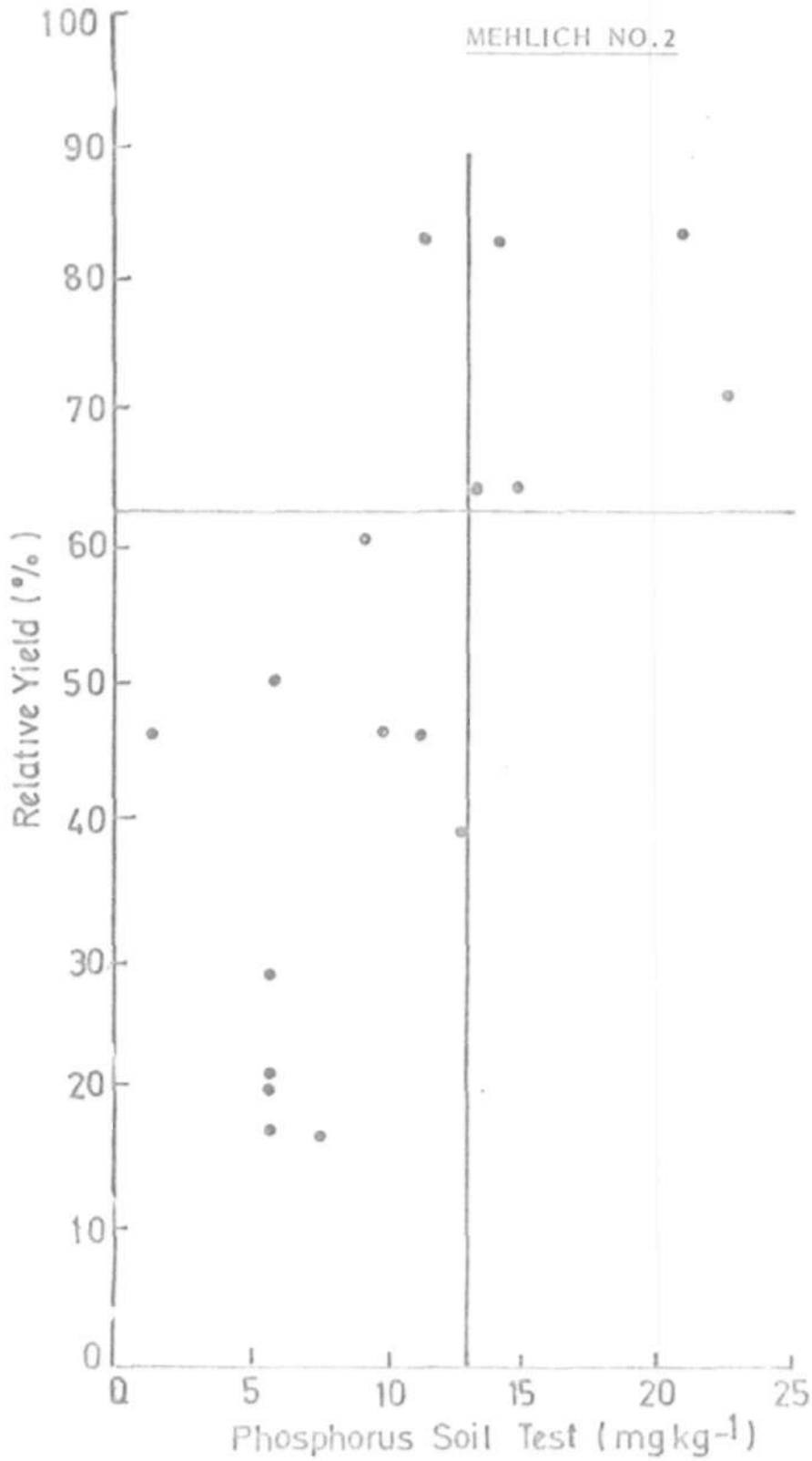


Fig. 15 : Scatter diagram of Mehlich No.2 Extractable Phosphorus against Relative Yield of maize for evaluation of critical level (field fertilizer rate studies)

Table 29: Data on maize grain yield, Mehlich No. 2 extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	±Ymax (kg/ha)	Mehlich No.2 Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
2339.90	1088.65	1251.25	1.49			53.47
3206.72	572.89	2633.83	5.71	0.13	0.01	82.13
2646.64	747.27	1899.37	5.72	0.18	0.01	71.77
3407.23	676.66	2730.57	5.74	0.92	0.07	80.14
2186.14	0	2186.14	5.75	1.30	0.10	100.00
1239.78	0	1239.78	5.75	0.72	0.06	100.00
3642.52	756.75	2885.77	5.75	1.92	0.15	79.22
2100.28	1055.42	1044.86	5.76	1.09	0.09	49.75
3107.17	545.63	2561.54	7.39	2.04	0.16	82.44
2864.98	1738.68	1129.30	9.09	1.36	0.11	39.42
4882.17	2288.86	2593.31	9.78	2.53	0.20	53.12
2555.33	1178.56	1376.77	11.19	2.17	0.17	53.88
3802.27	3159.89	642.38	11.28	1.01	0.08	16.89
5062.01	1974.08	3087.93	13.01	3.18	0.25	61.00
3871.67	2495.90	1375.77	13.39	3.04	0.24	35.53
1978.33	1644.25	334.08	14.19	1.18	0.90	16.89
4243.61	2745.30	1498.31	14.85	1.30	0.10	35.31
4759.00	3982.41	776.59	20.96			16.32
3849.79	2749.11	1100.68	22.46			28.59

* Calculated after converting $\pm Y_{max}$ from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 8.24	28.73	77.66
2 = 8.24 - 13.20	55.14	44.86
3 = 13.20 - 17.91	70.76	29.24
4 = > 17.91	77.55	22.45

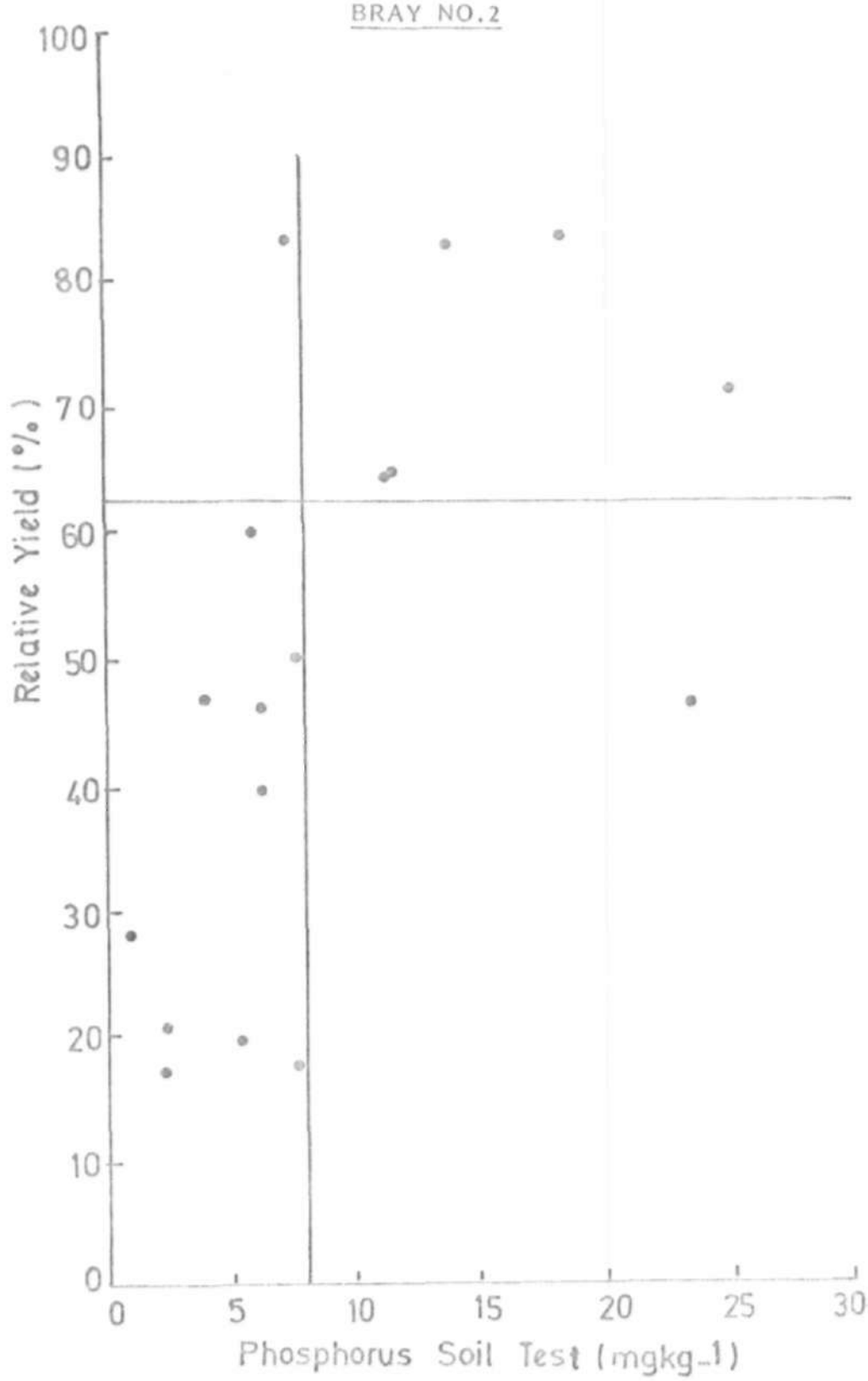


Fig. 16: Scatter diagram of Bray No.2 Extractable Phophorus against relative yield of maize for evaluation of critical level (field fertilizer rate studies).

Table 30: Data on maize grain yield, Bray No. 2 extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	zYmax (kg/ha)	Bray No. 2 Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
2646.64	747.27	1899.37	0.99			71.77
3107.17	545.63	2561.59	2.28	0.63	0.05	82.44
3642.52	756.75	2885.77	2.38	1.99	0.16	79.22
2186.14	0	2186.14	3.97	2.36	0.19	100.00
1239.78	0	1239.78	3.97	1.39	0.11	100.00
4882.17	2288.86	2593.31	3.99	2.42	0.19	53.12
3407.23	676.66	2730.57	5.25	3.96	0.31	80.14
2864.98	1735.68	1129.30	5.94	2.81	0.22	39.42
5062.01	1974.08	3087.93	6.17	5.27	0.41	61.00
1978.33	1644.25	334.08	7.35	2.77	0.22	16.89
3206.72	572.89	2633.83	7.68	4.47	0.35	82.13
2555.33	1178.56	1376.77	7.72	4.03	0.32	53.88
2100.28	1055.42	1044.86	7.74	3.10	0.24	49.75
4243.61	2745.30	1498.31	11.68	3.07	0.24	35.31
3871.67	2495.90	1375.77	11.71	2.92	0.23	35.53
3802.27	3159.89	642.38	13.97	1.55	0.12	16.89
4759.00	3982.41	776.59	18.46	0.62	0.05	16.32
2339.90	1088.65	1251.25	23.51			53.47
3849.79	2749.11	1100.68	24.95			28.59

* Calculated after converting zYmax from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 6.76	33.27	74.12
2 = 6.76 - 12.84	54.42	45.58
3 = > 12.84	71.18	28.82

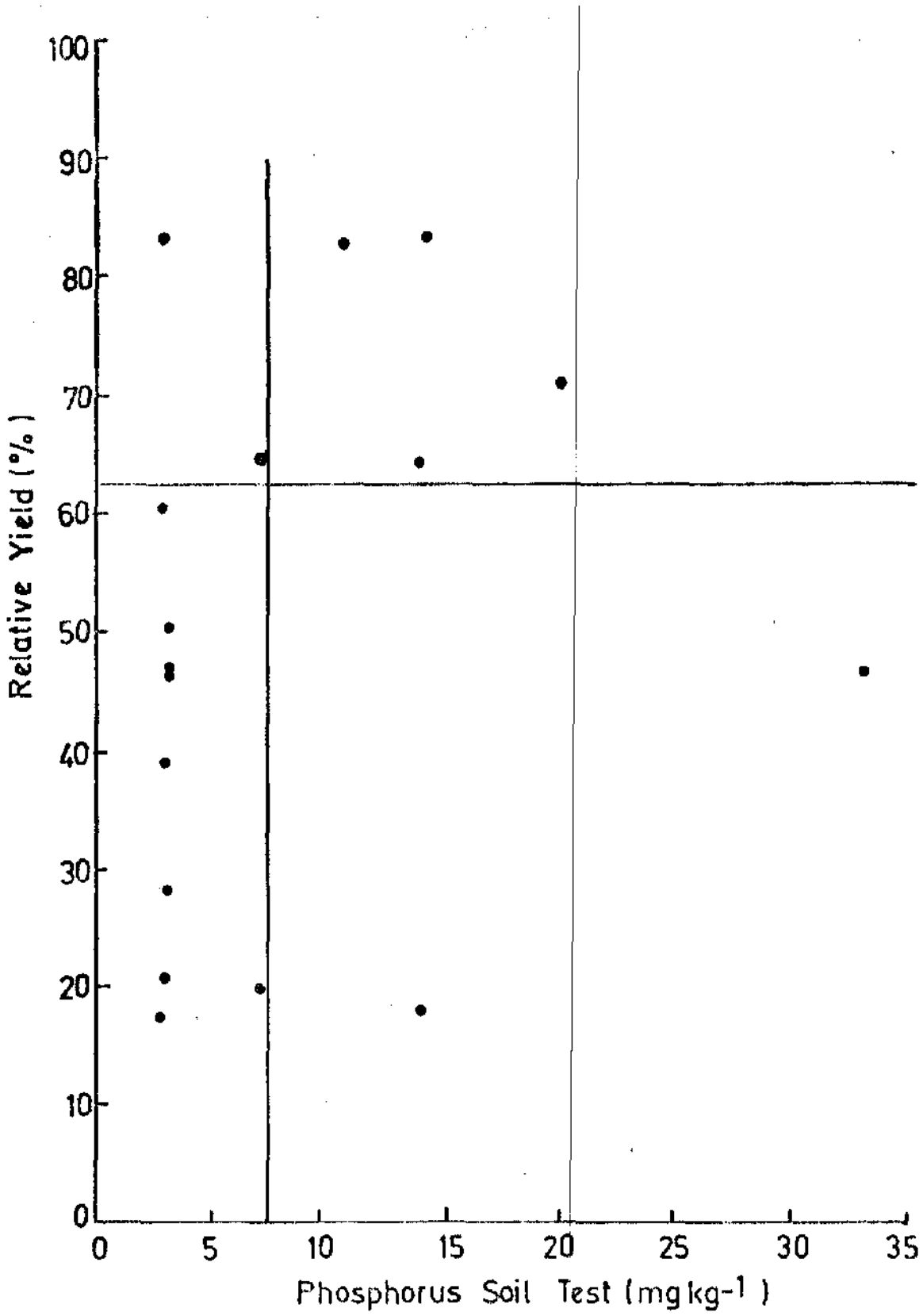


Fig 17 : Scatter diagram of Olsen's Extractable Phosphorus against relative yield of maize for evaluation of critical level (fied fertilizer rate studies).

Table 31: Data on maize grain yield, Olsen's extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	∆Ymax (kg/ha)	Olsen's Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
2864.98	1735.68	1129.30	2.78			39.42
3107.17	545.63	2561.54	2.84	0.05	0.004	82.44
1978.33	1644.25	334.08	2.84	0.47	0.04	16.89
5062.01	1974.08	3087.93	2.89	0.03	0.002	61.0
2646.64	747.27	1899.37	2.96	0.07	0.006	71.77
2555.33	1178.56	1376.77	2.97	0.01	0.001	53.88
2186.14	0	2186.14	2.98	0.10	0.008	100.0
1239.78	0	1239.78	2.98	0	0	100.0
3642.52	756.75	2885.77	2.98	0.40	0.03	79.72
2100.28	1055.42	1044.86	2.98	0.11	0.009	49.75
4882.17	2288.86	2593.31	2.99	0.56	0.04	53.12
3407.23	676.66	2730.57	6.93	1.57	0.12	80.14
3871.67	2495.90	1375.77	6.94	1.30	0.10	35.53
3802.27	3159.89	642.38	10.38	0.42	0.03	16.89
3206.72	572.89	2633.83	13.78	1.51	0.12	82.13
4243.61	2745.30	1498.31	13.86	1.55	0.12	35.31
4759.00	3982.41	776.59	13.97	0.62	0.05	16.89
3849.79	2749.11	1100.68	19.96			28.59
2339.90	1088.65	1251.25	32.87			53.47

* Calculated after converting $\triangle Y_{max}$ from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 6.94	41.24	65.64
2 = 6.94 - 13.92	57.54	42.47
3 = < 13.92	67.21	32.98

obtained with the graphical method and 6.94 mg kg^{-1} with the analysis of variance method.

The Olsen's method is one of the soil test methods that have been extensively studied in Nigeria. Although the method has been reported to extract phosphorus that correlates well with crop responses, it has not been adequately calibrated. However, Ayodele (1986) and Okeya (1977) determined critical levels of Olsen's phosphorus soil test data for maize in Alfisols and Ultisols of south-western Nigeria. The results obtained were 11.0 and 12.0 mg kg^{-1}, respectively.

7. Mississippi

Figure 18 is the plot of phosphorus extractable by the Mississippi method against relative yield of maize. From this relationship, the critical level of soil test phosphorus was determined by the Cate-Nelson graphical method. A value of 1.20 mg kg^{-1} was obtained. Also, a value of 1.12 mg kg^{-1} was obtained using the Cate-Nelson Analysis of Variance method (Table 32).

The effectiveness of the Mississippi method as a soil test method for phosphorus had not been investigated for Nigerian soils.

8. AB-DTPA

Figure 19 is the graph of AB-DTPA extractable phosphorus against relative yield of maize. From this graph a critical level of AB-DTPA soil test phosphorus of 2.70 mg kg^{-1} was evaluated for maize using the graphical method of Cate and Nelson (1965). Also, using the Analysis of Variance method of Cate and Nelson (1971) a critical level of 2.69 mg kg^{-1} was also obtained (Table 33).

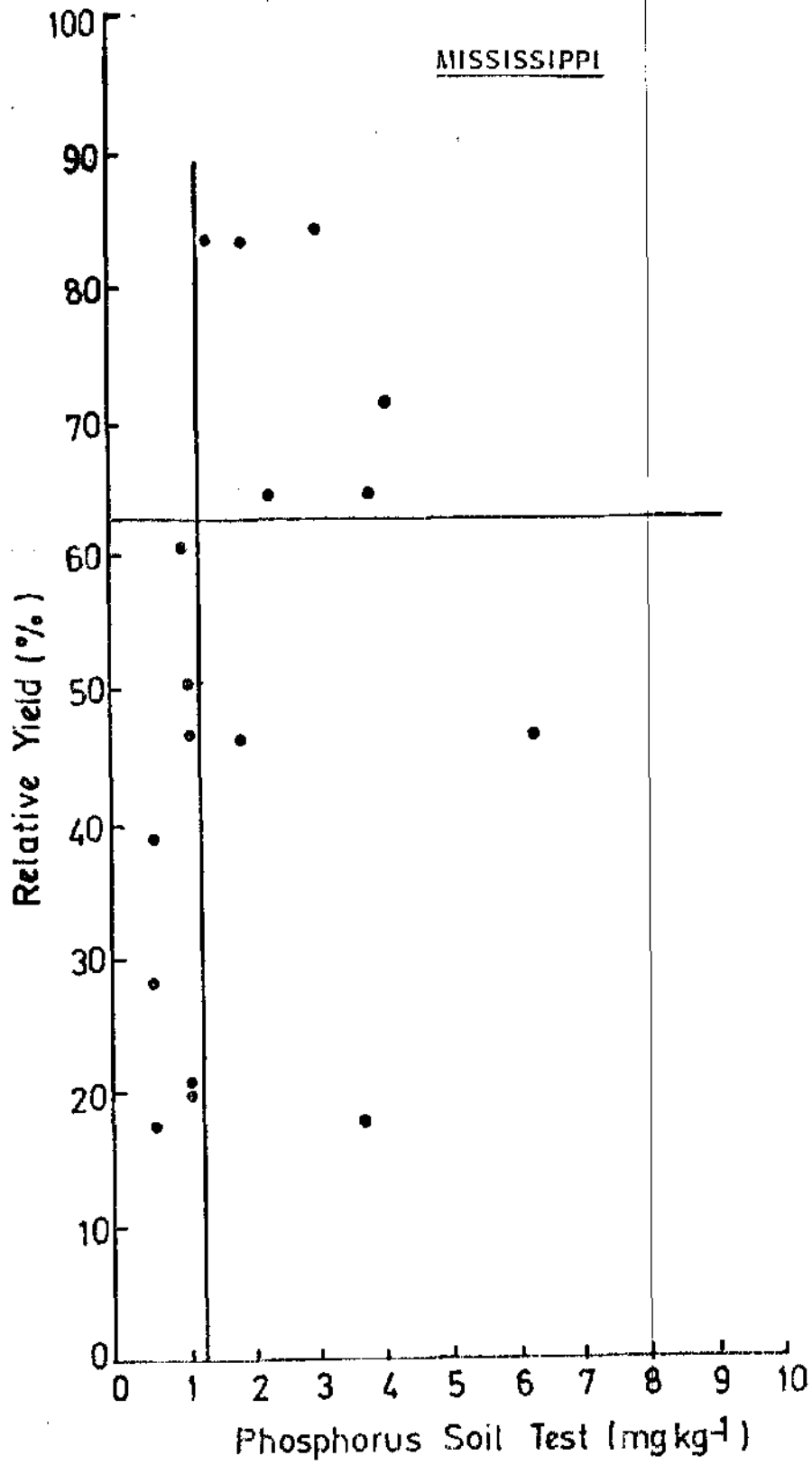


Fig. 18 : Scatter diagram of Mississippi Extractable Phosphorus against relative yield of maize for evaluation of critical level (field fertilizer rate studies).

Table 32: Data on maize grain yield, Mississippi extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	±Ymax (kg/ha)	Mississippi Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
3107.17	545.63	2561.54	0.47			82.44
5062.01	1974.08	3087.93	0.48	2.81	0.22	61.00
2646.64	747.27	1899.37	0.49	2.36	0.19	71.77
2186.14	0	2186.14	0.50	2.72	0.21	100.00
2864.98	1735.68	1129.30	0.93	1.51	0.12	39.42
1239.78	0	1239.78	0.99	0.87	0.07	100.00
3407.23	676.66	2730.57	0.99	1.93	0.15	80.14
3642.52	756.75	2885.77	0.99	3.64	0.29	79.22
2100.28	1055.42	1044.86	0.99	2.51	0.20	49.75
4882.17	2288.86	2593.31	1.00	3.96	0.31	53.12
1978.33	1644.25	334.08	1.23	1.89	0.15	16.89
2555.33	1178.66	1376.77	1.78	1.57	0.12	53.88
3802.27	3159.89	642.38	1.80	0.60	0.05	16.89
3871.67	2495.90	1375.77	2.18	0.42	0.03	35.53
4759.0	3982.41	776.59	2.99	0.04	0.003	16.32
3206.72	572.89	2633.83	3.64	0.63	0.05	82.13
4243.61	2745.30	1498.31	3.66	0.62	0.05	35.31
3849.79	2749.11	1100.68	3.99			28.59
2339.90	1088.65	1251.25	6.18			53.47

* Calculated after converting $\pm Y_{max}$ from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 1.12	35.39	71.69
2 = > 1.12	62.33	37.67

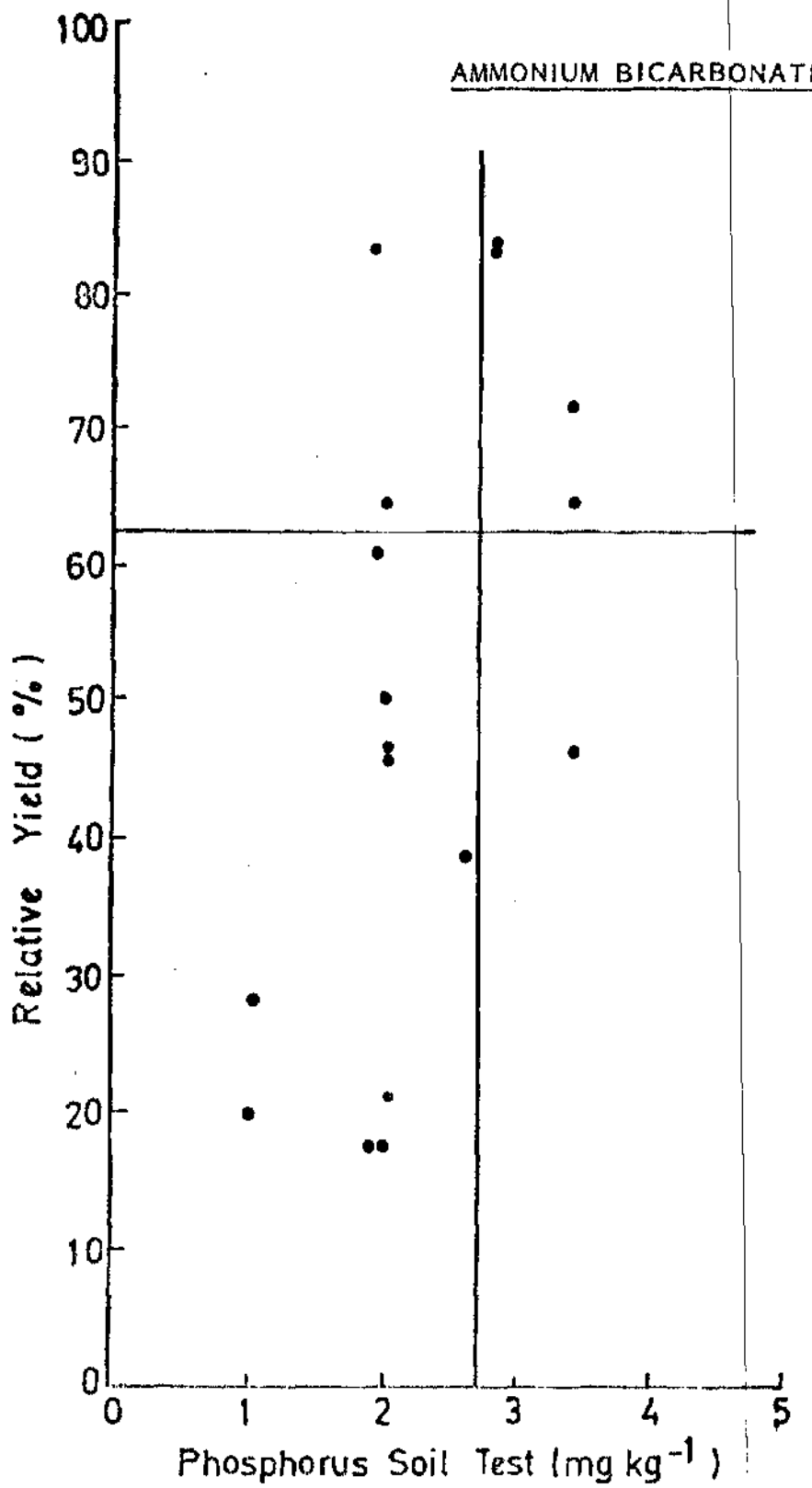


Fig. 19 : Scatter diagram of AB-DTPA Extractable Phosphorus against relative yield of maize for evaluation of critical level (field fertilizer rate studies).

Table 33: Data on maize grain yield, Ammonium Bicarbonate-DTPA extractable phosphorus and results of Cate-Nelson Analysis of variance - 2 class model.

Ymax (kg/ha)	Yo (kg/ha)	∆Ymax (kg/ha)	AB-DTPA Soil Test (mg kg^{-1})	Class sum of squares*	R^2	Response (%)
2186.14	0	2186.14	1.03			100.00
1239.78	0	1239.78	1.03	0	0	100.00
3407.23	676.66	2730.57	1.03	0.44	0.03	80.14
2646.64	747.27	1899.37	1.03	0.49	0.04	71.77
2864.98	1735.68	1129.30	1.86	0.12	0.01	39.42
1978.33	1644.25	334.08	1.89	0.12	0.01	16.89
3107.17	545.63	2561.54	1.90	0.01	0.001	82.44
3206.72	572.89	2633.83	1.97	0.26	0.02	82.13
3642.52	756.75	2885.77	1.98	1.10	0.09	79.22
3871.67	2495.90	1375.77	1.98	0.80	0.06	35.53
2100.28	1055.42	1044.86	1.98	0.36	0.03	49.75
2555.33	1178.56	1376.77	1.98	0.21	0.02	53.88
4882.17	2288.86	2593.31	2.00	0.84	0.07	53.12
5062.01	1974.08	3087.93	2.63	2.85	0.22	61.00
3802.27	3159.89	642.38	2.75	1.51	0.12	16.89
4759.00	3982.41	776.59	2.75	0.63	0.05	16.32
4243.61	2745.30	1498.31	3.37	0.62	0.05	35.31
2339.90	1088.65	1251.25	3.39			53.47
3849.79	2749.11	1100.68	3.39			28.59

* Calculated after converting ΔY_{max} from kg/ha to tonnes/ha.

Soil test class (mg kg^{-1})	Average relative yield (%)	Average response (%)
1 = < 2.69	42.89	64.66
2 = > 2.69	69.88	30.12

Like some of the other soil test methods investigated in this study, AB-DTPA had previously not been studied as a soil test method of phosphorus for Nigerian soils.

Table 34 shows the critical levels of phosphorus evaluated by both the graphical method and Analysis of Variance method. The results show that there is a near perfect agreement between the critical levels determined by both methods. It is only Bray 2 that produced differing values. The near perfect agreement is confirmed by the coefficient of determination, R^2, which shows that 98.22% of the variation in the results obtained by the graphical method is predicted by the variation in the results obtained with the analysis of variance method.

The Cate-Nelson Analysis of Variance method has been generally accepted to be superior to the graphical method in estimating optimal partitions although the two methods seem to produce quite similar results (Nelson and Anderson, 1980).

Soil Test Ratings

Descriptive terms such as "very low", "low", "medium", "high", "very high", and "extremely high" have been used to define the relationship between chemical soil test values and soil fertility levels (Morgan, 1935; Bray and Kurtz, 1945; Rouse, 1968; Cope and Rouse, 1980; Cope *et al.*, 1981; Cope and Evans, 1985; Barber, 1980; Thomas and Peaslee, 1980; Adepetu, 1986; Sobulo and Adepetu, 1987). The use of these terms has some limitations because varying concepts have been associated with them (Rouse, 1968; Cope and Rouse, 1980; Cope and Evans, 1985), and because, being relative terms, the implication they have with respect to fertilizer needs will vary according to the specific crop and soil (Thomas and Peaslee, 1980).

Table 34: Critical levels of phosphorus extractable by various soil test methods.

Soil test method	Range of soil test values ($mg\ kg^{-1}$)	Critical level ($mg\ kg^{-1}$)	
		Cate-Nelson graphical method	Cate-Nelson Analysis of Variance Method
Mehlich No. 1	2.56 - 19.46	7.25	7.29
Mehlich No. 2	1.49 - 22.46	13.00	13.20
Bray No. 1	1.23 - 15.67	8.00	7.83
Bray No. 2	2.28 - 24.95	8.00	6.76
Modified Mehlich No.1	1.74 - 17.76	6.75	6.36
Olsen's	2.84 - 19.96	7.25	6.94
Mississippi	0.48 - 6.18	1.20	1.12
AB-DTPA	1.03 - 3.39	2.70	2.69

$r = 0.991^{***}$
$R^2 = 98.22$
*** = $P < 0.001$

However, the system is still very commonly used for fertilizer recommendations based on soil tests.

It should be noted that there has not been a uniform system of estimating "relative yield". While some workers assign the highest yield at each location a value of 100 and all the other yields at that location are then related to this highest yield (Rouse, 1968; Nelson and Anderson, 1980), some others have suggested the use of plateau average as the denominator where a linear-plateau response pattern is obtained (Nelson and Anderson, 1980), and yet some others have compared actual yields of plots with a standard treatment which received adequate or optimum level of the nutrient element being studied (Cope, 1984; Cope and Evans, 1985; Cope *et al.*, 1981). Thus, while with some methods, relative yield values above 100% are expected, in others the maximum that could be assigned is 100%. This, definitely, will affect the points of demarcation of the ratings.

Cate and Nelson (1971), Fitts and Hanway (1971) and Nelson and Anderson (1980) described a simplified system of partition-ing soil test data based on probability of response to phosphorus and potassium. In the present study, the analysis of variance method of Cate and Nelson (1971) modified by Nelson and Anderson (1980) and the Mitscherlich-Bray growth function were employed in partitioning the phosphorus soil test values into various response classes.

1. Mehlich No.1

Table 26 shows the four probable classes of Mehlich 1 extractable phosphorus using the Cate-Nelson Analysis of Variance method as modified by Nelson and Anderson (1980):

Class 1 - <3.67 mg kg^{-1}

Class 2 - 3.67 - 7.29 mg kg^{-1}

Class 3 - 7.29 - 14.96 mg kg^{-1}

Class 4 - >14.96 mg kg^{-1}

The average relative yields obtained and the average responses of maize to fertilization for each of the classes is as shown in Table 26. It should be noted that the highest percentage of maximum yield obtained from the control plots is 83.7%. This shows that the highest soil test values obtained in this study were within the "medium" rating. It is also observed that the soils in class 4 (Laminga 89 and Wamba 88) did not respond to phosphorus fertilization. Two of the soils in class 3 (Ayangba 88 and Yandev 88) did not respond to phosphorus fertilization while the other three responded significantly to fertilization. So, classes 3 and 4 may not be merged into a single class.

2. Modified Mehlich No. 1

Using the Cate-Nelson Analysis of Variance method the Modified Mehlich 1 soil test values could be separated into four response classes (Table 27):

Class 1 - <4.09 mg kg^{-1}

Class 2 - 4.09 - 6.36 mg kg^{-1}

Class 3 - 6.36 - 12.14 mg kg^{-1}

Class 4 - >12.14 mg kg^{-1}

However, because of the response pattern of classes 3 and 4 and their average relative yields, classes 3 and 4 should be merged into one class. So, the response classes are:

Class 1 - <4.09 mg kg^{-1}

Class 2 - 4.09 - 6.36 mg kg^{-1}

Class 3 - 6.36 - 12.14^{+} mg kg^{-1}

3. Bray No.1

Bray 1 phosphorus soil test values were partitioned into three response classes (Table 28):

Class 1 - <3.28 mg kg^{-1}

Class 2 - 3.28 - 7.83 mg kg^{-1}

Class 3 - >7.83 mg kg^{-1}

4. Mehlich No.2

Table 29 shows the partitioning of the Mehlich 2 phosphorus soil test values into four response classes:

Class 1 - <8.24 mg kg^{-1}

Class 2 - 8.24 - 13.20 mg kg^{-1}

Class 3 - 13.20 - 17.91 mg kg^{-1}

Class 4 - >17.91 mg kg^{-1}

From the response pattern of classes 3 and 4 and the pattern of fertilizer requirements of the soils in the two classes, classes 3 and 4 could be merged into one class. Thus, the classes then become:

Class 1 - <8.24 mg kg^{-1}

Class 2 - 8.24 - 13.20 mg kg^{-1}

Class 3 - 13.20 - 17.91+ mg kg^{-1}

5. Bray No. 2

Bray 2 soil test data could be partitioned into three probable response classes (Table 30):

Class 1 - <6.76 mg kg^{-1}

Class 2 - 6.76 - 12.84 mg kg^{-1}

Class 3 - >12.84 mg kg^{-1}

Enwezor *et al.* (1989) put the Bray 2 soil test phosphorus ratings as follows: low = <15 mg kg^{-1}; medium = 15 - 25 mg kg^{-1}; and high = >25 mg kg^{-1}. The soil test values for these classes are almost double the values for the corresponding classes in the present study.

6. Olsen's Method

Olsen's soil test values could be separated into three response classes (Table 31):

Class 1 - <6.94 mg kg^{-1}

Class 2 - 6.94 - 13.92 mg kg^{-1}

Class 3 - >13.92 mg kg^{-1}

7. Mississippi

Cate-Nelson Analysis of Variance method could only separate the Mississippi soil test values into two responding classes (Table 32):

Class 1 - <1.12 mg kg^{-1}

Class 2 - >1.12 mg kg^{-1}

8. AB-DTPA

Table 33 shows the two response classes into which the AB-DTPA phosphorus soil test data were separated using the Cate-Nelson Analysis of Variance method as modified by Nelson and Anderson (1980):

Class 1 - <2.69 mg kg^{-1}

Class 2 - >2.69 mg kg^{-1}

From the above results it is seen that the Cate-Nelson Analysis of Variance method was successful in separating the soils into response classes (Table 35). Mehlich 1 soil test method was the most precise and effective in separating the soils. The order of effectiveness of the eight methods is as follows:

Mehlich 1 > Modified Mehlich 1 > Mehlich 2 > Bray 1 > Bray 2 > Mississippi > AB-DTPA > Olsen's.

It may not be satisfactory to assign fertility rating terms of "low", "medium" or "high" to any of the classes for now. However, a study of the works of Sobulo and Osiname (1981) on Bray 1 phosphorus in the forest zone of south-western Nigeria show that classes 1, 2 and 3 for Bray 1 phosphorus soil test values may be within the "low", "medium" and "high" ratings, respectively. They showed that with Bray 1 extractant, a soil containing less than 3.0 mg kg^{-1} phosphorus is considered low, between 4 and 6 mg kg^{-1} is medium, and response is unlikely above 10 mg kg^{-1} phosphorus. They found that when Bray 1 phosphorus soil test gives less than 5 mg kg^{-1} phosphorus, rice, maize and cowpea will respond to phosphorus application particularly in the forest soils. Values of 6 to 10 mg kg^{-1} appear adequate for most crops. These results appear to be at variance with the reports of Sobulo and Adepetu (1987) who put the criteria for soil fertility classes in the south-western Nigeria using Bray 1 phosphorus as follows:

Low : <8 mg kg^{-1}

Medium: 8 - 20 mg kg^{-1}

High : >20 mg kg^{-1}

From these criteria it means that response classes 1 and 2 in the present study are within the "low" rating while class 3 is "medium" rating or higher. However, the

Table 35: Phosphorus soil test classes based on Cate-Nelson Analysis of Variance Method.

Soil test method	Class 1	Class 2	Class 3	Class 4
	Soil test value ($mg\ kg^{-1}$)	Soil test value ($mg\ kg^{-1}$)	Soil test value ($mg\ kg^{-1}$)	Soil test value ($mg\ kg^{-1}$)
Mehlich No. 1	<3.67	3.67 - 7.29	7.29 - 14.96	>14.96
Modified Mehlich No. 1	<4.09	4.09 - 6.36	6.36 - 12.14*	
Bray No. 1	<3.28	3.28 - 7.83	>7.83	
Mehlich No. 2	<8.24	8.24 - 13.20	13.20 - 17.91*	
Bray No. 2	<6.76	6.76 - 12.84	>12.84	

southern Guinea savanna ratings may differ from those of the forest zone. So, the above criteria may not be applicable here.

The Mitscherlich-Bray Equation

It has been shown that the Mitscherlich equation, with minor modifications, can be used successfully to describe the rate of growth associated with different levels of immobile available nutrients in the soil and different amounts of applied fertilizers (Bray, 1944; 1945; Melsted and Peck, 1980a). The approach reported by Melsted and Peck (1980a) is presented below:

It is assumed that every plant species has a finite growth possibility, A, when all nutrients and growth factors are adequate but not in harmful excess. Then, if y represents a yield when a nutrient, b, is something less than adequate, one can say that for every level of b there must be a corresponding yield, y, *or*

$$dy = db$$

But y can increase only to where $y = A$, so a limit is set on the possible changes in b within those values which are required to produce values of y which are always less than A. Therefore,

$$\frac{dy}{db} = c_1(A-y), \text{ and}$$

$$\frac{dy}{(A-y)} = dbC_1,$$

which can be shown to become

$$\log(A-y) = \log A - C_1 b,$$

the Bray modified form of the Mitscherlich equation, commonly referred to as the Mitscherlich-Bray equation or growth function.

This expression is sometimes referred to as the percent yield equation as it makes no difference whether absolute yields of A and y, or their percent relationship when A is 100% and y is given as a percent of A, are used in the above equation. In the present study relative yields will be used with A assigned 100%, y is the relative yield of the control plot or any percent sufficiency, b is the soil test value of the unfertilized plot and C_1 the correlation constant which relates nutrient level to percent yield.

Using the relative yields of maize from the control plots in the field fertilizer rate studies (Table 23) and the soil test values obtained by extracting soils from the unfertilized plots with the eight soil test methods (Table 22), the constant, C_1, in the Mitscherlich-Bray equation was calculated for each site and for each soil test method (Table 36). An average C_1 for maize which may be applied to a wide range of soil types and climatic conditions in the southern Guinea savanna was calculated for each soil test method (Table 36).

The correlation constants, C_1, for maize for the soils of the southern Guinea savanna are as follows:

Mehlich 1 - 0.047

Mehlich 2 - 0.040

Bray 1 - 0.056

Bray 2 - 0.048

Olsen's - 0.069

Modified Mehlich 1 - 0.045

Table 36: Fertilizer rate studies: Correlation constants, C_1, for maize in the southern Guinea savanna.

		Mehlich No.1	Mehlich No.2	Bray No.1	Bray No.2	Olsen's	Modified Mehlich No.1	Mississippi	AB-DTPA
Kuru	: 1988	-	-	-	-	-	-	-	-
	: 1989	-	-	-	-	-	-	-	-
Bokkos	: 1988	0.033	0.015	0.017	0.011	0.006	0.027	0.023	0.043
	: 1989	0.020	0.183	0.017	0.012	0.008	0.016	0.044	0.080
Sabon Gida	: 1988	0.028	0.017	0.074	0.018	0.014	0.030	0.097	0.093
	: 1989	0.029	0.018	0.039	0.042	0.034	0.031	0.102	0.051
Wamba	: 1988	0.028	0.024	0.035	0.022	0.027	0.031	0.136	0.160
	: 1989	0.041	0.030	0.051	0.034	0.058	0.037	0.185	0.204
Lamingа:	: 1988	0.037	0.017	0.028	0.035	0.074	0.034	0.448	0.082
	: 1989	0.047	0.068	0.097	0.055	0.074	0.058	0.429	0.281
Obi	: 1988	0.025	0.011	0.068	0.037	0.030	0.035	0.179	0.044
	: 1989	0.056	0.025	0.056	0.145	0.049	0.045	0.294	0.140
Ankpa	: 1988	0.105	0.044	0.084	0.068	0.145	0.067	0.434	0.217
	: 1989	0.061	0.053	0.076	0.039	0.102	0.047	0.306	0.153
Yandev	: 1988	0.067	0.038	0.058	0.043	0.056	0.096	0.263	0.286
	: 1989	0.036	0.030	0.029	0.039	0.033	0.027	0123	0.134
Katsina-Ala	: 1988	0.045	0.024	0.052	0.035	0.091	0.054	0.151	0.136
	: 1989	0.039	0.028	0.069	0.069	0.092	0.049	0.275	0.138
Ayangba	: 1988	0.102	0.054	0.102	0.105	0.272	0.080	0.628	0.408
Mean		0.047	0.040	0.056	0.048	0.069	0.045	0.242	0.156

Mississippi - 0.243

AB-DTPA - 0.156

Agboola and Corey (1975) obtained a C_1 value for Bray 1 of 0.053 for maize for the soils of south-western Nigeria. This is very close to the value of 0.056 obtained for Bray 1 in this study. Apart from Bray 1 no reports of C_1 values for maize have been made for the other soil test methods for Nigerian soils.

Arbitrary values of y or percent sufficiencies were selected to cover a full range of soil deficiencies and the corresponding values of b determined using the Mitscherlich-Bray equation. Table 37 shows these selected percent sufficiencies, y, from 10 to 100%, and the corresponding soil test values, b.

Rouse (1968) discovering the limitations of the use of descriptive terms such as "low", "medium" and "high" in soil test calibration proposed a combination of ratings defined in terms of relative yield and a Fertility Index which is expressed as percent sufficiency. He indicated that the use of relative yield as a basis for describing soil test calibration has the desirable connotation of indicating the expected yield without additions of the element relative to the maximum yield potential. Relative yield above 100% indicates the relative margin of adequacy or the nearness to an excessive level. Fertility Index is used to eliminate the need for a percentage sign on relative yield values. It is reported to the nearest multiple of 10 from 0 to 990 (Cope and Rouse, 1980). The Fertility Index can be related to the soil test rating and relative yield as shown in Table 38.

Based on Table 38, the soil test calibration data in Table 37 were arranged according to fertility ratings with corresponding fertilizer recommendations as in

Table 37: Phosphorus soil test values, corresponding percent sufficiencies and corresponding phosphorus fertilizer recommendations for the attainment of 93% sufficiency using (a) the extension of Mitscherlich-Bray equation, and (b) the graphical method.

Percent sufficiency, y [Relative yield without P addition (%)]	Soil Test Values (mg kg^{-1})								Fertilizer Recommendation, x (kg P_2O_5/ha)	
	Mehlich No.1	Mehlich No.2	Bray No. 1	Bray No. 2	Olsen's	Modified Mehlich No.1	Mississippi	AB-DTPA	Using Mitscherlich-Bray equation (x_1)	Using Graphical method (x_2)
10	0.98	1.15	0.82	0.96	0.67	1.02	0.19	0.29	79	100
15	1.51	1.78	1.27	1.48	1.03	1.58	0.29	0.45	77	95
20	2.06	2.43	1.73	2.02	1.41	2.16	0.40	0.62	76	90
25	2.66	3.13	2.23	2.60	1.81	2.78	0.51	0.80	74	85
30	3.30	3.88	2.77	3.23	2.25	3.44	0.64	0.99	71	80
35	3.98	4.72	3.34	3.90	2.71	4.16	0.77	1.19	69	75
40	4.72	5.55	3.96	4.63	3.22	4.93	0.91	1.41	67	69
45	5.53	6.50	4.64	5.42	3.77	5.78	1.07	1.66	64	64
50	6.40	7.53	5.38	6.27	4.36	6.69	1.24	1.92	61	59
55	7.38	8.68	6.20	7.23	5.03	7.71	1.43	2.21	58	54
60	8.47	9.95	7.11	8.29	5.77	8.84	1.64	2.54	54	49
65	9.70	11.40	8.14	9.50	6.61	10.13	1.88	2.90	50	44
70	11.13	13.08	9.34	10.90	7.58	11.62	2.15	3.33	45	39
75	12.81	15.05	10.75	12.54	8.72	13.38	2.48	3.83	40	33
80	14.87	17.48	12.48	14.56	10.13	15.53	2.88	4.45	33	28
85	17.53	20.60	14.71	17.17	11.94	18.31	3.39	5.25	24	25
90	21.28	25.0	17.86	20.83	14.49	22.22	4.12	6.37	11	18
93	24.57	28.88	20.63	24.06	16.74	25.67	4.77	7.40	0	15
100	42.55	50.00	35.71	41.67	28.99	44.44	8.26	12.82	0	8

* x_1 vs x_2 : r = 0.952*** t = 0.446 ns R^2 = 90.68% *** = P < 0.001

Table 38: Comparison of soil test rating, relative yield, fertility index, and recommendations based on soil tests (Cope and Rouse, 1980).

Soil test rating	Relative yield without nutrient (%)	Fertility index (% sufficiency)	Recommendations
Very low	<50	0 - 50	Large applications for soil building purposes.
Low	50 - 75	60 - 70	Annual application to produce maximum response and increase soil fertility
Medium	75 - 100	80 - 100	Normal annual application to produce maximum yields
High	100	110 - 200	Small applications to maintain soil level. Amount suggested may be doubled and applied in alternate years.

Table 44. This table gives better soil test ratings for the soils of the Southern Guinea savanna zone than Table 35 since it is based on higher percent sufficiency and it embraces a full range of nutrient sufficiencies.

The above fertilizer recommendations obtained from calibration data using the Mitscherlich-Bray equation or graphical method (Table 44) agree very well with those reported in Table 42 which were based on 90% sufficiency and on partitioning of soil test data using the analysis of variance method of Cate and Nelson (1971). The class 1 soils in Table 42 are rated very low (Table 44), and those of classes 2 and 3 rated low and medium, respectively. Since Table 44 includes soils rated high, and is calculated on a higher percent sufficiency, soil test data could be interpreted to farmers with this Table or Table 37 or the calibration curves.

4.2.4 Soil Test Interpretation

(a) Phosphorus fertilizer recommendation based on fertilizer rate studies

Early fertilizer work on maize in the savanna region was mainly on nitrogen and phosphorus. From these work, Goldworthy (1967) recommended 39 kg P_2O_5/ha as the optimal rate of phosphorus application for an expected average grain yield of 2000 to 2800 kg/ha in the northern Guinea savanna and 1500 to 2000 kg/ha in the southern Guinea. More recent work of Balasubramanian *et al.* (1980) reported that grain yield of maize increased significantly as fertility level rose from 22.5 to 45 kg P_2O_5/ha. Based on this the recommendation for maize in the savanna region was fixed at 40 kg P_2O_5/ha. However, from their data, significant yield increases were obtainable beyond 45 kg P_2O_5/ha and the full potential of improved maize cultivars should be exploited by increasing the fertilizer rates beyond 45 kg P_2O_5/ha. Work

on improved maize cultivars show responses to phosphorus additions up to 80 kg P_2O_5/ha (Balasubramanian *et al.*, 1978; Osiname, 1979).

In the present study, it was shown that responses of maize to phosphorus additions varied from site to site. Fig. 20 compares the yields of maize for the 19 site-years using a single maximum maize grain yield of 4348 kg/ha recorded at phosphorus addition of 100 kg P_2O_5/ha at Yandev (Table 24). From the relative yields it was seen that the best overall yields were recorded at 80 kg P_2O_5/ha. Table 39 gives the average percentage yields of maize at the various phosphorus additions. The highest mean relative yield of 92.68% was recorded at phosphorus addition of 80 kg/ha. Analysis of the responses to phosphorus additions (Tables 40 and 41) show that, of the 18 site-years, maximum yields were attained at 80 kg/ha in 9, while maximum yields were recorded at 100, 20, 40 and 60 kg P_2O_5/ha in 6, 3, 1 and none site-years, respectively. However, significant yield increases were recorded in 9, 5, 1 and 2 site-years only up to but not above phosphorus additions of 20, 40, 60 and 80 kg P_2O_5/ha, respectively. This shows that although yield increases were recorded with increase in phosphorus additions up to 80 kg P_2O_5/ha, and in few cases up to 100 kg P_2O_5/ha, the yield increases were hardly statistically significant above phosphorus additions of 40 kg P_2O_5/ha.

From the above analysis, there is obvious temptation to suggest for these soils phosphorus recommendation not exceeding 40 kg P_2O_5/ha. Considering, however, that none of the phosphorus rates less than 80 kg/ha recorded, on the average, up to 80% of the yield potentials of the soils (Table 39), and considering the fact that the improved maize cultivars currently in use are high nutrient demanding, it is

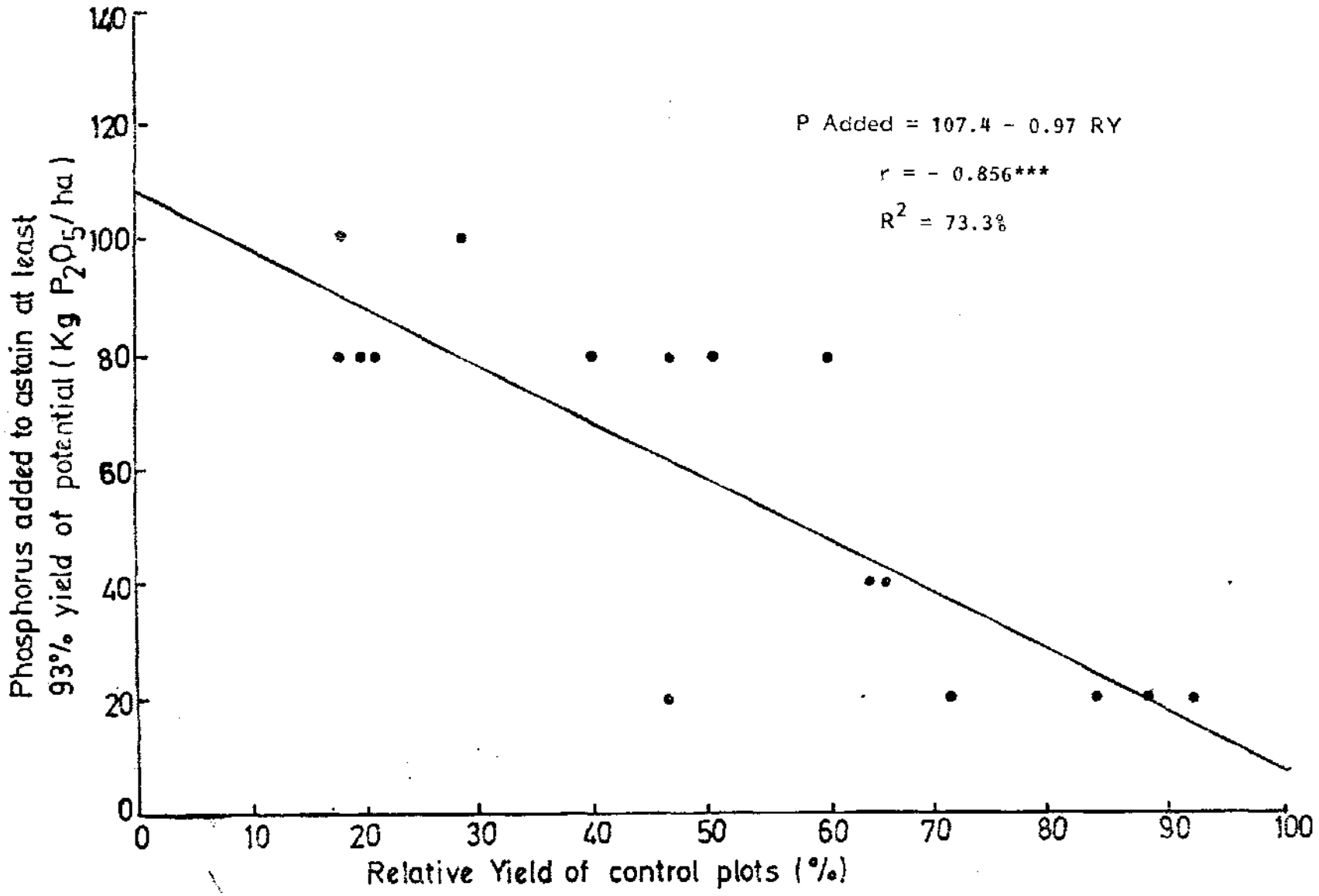


Fig. 20 Graph of relative yield of control Plots against phosphorus added to attain at least 93% of yield potential.

Table 39: Average percentage yields of maize at the various phosphorus additions.

P Addition (kg P_2O_5/ha)	Average percentage yield (%)
0	49.65 (44.43 if Kuru is added)
20	68.82
40	78.65
60	76.69
80	92.68
100	90.82

Table 40: Number of sites where maximum yields were recorded at the various phosphorus additions.

P Addition (kg P_2O_5/ha)	Number of Sites
20	3
40	1
60	none
80	9
100	6

Table 41: Number of sites where significant yield increases were recorded at the various P additions.

		P Addition (kg P_2O_5/ha)	Number of Sites
(a)	Significant up to but not above	20	9
(b)	Significant up to but not above	40	5
(c)	Significant up to but above	60	1
(d)	Significant up to but not above	80	2
(e)	Significant up to	100	1

suggested that phosphorus additions up to 80 kg P_2O_5/ha be recommended for improved maize varieties in the southern Guinea savanna. This is in agreement with the suggested rate for 120 day maize, irrigated maize and maize grown in wet areas of the northern States which is put at 75 kg P_2O_5/ha (FDA, 1980). However, Enwezor *et al.* (1989) put the general recommended rate for maize in the southern Guinea savanna at 50 kg P_2O_5/ha, and rate based on soil test for soils testing low at 60 kg P_2O_5/ha. These results agree with the results of a review of the various trials carried out between 1973 and 1976 and between 1983 and 1986 in the savanna region which showed that 50 to 60 kg P_2O_5/ha is required for optimum maize yield (Lombin, 1987).

(b) Phosphorus fertilizer recommendation based on critical levels

The critical levels of phosphorus for all the soil test methods investigated were obtained at a relative yield of about 62.5% (range of 61 to 64%). From the relative yield of the control plots it was found that soils with less than 70% of maximum yield responded significantly to phosphorus fertiliza-tion. Agboola and Obigbesan (1974) had reported in a study carried out in soils of the south-western Nigeria that response to phosphorus fertilization was certain below 80% of maximum yield.

Fig. 20 is the graph of relative yields of maize for the control plots against phosphorus added to the soils to attain a minimum yield potential of 93% (Table 23). From the graph it was found that at a relative yield of 62.5% the soils required phosphorus additions of 46 kg P_2O_5/ha to attain 93% or more of their yield potentials. This figure is very close to the observed value of 40 kg P_2O_5/ha.

The critical level partitions soils into two response classes - those whose phosphorus soil test values are above and those below critical levels. Based on this partition, only two fertilizer rates could be recommended, one for soils whose soil test values are below the critical level and the other for soils whose soil test values are above the critical level. From the present study it is recommended that soils whose soil test values are above the critical level should receive phosphorus fertilizer additions of 40 kg P_2O_5/ha. Those with soil test values below the critical level should receive the full dose of 80 kg P_2O_5/ha.

Barber (1980) explained that the philosophy of fertiliza-tion with limited information is to add a uniform amount of fertilizer when the test is below the critical value and not to add fertilizer when it is above this value. He indicated that this is one step beyond not using a soil test and fertilizing all cases just to be sure a deficiency does not occur. Based on the relative yield for which the critical levels of soil tests were obtained in this study, and the fact that responses of maize to fertilization were obtained at some levels above the critical level, not recommending fertilizers for some soils whose soil test values are above the critical levels determined in this study may not be appropriate. Cope and Evans (1985) stressed that "critical level" does not identify the level above which fertilization is not needed. Labhsetwar and Soltanpour (1985) determined in a greenhouse study the critical level of AB-DTPA phosphorus for soils of Colorado using alfalfa as the test crop. They showed that high probability of response may be expected below the critical level and low probability of response above this level. Their results indicate that yield responses to fertilization are probable above critical levels and to ensure security such soils should be fertilized for maximum production.

(c) Phosphorus fertilizer recommendation based on soil test classes

1. Mehlich No. 1

From the field fertilizer rate studies it was observed that soils in class 4 needed 20 kg P_2O_5/ha to attain over 95% of their maximum yield potential. For soils of this class, therefore, phosphorus addition of 20 kg/ha is adequate. The soils in class 3 required varying amounts of phosphorus, from 20 to 100 kg P_2O_5/ha to attain maximum yield. However, all the soils in this class required 40 kg P_2O_5/ha to attain 90% and above of their yield potentials. Soils in class 2 required 80 kg P_2O_5/ha while those in class 1 required varying amounts of phosphorus, ranging from 60 (one soil) to 100 kg P_2O_5/ha. In general, however, the soils in this class required 80 to 100 P_2O_5/ha to attain over 90% of their yield potentials.

2. Modified Mehlich No. 1

From the field fertilizer rate studies it was observed that class 3 soils required 20 to 40 kg P_2O_5/ha to attain over 90% of their yield potentials. Class 2 soils required phosphorus addition of 80 kg P_2O_5/ha, while class 1 soils required 80 - 100 kg P_2O_5/ha to attain 90% or above of their maximum yield potentials.

3. Bray No. 1

From the field fertilizer rate studies the class 3 soils required phosphorus addition of 20 to 40 kg P_2O_5/ha, class 2 80 kg P_2O_5/ha, and class 1 80 to 100 kg P_2O_5/ha to attain 90% and above of their maximum yield potentials.

4. Mehlich No.2

From the amounts of added fertilizers required by the soils to attain 90% or more of their yield potentials it was found that class 3 soils required 20 to 40 kg P_2O_5/ha, class 2 soils required 80 kg P_2O_5/ha although a few like Katsina-Ala 88 and Laminga 89 required much less than this amount, and class 1 soils required 80 to 100 kg P_2O_5/ha.

5. Bray No. 2

From the fertilizer rate studies the amounts of added phosphorus fertilizers required by the soils to attain 90% or more of their yield potentials were:

Class 3 - 20 - 40 kg P_2O_5/ha

Class 2 - not well defined

Class 1 - 80 - 100 kg P_2O_5/ha

6. Olsen's methods

From the fertilizer rate studies it was found that the Olsen's method did not effectively separate the soils according to the amount of fertilizers required for each class to attain a specific level of yield potential.

7. Mississipi

With the exception of Bokkos soils which required 60 to 100 kg P_2O_5/ha, the class 2 soils required phosphorus addition of 20 to 40 kg P_2O_5/ha to attain 90% or more of their maximum yield potentials. Class 1 soils required 80 to 100 kg P_2O_5/ha.

8. AB-DTPA

The soils of class 2 required phosphorus addition of 20 to 40 kg P_2O_5/ha to attain 90% or more of their maximum yield potentials. There were soils grouped in

class 1 that required 20 to 60 kg P_2O_5/ha. However, most of the soils required phosphorus addition of 80 - 100 kg P_2O_5/ha.

Table 42 is a summary of the amount of phosphorus required by the soils of the various classes to attain 90% or more of their yield potentials. The soil test methods are in good agreement on the amount of phosphorus needed by each class for the optimal production of maize in the southern Guinea savanna agro-ecological zone.

Phosphorus fertilizer requirements of maize at different soil test classes in the south-western Nigeria have been put as follows (Adepetu, 1986):

Phosphorus soil test value ($mg\ kg^{-1}$)	Phosphorus fertilizer recommendation (kg P_2O_5/ha)
0 - 8	120 - 70
8 - 15	70 - 45
15 - 20	45 - 25

These results are in good agreement with the results of the present study which showed that soils that belong to the class 1 soil test rating required 100 to 80 kg P_2O_5/ha to attain their maximum yield potentials. Class 2 soils required about 80 kg P_2O_5/ha while class 3 soils required 40 to 20 kg P_2O_5/ha. However, Chiezey *et al.* (1990) presented results of work done in the southern Guinea savanna which put the phosphorus fertilizer recommendations for maize as follows:

Low - 50 kg P_2O_5/ha

Medium - 25 - 35 kg P_2O_5/ha

High - 0 - 15 kg P_2O_5/ha

It is possible that the reports of Chiezey *et al.* (1990) which were based on review of work done in the savanna between 1973 and 1976 and between 1983 and 1986

Table 42: Phosphorus required by the soil test classes to attain 90% or more of maximum yield.

Soil test method	Class 1		Class 2		Class 3		Class 4	
	Soil test value (mg kg^{-1})	P required (kg P_2O_5/ha)	Soil test value (mg kg^{-1})	P required (kg P_2O_5/ha)	Soil test value (mg kg^{-1})	P required (kg P_2O_5/ha)	Soil test value (mg kg^{-1})	P required (kg P_2O_5/ha)
Mehlich No. 1	<3.67	80 - 100	3.67 - 7.29	80	7.29 - 14.96	40	>14.96	20
Modified Mehlich No. 1	<4.09	80 - 100	4.09 - 6.36	80	6.36 - 12.14*	20 - 40		
Bray No. 1	<3.28	80 - 100	3.28 - 7.83	80	>7.83	20 - 40		
Mehlich No. 2	<8.24	80 - 100	8.24 - 13.20	80	13.20 - 17.91*	20 - 40		
Bray No. 2	<6.76	80 - 100	6.76 - 12.84	?	>12.84	20 - 40		

were based mostly on relatively low yielding maize cultivars. It is expected that high yielding cultivars would require greater amounts of phosphorus fertilizers at the low and medium phosphorus fertility ratings.

Fertilizer recommendations based on critical levels and soil test classes may lump together soils that differ in their nutrient needs. To avoid this the soil test values can be partitioned into many more groups. Alternatively regression equations could be used to obtain an infinite number of categories (Barber, 1980).

(d) Phosphorus fertilizer recommendation based on the Mitscherlich-BrayEquation

The Mitscherlich-Bray growth function can be expanded to permit the calculation of the amount of fertilizer needed to raise to any other desired upper level for which fertilization is desired (Melsted and Peck, 1980a). The function now takes the form:

$$\text{Log}(A\text{-}y) = \text{Log}A - C_1b - Cx$$

where C is the efficiency factor for the method of applying the fertilizer, and x is the quantity of fertilizer that needs to be applied.

The efficiency factor, C, for the band applied phosphorus fertilizer in the field fertilizer rate studies was calculated for each site and for each soil test method (Table 43). The mean C values calculated for each of the soil test methods were nearly constant. Rashid *et al.* (1991) had reported an acceptable degree of constancy of C values for various soil test methods. The C values were then averaged to give a C value of 0.014 which is the efficiency factor for band applied phosphorus fertilizer for the soils of the southern Guinea savanna.

From the fertilizer rate studies, it was found that the best rate of phosphorus for maize in the soils of the southern Guinea savanna was 80 kg P_2O_5/ha. This rate

Table 43: Efficiency factor, C, for the method used for the fertilizer application.

		Mehlich No.1	Mehlich No.2	Bray No.1	Bray No.2	Olsen's	Modified Mehlich No.1	Mississippi	AB-DTPA
Kuru	: 1988	-	-	-	-	-	-	-	-
	: 1989	-	-	-	-	-	-	-	-
Bokkos	: 1988	0.004	0.003	0.002	0.001	-0.006	0.004	-0.006	0.002
	: 1989	0.017	0.024	0.014	0.011	-0.003	0.016	0.006	0.018
Sabon Gida	: 1988	0.003	0.022	0.024	0.022	0.019	0.023	0.022	0.023
	: 1989	0.015	0.014	0.015	0.016	0.014	0.015	0.014	0.013
Wamba	: 1988	0.017	0.017	0.017	0.013	0.011	0.018	0.016	0.022
	: 1989	0.019	0.018	0.019	0.018	0.019	0.019	0.018	0.021
Laminga:	: 1988	0.022	0.019	0.020	0.021	0.023	0.021	0.024	0.020
	: 1989	0.001	0.005	0.005	0.002	0.001	0.003	0.005	0.005
Obi	: 1988	0.023	0.021	0.024	0.024	0.023	0.024	0.024	0.021
	: 1989	0.005	0.004	0.005	0.006	0.004	0005	0.005	0.005
Ankpa	: 1988	0.023	0.020	0.022	0.021	0.023	0.022	0.022	0.021
	: 1989	0.022	0.022	0.022	0.020	0.022	0.021	0.022	0.021
Yandev	: 1988	0.005	0.001	0.002	0.001	0.000	0.007	0.003	0.006
	: 1989	0.018	0.018	0.014	0.018	0.013	0.016	0.014	0.018
Katsina-Ala	: 1988	0.015	0.012	0.014	0.013	0.016	0.015	0.013	0.014
	: 1989	0.021	0.020	0.022	0.023	0.022	0.022	0.022	0.021
Ayangba	: 1988	0.004	0.002	0.004	0.005	0.006	0.003	0.005	0.005
Mean		0.014	0.014	0.016	0.014	0.012	0.015	0.013	0.015

Average Mean = 0.014, = C

produced the best overall yields which averaged about 93% of the yield potentials of the soils. Since maize response to added phosphorus in these studies was not significant beyond 70% sufficiency, three upper levels of percentage yield, namely, 90, 93 and 100%, were compared to determine the best upper level of sufficiency for calibration. In this connection, the amounts of phosphorus fertilizer required by each of the soils to attain 90, 93 and 100% of its yield potential were evaluated from Table 23. Linear regression analysis was carried out between the relative yields of the control plots as independent variable and the amounts of added phosphorus fertilizer required to raise the yields of maize to 90, 93 and 100% of the yield potentials of the soils, respectively, as dependent variable. The linear correlation coefficients, *r*, obtained were -0.789 (R^2 = 62.3%), -0.856 (R^2 = 73.3%), and -0.806 (R^2 = 65.0%) for 90, 93 and 100% upper yield levels, respectively. From these results, it was shown that 93% upper yield level was the best with the best predictive value of 73.3%. So, 93% relative yield was chosen as the upper sufficiency level for the calculation of the amount of phosphorus fertilizer needed to raise the relative yields of maize from the selected lower levels in Table 37 to this upper level.

Table 37 shows the phosphorus fertilizer recommendations for each soil test value calculated using the expanded form of the Mitschelich-Bray growth function. From these results it was observed that the phosphorus recommended to raise the percent yield of maize from 10%, which is much lower than the lowest relative yield of any of the control plots in these studies (except Kuru), to 93% of the yield potentials of the soils is 79 kg P_2O_5/ha. This figure agrees with the observed figure of 80 kg P_2O_5/ha recorded in the field trials.

Figures 21 to 25 are the calibration curves between soil test values and the corresponding fertilizer recommendations. Since the percent sufficiencies were carefully selected, Table 37 or the calibration curves (graphs) could be conveniently used to interpret soil test values to farmers (Melsted and Peck, 1980a; Adepetu and Olufokunbi, 1987; Sobulo and Adepetu, 1987).

(e) Phosphorus fertilizer recommendation based on the Graphical Method

The use of response equations and detailed calculations for individual samples has generally been considered unjustified because the entire process of sampling and analysing soil samples and interpreting the data involves a series of approximations (Cope and Evans, 1985). Soil test interpretation by graphical method is considered satisfactory and less cumbersome. This method was used in addition for the calibration and interpretation of soil test data against the responses of maize to phosphorus fertilization.

To be able to interprete soil test data by the graphical method three sets of plots were required:

(a) plot of relative yields of control plots against the amounts of added phosphorus fertilizer required to raise the yield of maize to 93% of the maximum potential of the soil (Fig. 21);

(b) plot of relative yield of the control plots against corresponding soil test values for each soil test method (Figs. 26 to 30); and

(c) plot of added phosphorus fertilizers in (a) against soil test values for each soil test method (Figs. 31 to 35).

From these plots, phosphorus fertilizers recommended for the various soil test values for each soil test method from an initial value without phosphorus

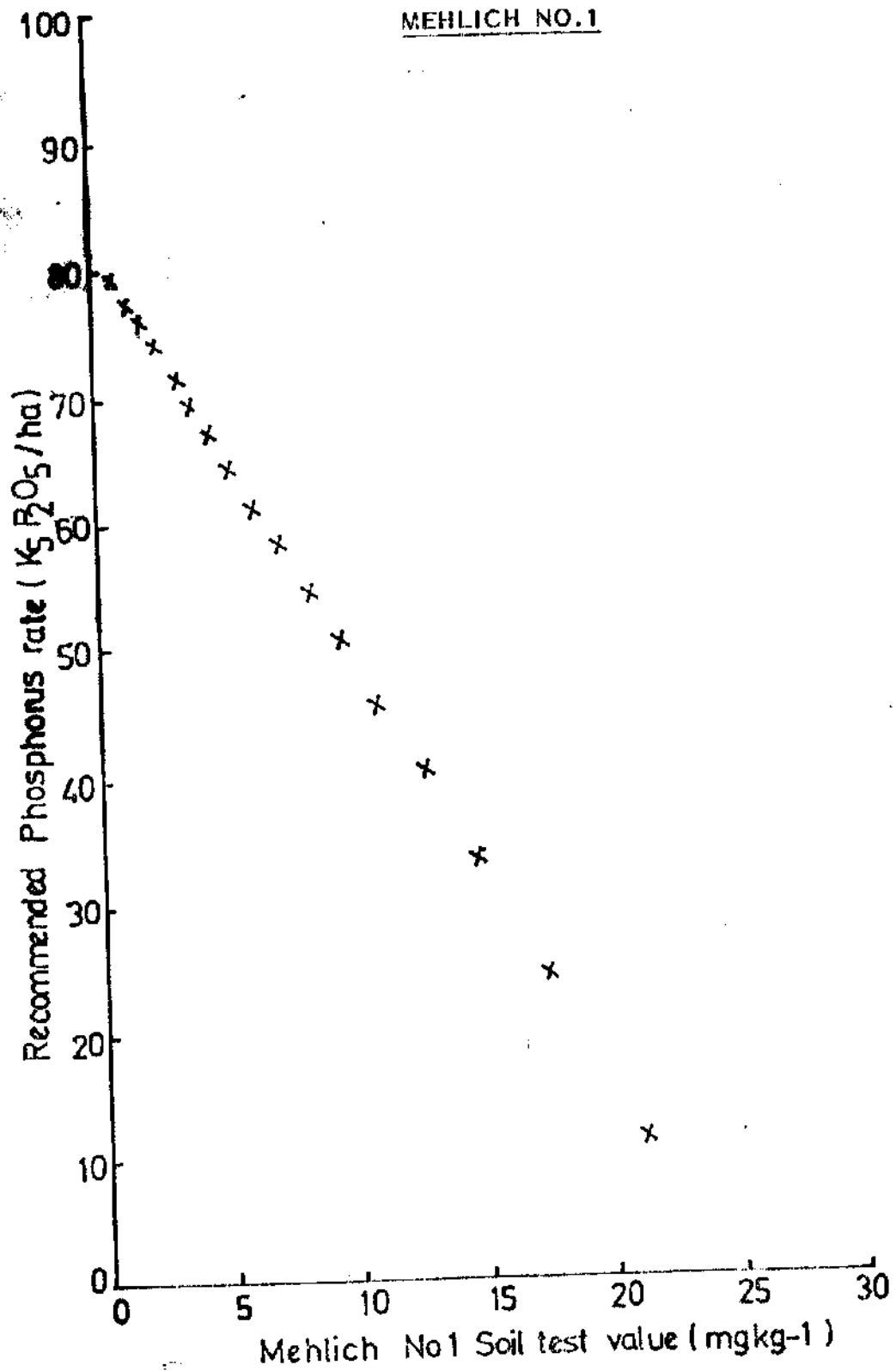


Fig. 21. Calibration curve for Mehlich No.1 using Mitscherlich-Bray equation.

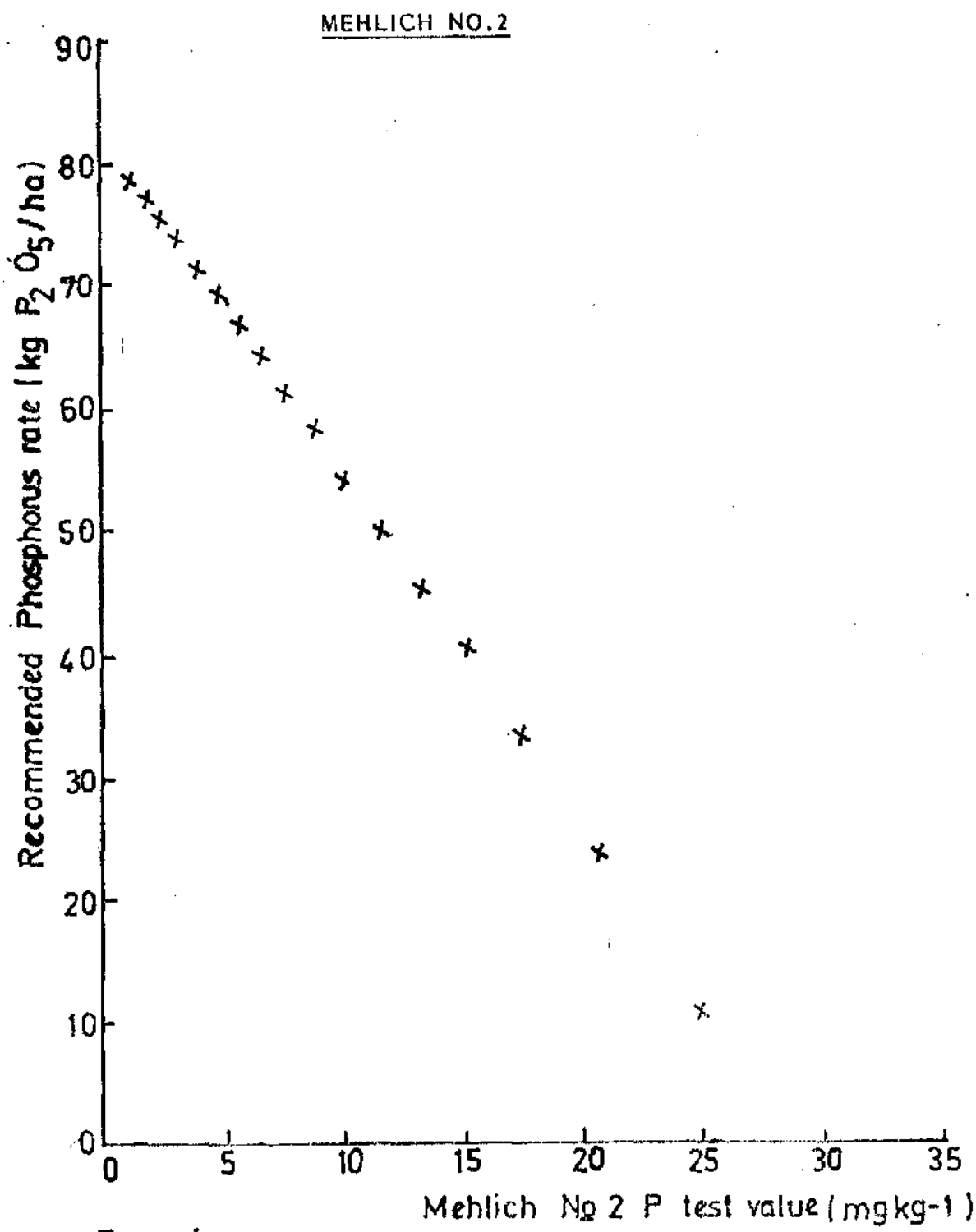


Fig. 22 : Calibration curve for Mehlich No.2 using Mitscherlich-Bray equation.

BRAY NO.1

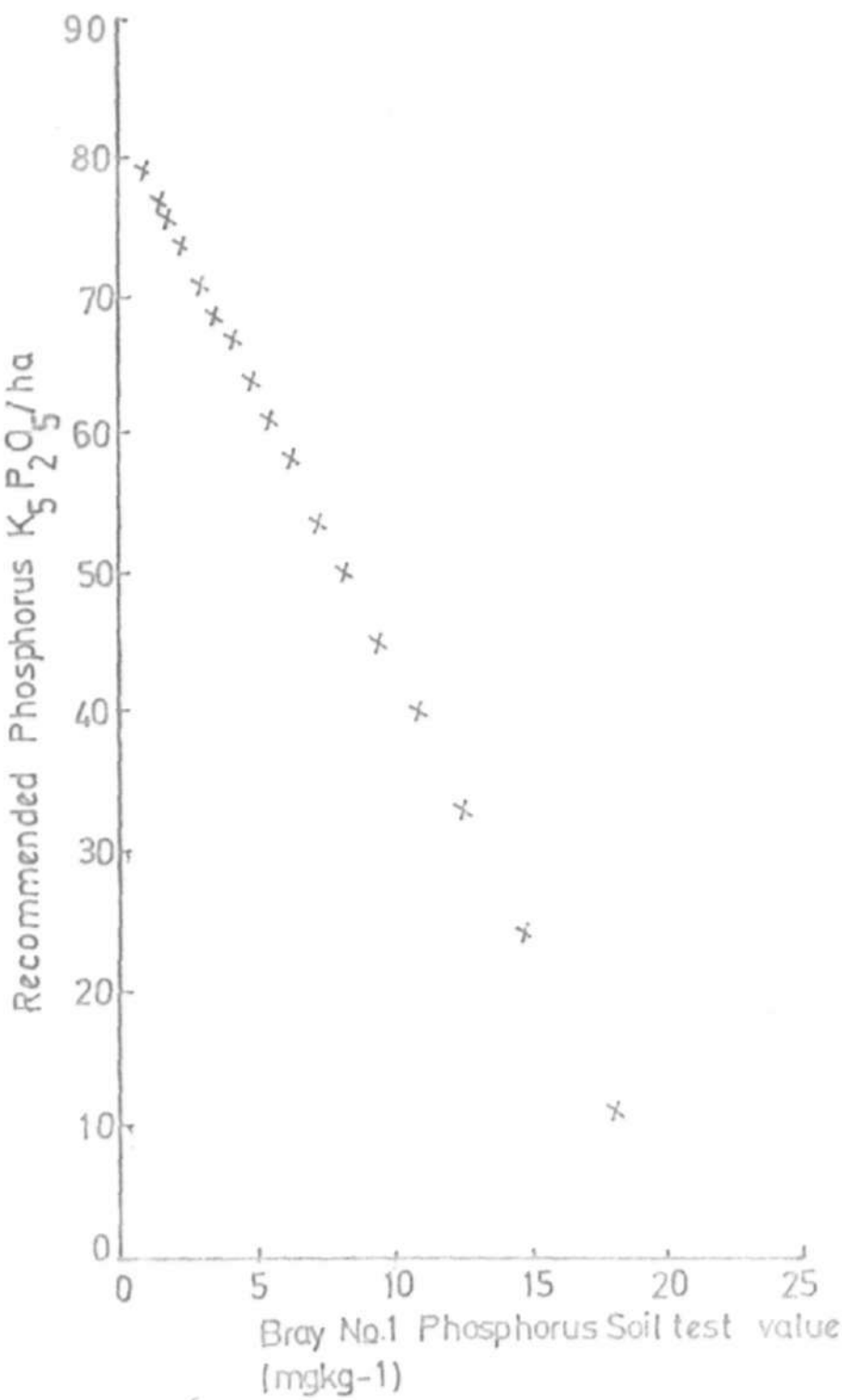


Fig. 23 : Calibration curve for Bray No.1 using Mitscherlich-Bray equation.

BRAY NO: 2

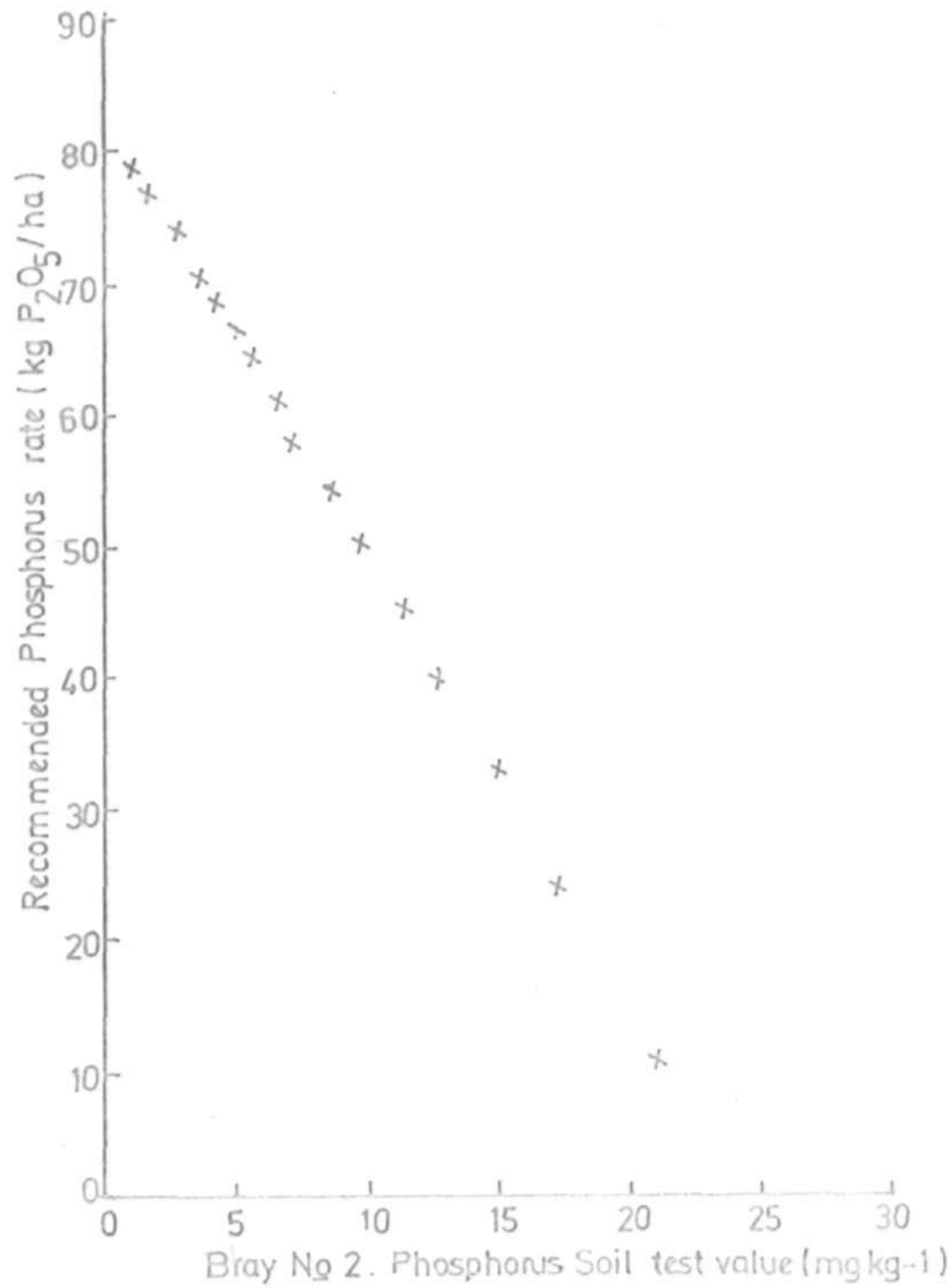


Fig.24. Calibration curve for Bray No.2 using Mitscherlich-Bray equation.

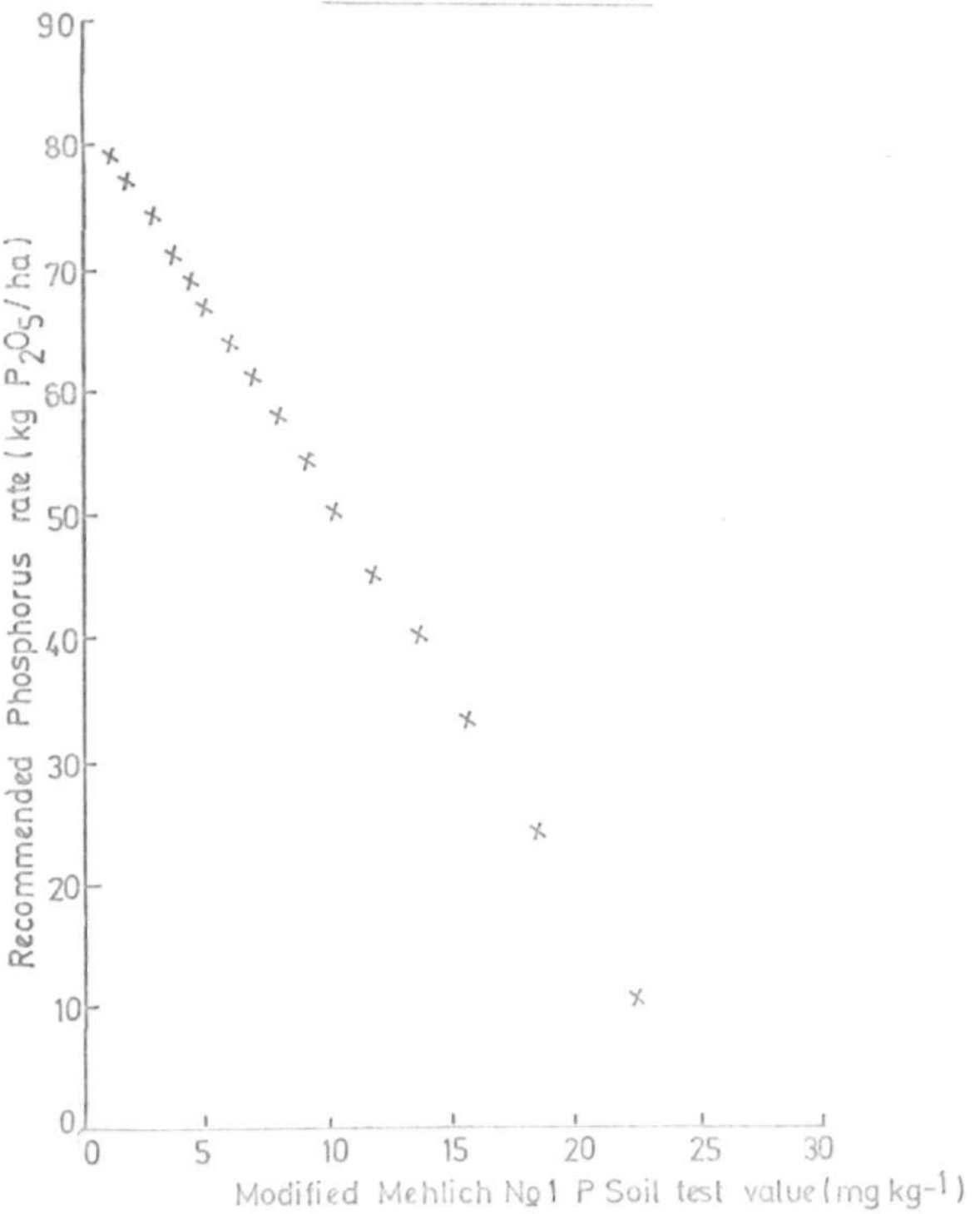


Fig.25 : Calibration curve for Modified Mehlich No.1 using Mitscherlich-Bray equation.

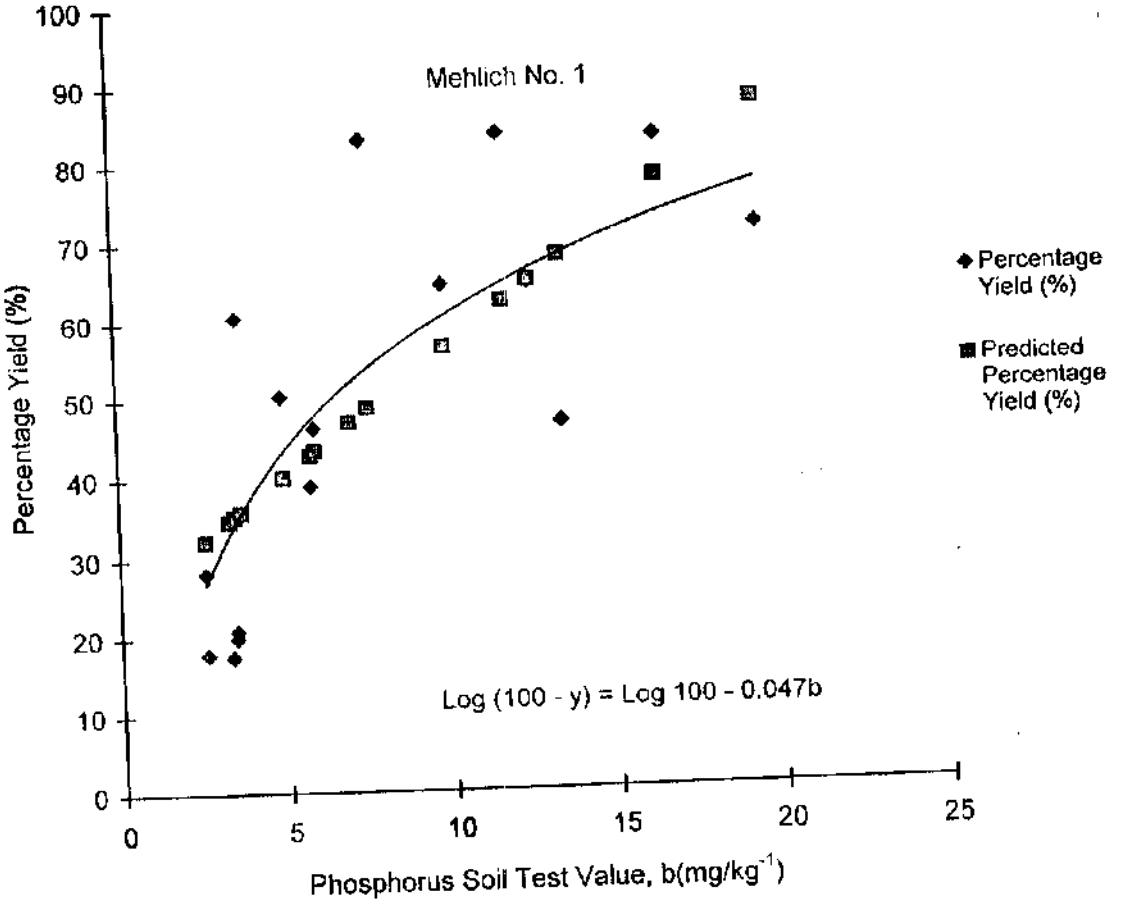


Fig. 26: Graph of Mehlich No. 1 Extractable phosphorus versus percentage yield.

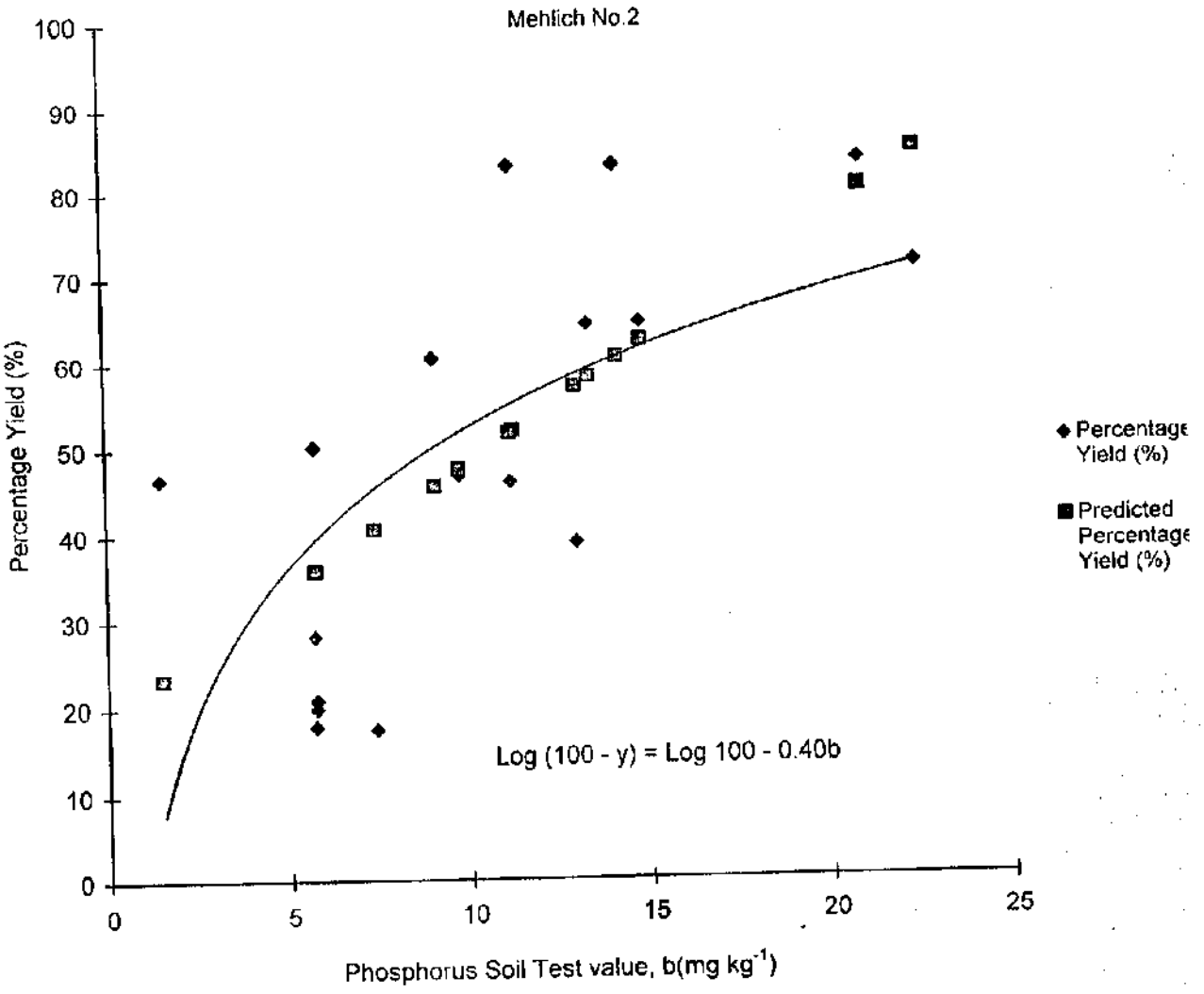


Fig. 27: Graph of Mehlich No. 2 Extractable Phosphorus Versus Percentage Yield.

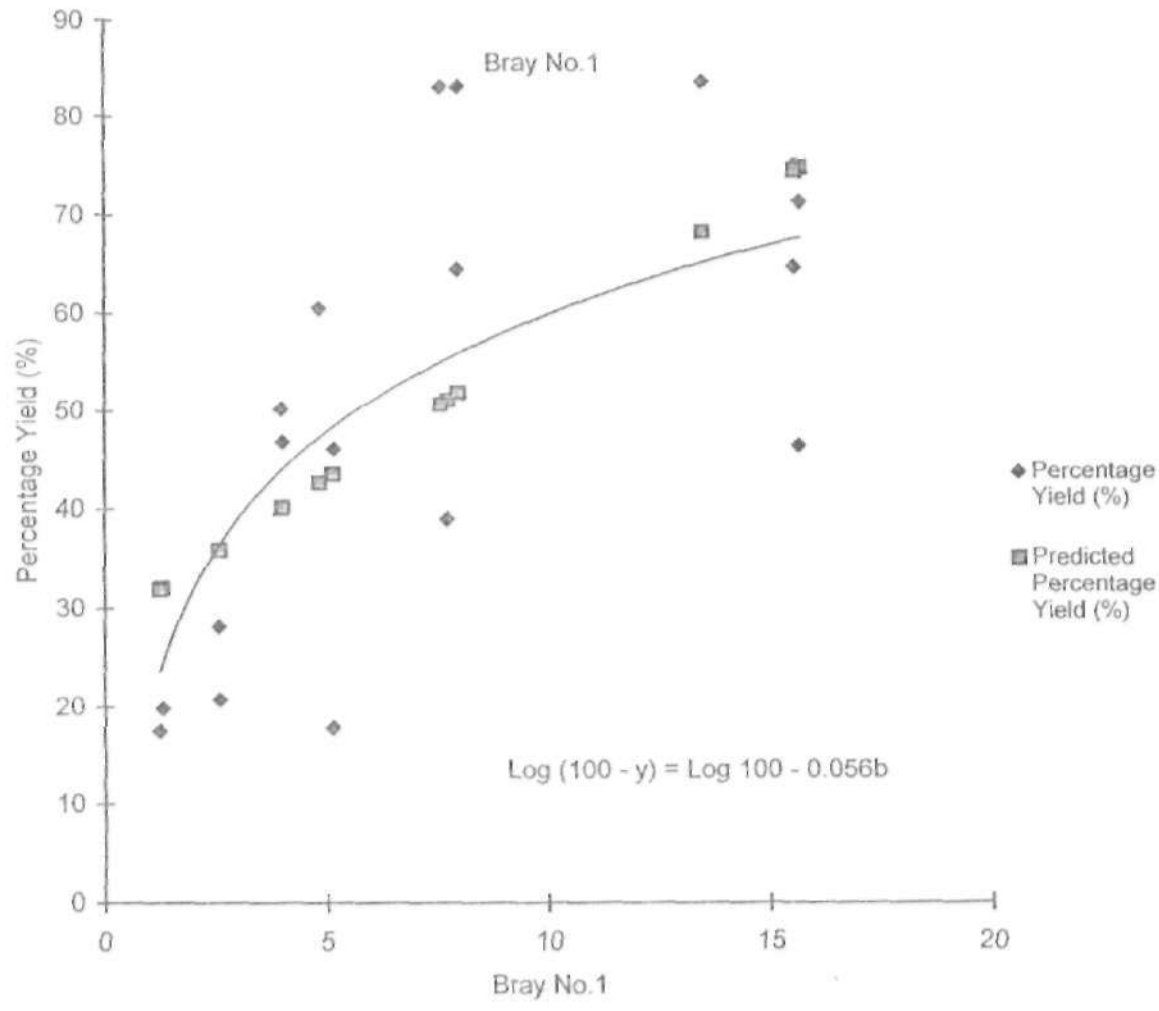


Fig. 28: Graph of Bray No. 1 Extractable Phosphorus Versus Percentage Yield.

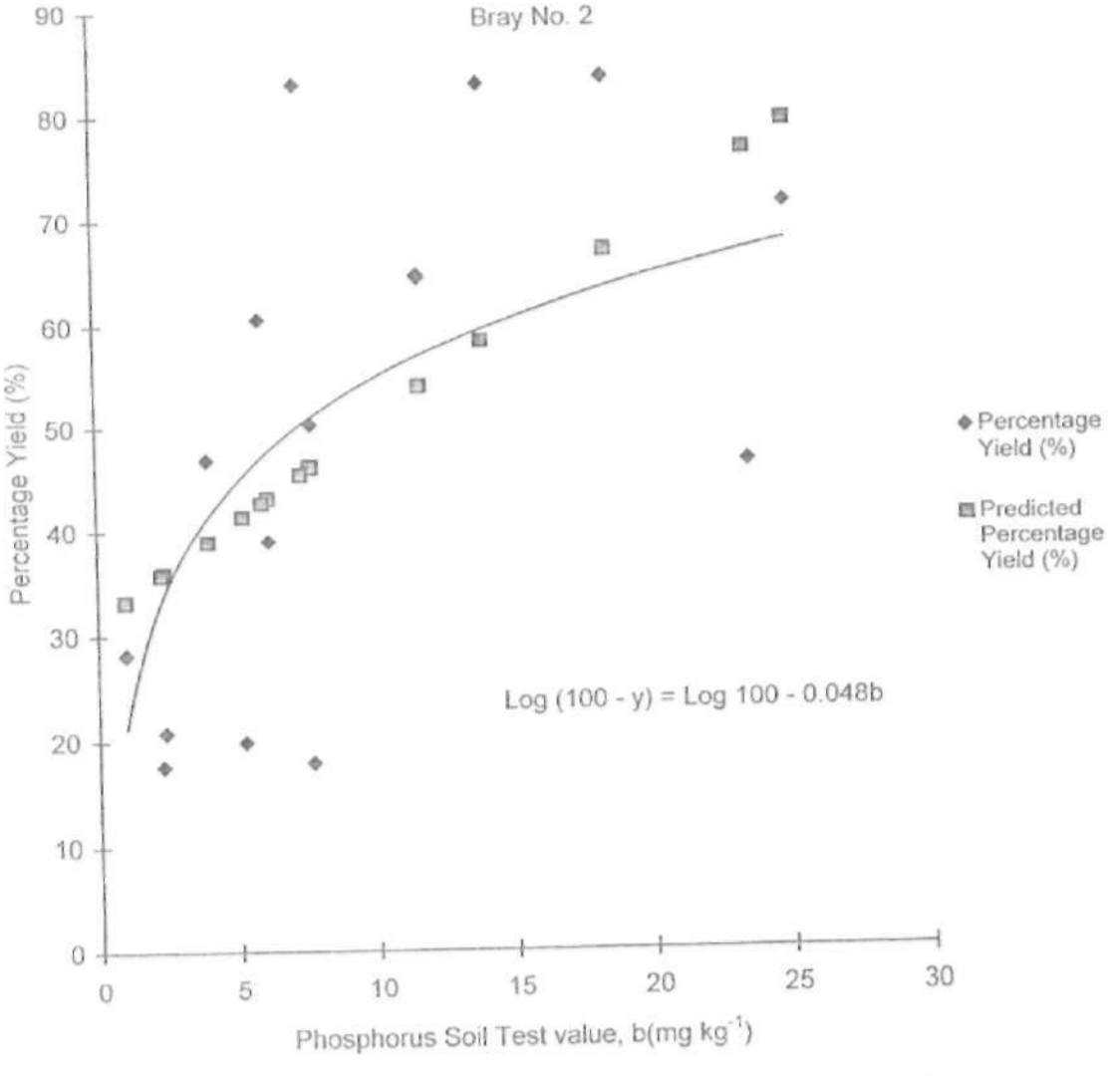


Fig. 29: Graph of Bray No. 2 Extractable Phosphorus Versus Percentage Yield.

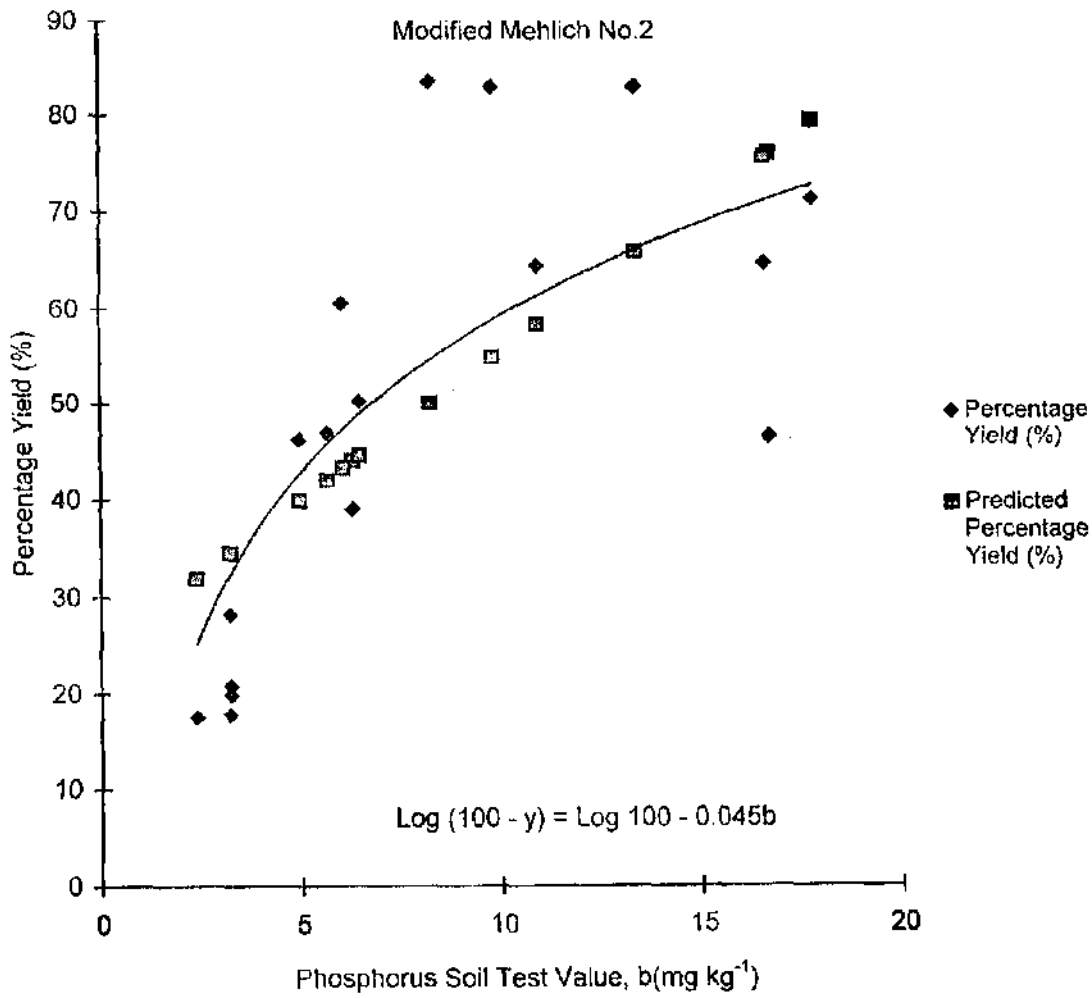


Fig. 30: Graph of Modified Mehlich No. 2 Extractable Phosphorus verus Percentage Yield.

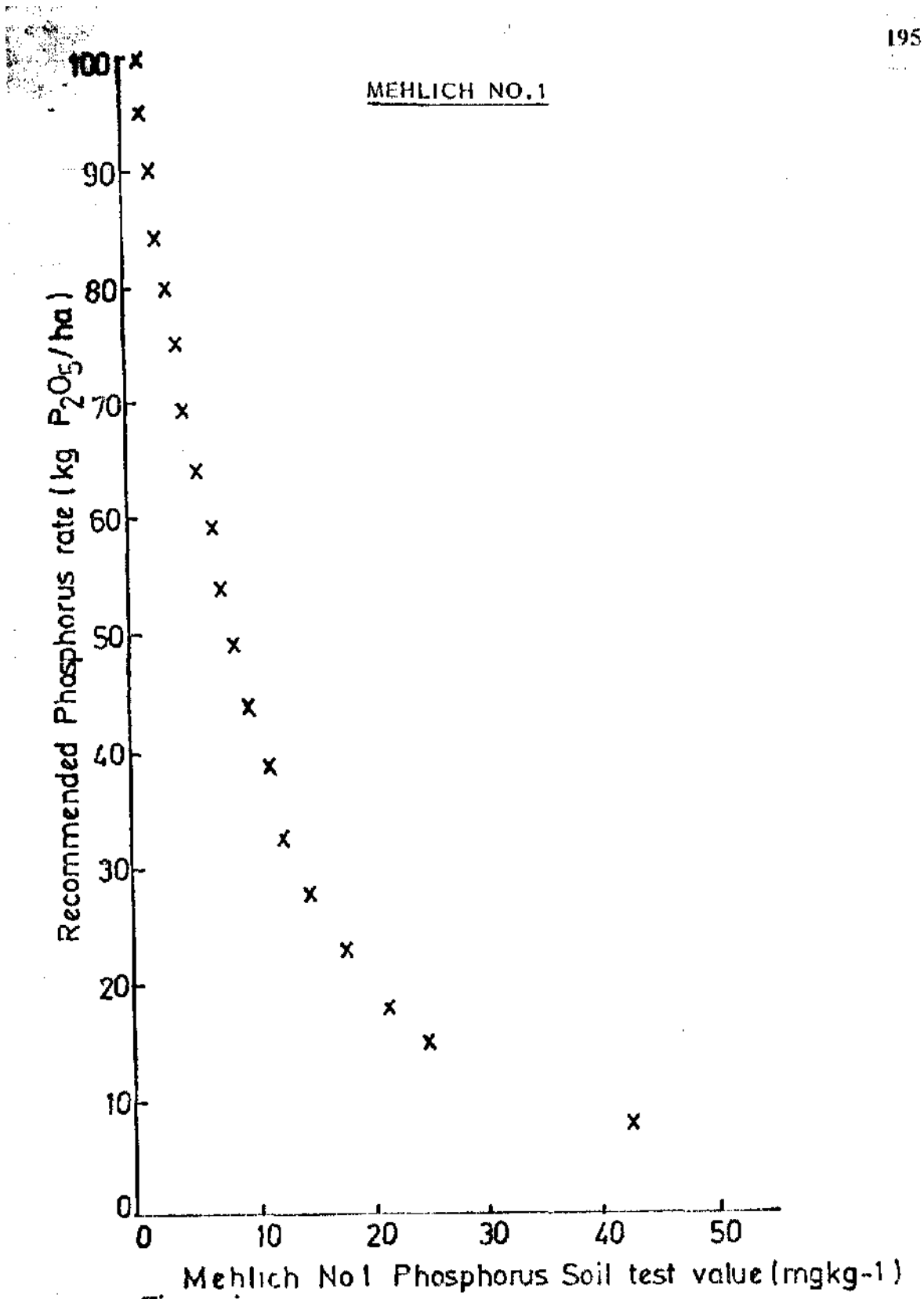


Fig. 31 : Calibration curve for Mehlich No.1 using the graphical method.

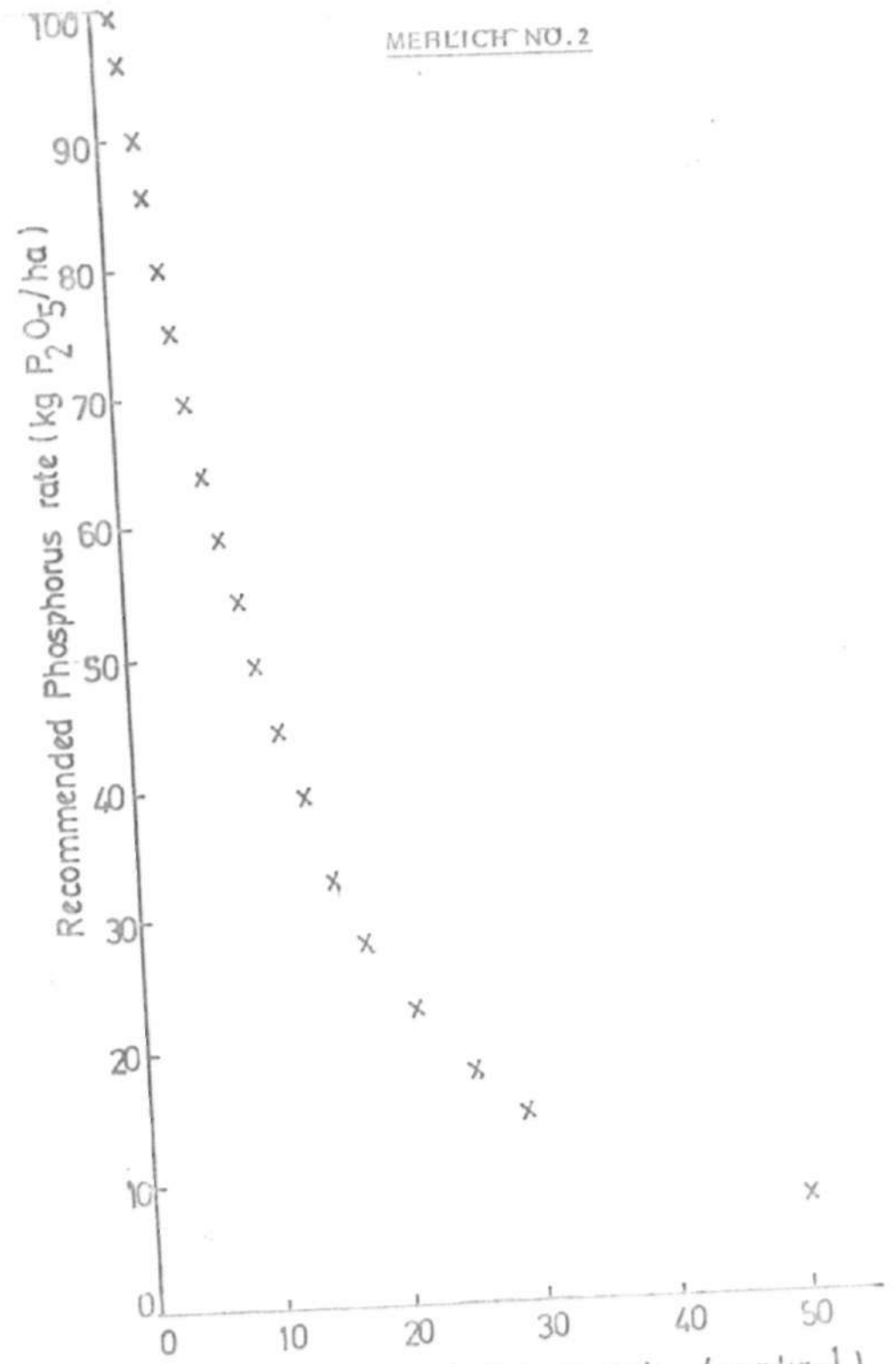


Fig. 32: Calibration curve for Mehlich No.2 using the graphical Method.

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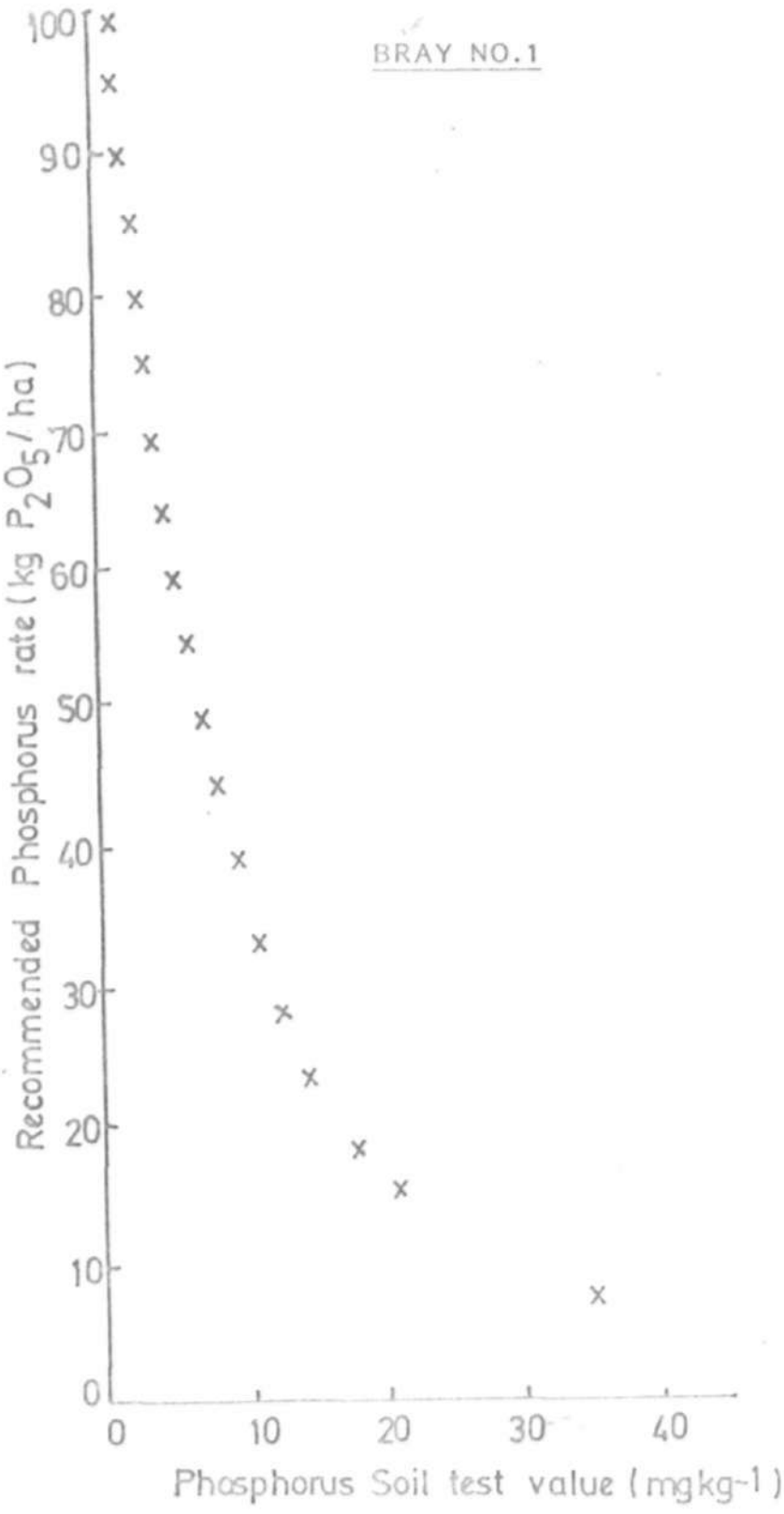


Fig. 33 : Calibration curve for Bray No.1 using the graphical method.

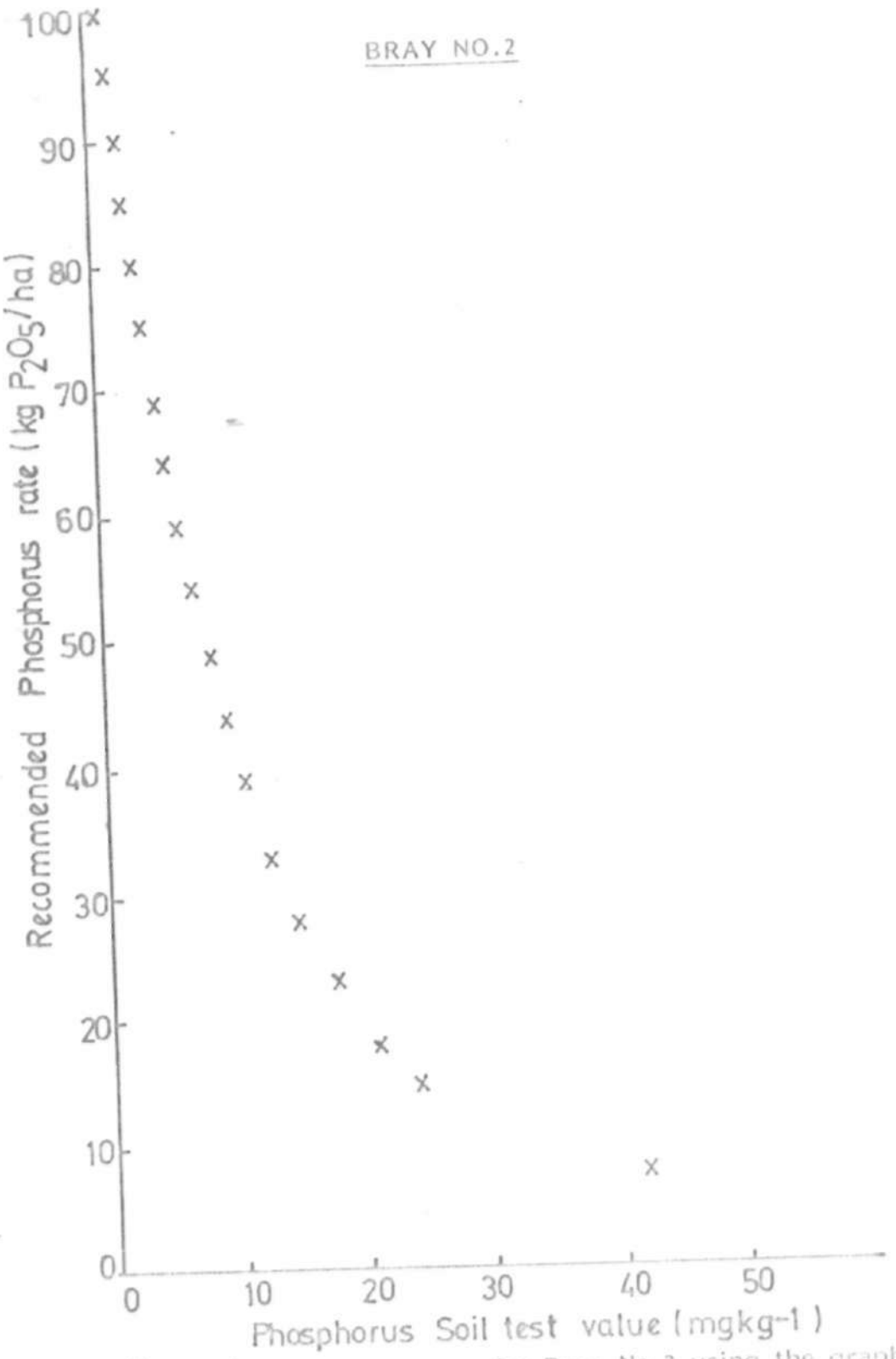


Fig. 34: Calibration curve for Bray No.2 using the graphical method.

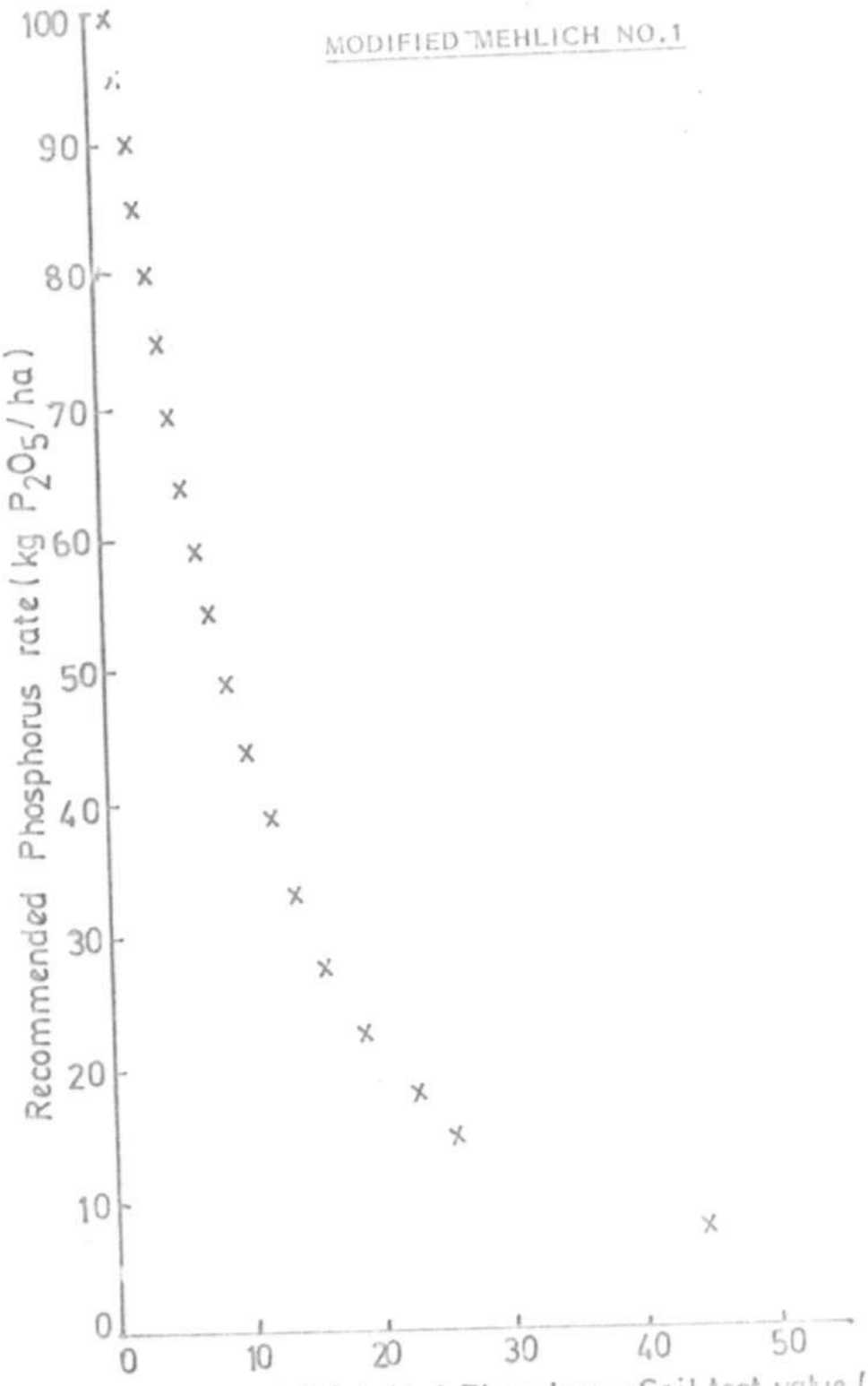


Fig. 35: Calibration curve for modified Mehlich No.1 using the graphical method.

addition to 100% upper level of sufficiency were evaluated. The results are shown in Table 37. The results show that between 80 and 100 kg P_2O_5/ha were needed by soils that yielded 30% or less of their maximum potentials without phosphorus fertilization. For soils that recorded between 35 and 50%, and above 70% relative yields, phosphorus requirements were between 75 and 60, and below 40 kg P_2O_5/ha, respectively. Figures 31 to 35 are the calibration curves for Mehlich 1, Mehlich 2, Bray 1, Bray 2 and Modified Mehlich 1 soil test methods, respectively.

Comparison of Results from Mitscherlich-Bray Equation and Graphical Method

From Table 37 it is shown that phosphorus fertilizers recommended at various soil test levels using the Mitscherlich-Bray equation and graphical methods differed at low soil test values or where the control plots yielded less than 40% of the maximum potentials of the soils, and also at high soil test values where the control plots yielded more than 85%. Between 40 and 85% relative yields the two methods agree very well in amounts of phosphorus recommended. At the lower range of 10 to 40%, the phosphorus recommended through the graphical method was higher to the tune of between 21 and 2 kg P_2O_5/ha. Between 50 and 85%, the recommendations by the Mitscherlich-Bray equation were higher to the tune of 1 to 7 kg P_2O_5/ha. For soils with very low soil test values corresponding to less than 35% sufficiency any of the methods could be used depending on what the farmer wishes to achieve. Since losses to the grower from use of too little fertilizer are normally greater than from the use of more than is needed, recommendations should be higher than are indicated by response data. This extra quantity is recommended as a safety factor against inaccuracies that may be involved in sampling, analysis, and interpretation and to maintain "high" fertility (Cope and

Rouse, 1980). In the present study it was found from the response data that the best overall yields were recorded at fertilizer rate of 80 kg P_2O_5/ha. Although yield depressions occurred in some soils at phosphorus rates higher than 80 kg P_2O_5/ha, this was mostly in soils that yielded more than 35% of their maximum potentials without phosphorus fertilization (Table 23). At higher soil test values corresponding to 40 to 90% sufficiencies, phosphorus recommendations obtained with any of the two methods could be used for similar effects. In general, the two methods agree on amounts of phosphorus fertilizer recommended for the various soil test levels. This is confirmed by the coefficient of determination, R^2, which gave a predictive value of 90.67% and by linear correlation coefficient ($r = 0.952$) which is significant at $P < 0.001$, and the result of t-test ($t = 0.446$) which is not significant.

Based on Table 38, the soil test calibration data in Table 37 were arranged according to fertility ratings with corresponding fertilizer recommendations as in Table 44. This table gives better soil test ratings than Table 35 since it is based on higher percent sufficiency and it embraces a full range of nutrient sufficiencies.

The above fertilizer recommendations obtained from calibration data using the Mitscherlich-Bray equation or graphical method (Table 44) agree very well with those reported in Table 42 which were based on 90% sufficiency and on partitioning of soil test data using the analysis of variance method of Cate and Nelson (1971). The class 1 soils in Table 42 are rated very low (Table 44), and those of classes 2 and 3 rated low and medium, respectively. Since Table 44 includes soils rated high, and is calculated on a higher percent sufficiency, soil test data could be interpreted to farmers with this table or Table 37 or the calibration curves.

Table 44: Phosphorus fertilizer recommendations based on soil test rating, relative yield and fertility index.

Soil test rating	Relative yield of control plots (%)	Fertility index (percent sufficiency)	Soil Test Values (mg/kg)								Phosphorus fertilizer recommendations kg P_2O_5/ha
			Mehlich No.1	Mehlich No. 2	Bray No. 1	Bray No. 2	Olsen's	Modified Mehlich No.1	Mississippi	AB-DTPA	
Very low	<50	0 - 50	0 - 6	0 - 8	0 - 5	0 - 6	0 - 4	0 - 7	0 - 1	0 - 2	100 - 60
Low	50 - 75	60 - 70	7 - 13	9 - 15	6 - 11	7 - 13	5 - 9	8 - 13	1.4 - 2.5	2.5 - 4	55 - 40
Medium	75 - 100	80 - 100	14 - 43	16 - 50	12-36	14 - 42	10 - 29	14 - 44	3 - 8	5 - 13	30 - 20
High	100	110 - 200	≥ 44	≥ 51	≥37	≥ 43	≥ 30	≥45	≥9	≥ 14	10 - 0

4.2.5 Analysis of Cost of Recommended Rates

The phosphorus fertilizer recommendation for maize in the southern Guinea savanna zone based on soils that test low in phosphorus is 60 kg P_2O_5/ha (Enwezor *et al.*, 1989). This recommendation is based on phosphorus additions that would give maximum profitable yields of maize for phosphate deficient soils across the zone. From the present study, the upper level of fertilization for soils testing very low based on the Mitscherlich-Bray equation is 80 kg P_2O_5/ha. It is, therefore, desirable to consider the two phosphorus recommended rates in the light of the effects of the increased additions including the returns to the farmer.

Melsted and Peck (1980b) had pointed out that to determine the upper level of fertilization, economic considerations are important, especially the value of the expected crop increase in relation to the cost of the fertilizer. According to them the selected upper level of fertilization may represent that point at which maximum returns per acre are expected, or that point at which the last small increment of fertilizer used will give a yield increase just equal to the cost of the last fertilizer increment, or some lower profit at which the value of the crop increases may be several times that of the fertilizer cost.

Table 45 shows the cost analysis of the quantity of phosphorus fertilizer used to raise the recommended rate for maize from 60 to 80 kg P_2O_5/ha and the maize grain yield increase resulting from this increase in phosphorus fertiliza-tion. It is shown that the cost of extra maize yield from the increment of the upper level of fertilization from 60 to 80 kg P_2O_5/ha over the cost of three bags of single superphosphate fertilizer used to effect this increment was highly significant. There is a gross profit ranging from ₦3.00 per hectare for the Bokkos site to ₦3,337.50

Table 45: Cost analysis of added phosphorus and expected maize yield increases* at phosphorus additions of 60 and 80 kg P_2O_5/ha (1994).

Site	Yield at 60 kg P_2O_5/ha (kg/ha)	Yield at 80 kg P_2O_5/ha (kg/ha)	Yield increase (kg/ha)	Cost of increase @ ₦4.50** per kg of maize grain (₦/K)	Difference between cost of extra SSP*** and extra yield (₦/K)
Kuru	1133	1542	409	1840.50	1510.50
Bokkos	2118	2192	74	333.00	3.00
Sabon Gida	2629	3444	815	3667.50	3337.50
Wamba	3405	3850	445	2002.50	1672.50
Laminga	3784	4153	369	1660.50	1330.50
Obi	2338	2489	151	679.50	349.50
Ankpa	2140	2483	343	1543.50	1213.50
Yandev	3656	4233	577	2596.50	2266.50
Katsina-Ala	3236	3673	437	1966.50	1636.50

* - Two-year averages.

** - Average cost of 100 kg bag of maize for October-November delivery at local markets where farmers sell directly to consumers (Jengre, Bokkos and Mangu) is ₦450.00.

*** - Price of single superphosphate (SSP) fixed by the Federal Government for the 1994 cropping season is ₦110.00. This excludes cost of transportation and handling charged to farmers. Extra bags of SSP required per ha is 2.22 (difference between P additions at 60 and 80 P_2O_5/ha). The extra quantity to be purchased is 3 bags.

Cost of 3 bags of SSP is ₦330.00 excluding cost of transportation and handling which vary widely depending on location of purchase and distance from farm.

per hectare for the Sabon Gida site. This shows that it is economically profitable to fix the level of fertilization for maize for soils testing very low in P in the southern Guinea savanna at 80 kg P_2O_5/ha.

In Bokkos the returns were particularly poor. A possible loss is expected from this site at that level of investment and management. The reason is that the yields at both levels of fertilization were about the same. However, increasing the phosphorus addition to 100 kg/ha resulted in a significant yield increase (Table 24) showing that at phosphorus addition of 80 kg P_2O_5/ha the soil had not attained its upper level of fertilization for maximum economic yield. Phosphorus fertilizer recommendation for such soils could, therefore, be put at 100 kg P_2O_5/ha which is the upper level of fertilization for soils testing very low based on soil test ratings (Table 44).

The above analysis did not take into consideration the following:

(a) the cost of transporting and handling the extra bags of single superphosphate;

(b) the cost of harvesting, handling and transporting the increased yield; and

(c) extra cost of labour in applying the additional quantity of fertilizer, it any.

Tisdale and Nelson (1975) had shown that machinery, labour, management, interest and other costs remained the same at all levels of fertilizer. However, operating costs including fertilizer, lime, machinery operation, seed and pest control increased.

Cope and Rouse (1980) pointed out that when less fertilizers are recommended than is needed for maximum profits growers are done a lot of disservice because of the favourable ratio between the cost of fertilizers and the price of most farm produce. On the other hand recommending more fertilizer than is scientifically and economically sound reduces grower profits and increases the

amount of applied nutrients that may pollute surface or ground water. However, Barber (1980) stressed that when much fertilizer is added the economic loss is not as great as when unfertilized by the same proportion. Since losses to the grower from the use of too little fertilizer are normally much greater than from the use of more than is needed, Cope and Rouse (1980) suggested that recommendations should be higher than are indicated by response data in order to build safety factors against inaccuracies that may be involved in sampling, analysis and interpretation. The residual effect of the additional fertilizer should be considered and should more than compensate for the interest on additional investment in fertilizer. It is, therefore, more profitable to be sure that the optimum amount of phosphorus was recommended even with the chance that the rate would be more than optimum (Barber, 1980) since there is no fear of leaching loss from the soil.

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1 Summary

The development of a soil testing programme which leads to the establishment of a rational basis for fertilizer recommendations to crops from soil analysis involves five basic steps, namely: soil sampling, soil analysis, correlation, calibration and fertilizer recommendations. The steps are integrated to evolve a single package leading to fertilizer recommendations. The objective of this study is to establish an effective and economic phosphorus fertilizer recommendations based on soil tests. This was done by grouping the five steps into three study areas, namely, the soil test correlation, soil test calibration, and interpretation of results.

5.1.1 Soil Test Correlation Studies

The soil test correlation studies involved the establishment of an extractant that solubilises forms and quantities of phosphorus that best predict the responses of crops grown in the soils. Thirty-six composite surface soil samples (0-20 cm) were collected from 36 sites evenly spread through three states within the southern Guinea savanna, namely, Plateau, Benue and parts of Kogi States.

About 2 kg of each soil sample were air-dried, sieved through a 2-mm sieve and prepared for both physical and chemical analysis. The following determinations were carried out: mechanical analysis, soil pH, organic carbon, total nitrogen, total phosphorus, exchangeable bases, cation exchange capacity (CEC), percentage base saturation, and available phosphorus using Mehlich 1, Mehlich 2, Bray 1, Bray 2,

Olsen's, Modified Mehlich 1, Mississippi, and Ammonium Bicarbonate-DTPA methods.

The rest of the composite soil samples were air-dried, sieved through a 2 mm sieve and 2.5 kg of each sample weighed into 3 litre capacity well labelled plastic pots. The pots which were arranged in two treatments, P_o and P_1, received the necessary nutrients and were grown to maize in a greenhouse.

The growth of the maize plants was terminated after 35 days. The aerial parts were harvested, oven-dried, weighed and processed for total phosphorus determination.

The suitability of the eight methods employed for the extraction of available phosphorus from the soils was assessed. It was found that each of the methods extracted a wide range of phosphorus showing that the soils varied in their available (extractable) phosphorus contents.

The dry matter yields of maize at P_o varied among the soils and ranged from 1.03 to 13.72 g/pot. Analysis of variance showed that the variation in yields among the soils was significant at $P < 0.001$, with a high coefficient of variation of 21.1%. Phosphorus uptake at P_o also varied very significantly (at $P < 0.001$) among the soils and ranged from 1.29 to 24.0 mg/pot with a coefficient of variation of 21.2%. The above results show that the soils used for the greenhouse studies varied widely in their available phosphorus contents.

The variation in yields at P_1 was narrow and ranged from 23.48 to 39.09 g/pot. Although analysis of variance showed that the soils varied significantly at $P < 0.001$ in their yields at P_1 the coefficient of variation was low (6.6%). Phosphorus uptake at P_1 varied from 32.39 to 150.37 mg/pot. The variation in phosphorus uptake

at P_i was not statistically significant showing that all the plants absorbed satisfactory quantities of phosphorus for maximum development at that stage of growth.

The effectiveness of the eight methods employed in this study to solubilise available phosphorus was evaluated through linear correlation coefficients, *r*. Actual dry matter yield, relative yield, actual yield increase and phosphorus uptake were correlated separately with phosphorus extractable by the soil test methods. It was shown that, in general, the precision in prediction of the four indices of growth was in the order: relative yield > actual yield > phosphorus uptake > actual yield increase. It was also found that all the eight methods studied are suitable for solubilising available phosphorus from the soils of the southern Guinea savanna. However, Mehlich 1 was the most precise and effective in predicting phosphorus response. This is followed by Modified Mehlich 1, Bray 1 and Mehlich 2. From the correlation coefficients, each of the four methods could be satisfactorily used as a soil test method for phosphorus in the soils of the southern Guinea savanna. However, when all factors are considered, Mehlich No. 1 appears to have an edge and is primely recommended for these soils.

5.1.2 Soil Test Calibration and Interpretation

For effective soil test calibration and interpretation a good number of rated experiments should be set up at various locations throughout the study area. In the present study10 sites, namely, Kuru, Bokkos, Sabon Gida, Wamba, Laminga, and Obi in Plateau State, Yandev and Katsina-Ala in Benue State, and Ankpa and Ayangba in Kogi State were selected for the field fertilizer rate studies.

Six phosphorus rates or treatments, 0, 20, 40, 60, 80 and 100 kg P_2O_5/ha were chosen. Each treatment was replicated three times. The plots were planted to maize, TZSR-Yellow variety. The fertilizers used to supply the required phosphorus, nitrogen, potassium, and zinc were single superphosphate, urea, muriate of potash and zinc sulphate, respectively. All the required phosphorus, potassium and zinc and half of nitrogen were applied at planting. The other half of nitrogen was applied six weeks after planting. Prior to planting and fertilizer application composite soil samples were collected from each site for physical and chemical determinations. The study was carried out for two successive cropping seasons, 1988 and 1989, in each site except Ayangba.

The soils graded from loamy sand to silty clay loam. Only Kuru, Bokkos, Sabon Gida and Obi had clay and silt contents above 20%. Wamba, Laminga, Ankpa, Ayangba, Yandev and Katsina-Ala were generally coarse-textured with sand fraction constituting over 70% of the particles. The soils were strongly to moderately acid with pH values ranging from 4.8 to 6.4 with an average of 5.7. The organic carbon contents were very low, ranging from 2.6 to 13.4 g kg^{-1} with an average of 6.3 g kg^{-1}. Total nitrogen contents of the surface soils were very low. They had values between 0.35 and 1.05 g kg^{-1} with an average of 0.61 g kg^{-1}. The soils were also very low in total phosphorus with values ranging from 125 to 500 mg kg^{-1}. The cation exchange capacity, CEC, was low and varied from 1.52 to 5.83 cmol(±) kg^{-1} with exchangeable calcium constituting about 56% of the CEC. Available phosphorus extractable by Mehlich 1, Mehlich 2, Bray 1, Bray 2, Olsen's, Modified Mehlich 1, Mississippi and AB-DTPA soil test methods was low, averaging 6.63,

11.55, 6.33, 8.98, 7.20, 6.34, 1.70 and 2.04 mg kg^{-1}, respectively, for 1988, and 8.20, 8.20, 6.83, 8.88, 8.77, 8.73, 2.03 and 2.17 mg kg^{-1}, respectively, for 1989.

Grain yields varied from treatment to treatment in each site, from site to site for each treatment, and from year to year for each site-treatment. Analysis of variance of maize grain yields for all the sites combined for each year of trial showed that the sites differed significantly in their capacity to produce maize. For each year there were highly significant yield differences between the treatments. Also, there were highly significant site-treatment interactions suggesting the peculiarities of each site in its soil-phosphate-plant relationship. In general, the soils in all the 19 site-years responded significantly to phosphorus fertilization. The degree of response varied from site to site, and for the same site, from year to year. In all cases yield increases were recorded in treatments 2 over the control plots. Maximum yields were obtained at varying treatments.

Two methods were employed to determine the critical levels of phosphorus soil test values for maize for the various soil test methods. These are the Cate-Nelson graphical method and Cate-Nelson Analysis of Variance method. The results obtained using the graphical method and analysis of variance method, respectively, are as follows:

(a) Mehlich 1 - 7.25 and 7.29 mg kg^{-1}

(b) Modified Mehlich 1 - 6.75 and 6.36 mg kg^{-1}

(c) Bray 1 - 8.0 and 7.83 mg kg^{-1}

(d) Mehlich 2 - 13.0 and 13.20 mg kg^{-1}

(e) Bray 2 - 8.0 and 6.76 mg kg^{-1}

(f) Olsen's - 7.25 and 6.94 mg kg^{-1}

(g) Mississippi - 1.20 and 1.12 mg kg^{-1}

(h) AB-DTPA - 2.70 and 2.60 mg kg^{-1}

It was shown that the two methods produced quite similar results.

Using the Cate-Nelson model (1971), the soil test values were partitioned into 3 or 4 classes which are closely related to the soil test ratings of very low, low, medium and high.

From the present study it was recommended that soils whose soil test values are above and below the critical level should receive phosphorus fertilizer additions of 40 and 80 kg P_2O_5/ha, respectively. Phosphate fertilizer recommendations were also suggested for each of the soil test classes based on observed trends in the fertilizer rate studies. The recommendations were 80 - 100 kg P_2O_5/ha for class 1, 80 kg/ha for class 2, 20-40 kg/ha for class 3, and 20 kg P_2O_5/ha for class 4.

Fertilizer recommendations based on critical levels and soil test classes may lump together soils that differ in their nutrient needs. To avoid this the soil test values could be partitioned into many more groups. To achieve this, the Mitscherlich-Bray equation and the graphical method were employed. From the Mitscherlich-Bray equation - $Log(A\text{-}y) = LogA - C_1b$, and its expanded form - $Log(A\text{-}y) = LogA\text{-}C_1b\text{-}Cx$, the following correlation factors, C_1 were obtained for the various soil test methods:

(a) Mehlich 1 - 0.047;

(b) Mehlich 2 - 0.040;

(c) Bray 1 - 0.056;

(d) Bray 2 - 0.048;

(e) Olsen's - 0.069;

(f) Modified Mehlich 1 - 0.045;

(g) Mississippi - 0.243; and

(h) AB-DTPA - 0.156.

Also the efficiency factor for band applied phosphorus fertilizer, *C*, was calculated as 0.014. Based on this method and the graphical method, arbitrary values of percent sufficiencies, *y*, of 10 to 100% which cover a full range of soil deficiencies, and the corresponding soil test values, phosphorus fertilizer recommendations were obtained.

Calibration curves between soil test values and the corresponding phosphorus fertilizer recommendations and tables were produced for the various soil test methods. These would be used to interpret soil test data to farmers.

5.2 Conclusion

The field trials were conducted in 10 sites and carried out for two cropping seasons. This met the 20 site-year requirement for effective and reliable soil test calibration and interpretation. The data generated from the studies were reliable and could form the basis for:

(a) determining the phosphorus fertility status of soils of the study area and areas within the same agro-ecological zone; and

(b) providing recommendations on the amount of phosphorus fertilizer to apply to maize and other crops with similar response pattern and nutrient requirements.

Information gained could also be satisfactorily used to: (i) maintain fertility status of a given field in the zone; and (ii) predict the probability of obtaining a profitable response to phosphorus fertilization.

Soil testing is a very tedious, expensive and time-consuming process since much research is required to calibrate soil test levels to crop growth. However tedious and expensive the initial process is, determining the fertility level of a soil through soil test is the first step in planning a sound lime and fertilizer programme, and is the place to start when designing a fertility programme for maximum economic crop yields. A good soil testing programme is essential to sound fertilizer use. It can indicate how serious the deficiency is and provide an anchor on which many of the subsequent required judgements depend. A sound soil testing programme is today's best and perhaps only way of determining what constitutes adequate but not excessive fertilizer use for high and efficient crop production. From the experiences gathered in this study, soil testing holds good promise for Nigerian agriculture.

5.3 Suggestions and Areas for Further Research

(a) The much work done in Nigeria in the field of soil testing has been through individual efforts of researchers and students. No coordinated or systematic soil testing programmes have been undertaken in most parts of the country. As a result of this it has not been possible to take record of the amount of work already done or the areas effectively covered and to assess the areas of need. A systematic and well coordinated approach should be adopted for soil testing in each region. A national coordinating committee on soil testing should be set up by Government, either through any of its agencies or through the Soil Science Society of Nigeria, to work out a programme of systematic soil testing in all the agro-ecological zones. This committee will identify areas covered, areas of need, and fund all relevant/necessary research

by students, researchers and organisations. The committee will also mount serious and organised educational campaign throughout the country on the benefits of soil testing as a tool for improved and economic food production.

(b) Most researchers in most parts of the country have been interested in extractants for single nutrient elements. There is need for the development of a universal extractant for two or more nutrient elements for each ecological zone. With a universal extractant the cost of analysis to the farmer will be reduced.

(c) Calibration for all agronomic crops and all soil series will be tedious and expensive. Crops should be grouped according to their responses, nutrient requirements and physiological patterns and calibration carried out for each group. Soils could also be grouped using such fertility indices as the cation exchange capacity.

(d) Mixed cropping is practised extensively in Nigeria. Calibration for various crop mixtures should be evolved.

(e) Calibration for all essential nutrient elements, starting from those most limiting to crops should be embarked on throughout the country.

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Appendix 1: Greenhouse cropping: Dry matter yield of maize at P_o and P_1 (g/pot).

Soil Sample No.	Phosphorus Omitted			Phosphorus Added		
	Replicate A	Replicate B	Mean	Replicate A	Replicate B	Mean
BAS/01	1.47	1.83	1.65	33.02	35.0	34.01
KUR/02	2.11	1.60	1.86	34.43	37.87	36.15
BLA/03	1.82	2.31	2.07	24.21	23.17	23.69
MAN/04	1.82	1.65	1.74	28.00	29.43	28.72
PAN/05	2.08	1.44	1.76	28.34	25.19	26.77
DEN/06	2.75	1.63	2.19	32.73	35.88	34.31
LAN/07	2.90	2.97	2.94	36.65	36.28	36.47
WAS/08	2.38	3.0	2.69	35.68	30.80	33.24
SHE/09	1.47	2.38	1.93	34.97	32.16	33.57
NAM/10	4.93	6.73	5.83	33.67	33.14	33.41
ZAL/11	2.28	1.49	1.89	35.93	35.77	35.85
AKW/12	2.02	2.41	2.22	36.35	29.79	33.07
GIT/13	2.17	1.45	1.81	32.98	34.71	33.85
AMB/14	1.90	1.99	1.95	35.19	34.38	34.79
NAS/15	1.95	2.44	2.20	32.78	34.51	33.65
TOT/16	1.81	2.43	2.12	27.67	30.51	29.09
ODE/17	1.53	2.28	1.91	39.08	38.51	38.80
LAF/18	2.44	1.59	2.02	34.74	32.26	33.50
AWE/19	3.71	4.02	3.87	39.49	35.36	37.43
UDE/20	1.07	1.94	1.51	37.0	31.44	34.22
MAK/21	1.89	2.93	2.42	37.11	35.95	36.53
YAN/22	6.82	8.96	7.89	34.70	31.69	33.20
KYA/23	3.24	2.10	2.67	38.09	34.71	36.40
HAR/24	12.27	15.16	13.72	37.73	34.37	36.05
KOT/25	1.78	1.85	1.82	31.50	29.10	30.30
ALI/26	2.65	2.11	2.38	32.29	35.05	33.67
OJU/27	2.19	2.03	2.11	28.82	33.97	31.40
IGA/28	2.34	2.73	2.54	33.92	39.74	36.83
OKP/29	2.31	2.70	2.51	36.60	32.47	34.54
ANK/30	1.18	0.88	1.03	30.59	29.54	30.07
ABE/31	1.57	1.69	1.63	30.88	32.26	31.57
OGU/32	5.79	5.71	5.75	31.92	29.11	30.52
DEK/33	1.50	1.05	1.28	26.45	20.93	23.69
AKP/34	1.07	1.42	1.25	24.0	22.95	23.48
OGB/35	2.36	1.46	1.91	31.95	31.28	31.62
IDA/36	9.06	8.77	8.92	40.96	37.22	39.09

Appendix 2: Greenhouse cropping: Analysis of variance of herbage dry matter yield of maize when no phosphorus was added to the soils.

Item (Source of variation)	Degree of freedom, df	Sums of squares, SS	Mean square, MS	Variance Ratio, VR	LSD (0.05)	CV %
Total	71	465.415				
Replicates	1	0.587	0.587	1.525 ns		
Treatments (soils)	35	451.358	12.895	33.507***		21.1
Residual (Error)	35	13.471	0.385			

Appendix 3: Greenhouse cropping: Analysis of variance of herbage dry matter yield of maize when phosphorus was added to the soils.

Item (Source of variation)	Degree of freedom, df	Sums of squares, SS	Mean square, MS	Variance Ratio, VR	LSD (0.05)	CV %
Total	71	1272.183				
Replicates,	1	15.980	15.980	3.730 ns		
Treatments (soils)	35	1090.219	31.149	6.569***		6.60
Residual (Error)	35	165.984	4.742			

Appendix 4: Greenhouse cropping: Analysis of variance of herbage dry matter yield of maize when phosphorus was added versus when no phosphorus was added.

Item (Source of variation)	Degree of freedom, df	Sums of squares, SS	Mean square, MS	Variance Ratio, VR	LSD (0.05)	CV %
Total	71	16891.145				
Replicates	1	496.466	14.185	1.81 ns		
Treatments (soils)	35	16120.896	16120.896	2060.87***		15.60
Residual (Error)	35	273.782	7.822			

n = 72; *** = P<0.001; ns = non-significant

Appendix 5: Greenhouse cropping: P uptake by plants when no phosphorus was added.

Soil Sample No.	Replicate A			Replicate B		
	Concentration		Uptake	Concentration		Uptake
	mg/kg	g/kg	mg/pot	mg/kg	g/kg	mg/pot
BAS/01	1500	0.150	2.205	1250	0.125	2.288
KUR/02	2000	0.200	4.220	2250	0.225	3.600
BLA/03	1500	0.150	2.730	1250	0.125	2.888
MAN/04	1500	0.150	2.730	1500	0.150	2.475
PAN/05	1000	0.100	2.080	1250	0.125	1.800
DEN/06	1500	0.150	4.125	1500	0.150	2.445
LAN/07	1250	0.125	3.625	1250	0.125	3.713
WAS/08	2000	0.200	4.760	1750	0.175	5.250
SHE/09	2000	0.200	2.940	1750	0.175	4.165
NAM/10	2000	0.200	9.860	1750	0.175	11.778
ZAL/11	1000	0.100	2.280	1500	0.150	2.235
AKW/12	1500	0.150	3.030	1750	0.175	4.218
GIT/13	2250	0.225	4.883	2000	0.200	2.900
AMB/14	2250	0.225	4.275	2000	0.200	3.980
NAS/15	1750	0.175	3.413	2000	0.200	4.880
TOT/16	1500	0.150	2.715	1750	0.175	4.253
ODE/17	2000	0.200	3.060	2000	0.200	4.560
LAF/18	2000	0.200	4.880	2000	0.200	3.180
AWE/19	2250	0.225	8.348	2500	0.250	10.050
UDE/20	2000	0.200	2.140	2250	0.225	4.365
MAK/21	1750	0.175	3.308	2000	0.200	5.860
YAN/22	2250	0.225	15.345	2250	0.225	20.160
KYA/23	2250	0.225	7.290	2500	0.250	5.250
HAR/24	1750	0.175	21.473	1750	0.175	26.530
KOT/25	1750	0.175	3.115	2000	0.200	3.700
ALI/26	2000	0.200	5.300	2250	0.225	4.748
OJU/27	1500	0.150	3.285	2000	0.200	4.060
IGA/28	1500	0.150	3.510	1500	0.150	4.095
OKP/29	1250	0.125	2.888	1500	0.150	4.050
ANK/30	1250	0.125	1.475	1250	0.125	1.100
ABE/31	1750	0.175	2.748	1500	0.150	2.535
OGU/32	2250	0.225	13.028	2000	0.200	11.420
DEK/33	1250	0.125	1.875	1500	0.150	1.575
AKP/34	1250	0.125	1.338	1250	0.125	1.775
OGB/35	1750	0.175	4.130	1750	0.175	2.555
IDA/36	2250	0.225	20.385	2250	0.225	19.733

Appendix 6: Greenhouse cropping: Phosphorus uptake by plants when adequate amount of phosphorus was added.

Soil Sample No.	Replicate A			Replicate B		
	Concentration		Uptake	Concentration		Uptake
	mg/kg	g/kg	mg/pot	mg/kg	g/kg	mg/pot
BAS/01	3750	3.75	123.825	1750	1.75	61.250
KUR/02	1500	1.50	51.645	1500	1.50	56.805
BLA/03	1750	1.75	42.368	1250	1.25	28.963
MAN/04	1000	1.00	28.000	1250	1.25	36.788
PAN/05	2000	2.00	56.680	3500	3.50	88.165
DEN/06	3750	3.75	122.738	3750	3.75	134.550
LAN/07	3500	3.50	128.275	4500	4.50	163.260
WAS/08	3000	3.00	107.040	4250	4.25	130.900
SHE/09	3500	3.50	122.395	5000	5.00	160.800
NAM/10	4000	4.00	134.680	3250	3.25	107.705
ZAL/11	3750	3.75	134.738	2250	2.25	80.483
AKW/12	2000	2.00	72.700	2250	2.25	67.028
GIT/13	3500	3.50	115.450	4000	4.00	138.840
AMB/14	2000	2.00	70.380	3250	3.25	111.735
NAS/15	3750	3.75	122.925	4250	4.25	146.668
TOT/16	2750	2.75	76.093	3000	3.00	91.530
ODE/17	4000	4.00	156.320	3750	3.75	144.413
LAF/18	2250	2.25	78.165	4250	4.25	137.105
AWE/19	3000	3.00	118.470	2250	2.25	79.560
UDE/20	3250	3.25	120.250	3500	3.50	110.040
MAK/21	2250	2.25	83.498	4500	4.50	161.775
YAN/22	3250	3.25	112.775	5000	5.00	158.450
KYA/23	3250	3.25	123.793	4500	4.50	156.195
HAR/24	4000	4.00	150.920	2500	2.50	85.925
KOT/25	3500	3.50	110.250	4000	4.00	116.400
ALI/26	2000	2.00	64.580	3500	3.50	122.675
OJU/27	1750	1.75	50.435	2250	2.25	76.433
IGA/28	3500	3.50	118.720	3750	3.75	149.025
OKP/29	3250	3.25	118.950	4250	4.25	137.998
ANK/30	4500	4.50	137.655	3250	3.25	96.005
ABE/31	3250	3.25	100.360	3250	3.25	104.845
OGU/32	3000	3.00	95.760	4500	4.50	130.995
DEK/33	3750	3.75	99.188	5000	5.00	104.650
AKP/34	4500	4.50	108.000	2250	2.25	51.638
OGB/35	2250	2.25	71.888	2000	2.00	62.560
IDA/36	2000	2.00	81.920	1750	1.75	65.136

Appendix 7: Greenhouse cropping: Analysis of variance of phosphorus concentration (%) in the aerial parts of maize when no phosphorus was added to the soils.

Item	Degrees of freedom, df	Sums of squares, SS	Mean square, MS	Variance Ratio, VR	LSD (0.05)	CV %
Total	71	0.0998611				
Replicates	1	0.0005556	0.0005556	2.20ns		2.2
Treatments (soils)	35	0.0904861	0.0025853	10.26***	0.033	9.0
Error	35	0.0088194	0.0002520			

Appendix 8: Greenhouse cropping: Analysis of variance of phosphorus uptake (mg/pot) by maize when no phosphorus was added to the soils.

Item	Degrees of freedom, df	Sums of squares, SS	Mean square, MS	Variance Ratio, VR	LSD (0.05)	CV %
Total	71	1962.961				
Replicates	1	3.284	3.284	2.45ns		5.5
Treatments (soils)	35	1912.923	54.655	40.91***	2.349	21.2
Error	35	46.754	1.336			

Appendix 9: Greenhouse cropping: Analysis of variance of phosphorus uptake (mg/pot) by maize when phosphorus and other elements were added to the soils.

Item	Degrees of freedom, df	Sums of squares, SS	Mean square, MS	Variance Ratio, VR	LSD (0.05)	CV %
Total	71	88094.9				
Replicates	1	837.0	837.0	1.321ns		4.6
Treatments (soils)	35	65082.4	1859.5	2.935ns		24.3
Error	35	22175.6	633.6			

n = 72: ns = non-significant *** = P<0.05; *** = P<0.001

Appendix 10: Field fertilizer rate studies: Analysis of variance of grain yields of maize in a combination of all the sites for the 1988 trials.

Item	Degrees of freedom. Df	Sum of squares. SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates. r	(r-1) 2	207491	103745	0.956 ns	
		REPLICATES - SITES STRATUM			
Site. S	(s-1) 8	147659712	18457464	220.832***	**204.37**
Residual (Error)	(r-1(s-) 16	1337305	83582	0.770 ns	
Total	r(s-) 24	148997024	6208210	57.205***	
		TREATMENTS - SITES STRATUM			
Treatments. t	(t-1) 5	56357744	11271549	103.861***	178.50
Site-treatment interaction	(s-1)(t-1) 40	29979020	749476	6.906***	524.96
Residual (Error)	s(t-1)(r-1) 90	9767245	108525		
Total	sr(t-1) 135	96104016	711882		
GRAND TOTAL	(rts)-1 161	245308528			

SED:
Treatments = 89.7
Site = 96.4
Site-trts = 263.8

n = 162; ns = non-significant; * = P<0.05; ** = P<0.01; *** = P<0.001.

Appendix 11: Field fertilizer rate studies: Analysis of variance of grain yields of maize in a combination of all the sites for the 1989 trials.

Item	Degrees of freedom, Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates, r	(r-1) 2	294090	147045	1.419 ns	
		REPLICATES - SITES STRATUM			
Site, S	(s-1) 8	173475264	21684408	123.057***	296.59
Residual (Error)	(r-1(s-1) 16	2819438	176215	1.700 ns	
Total	r(s-1) 24	176294704	7345613	70.880***	
		TREATMENTS - SITES STRATUM			
Treatments, t	(t-1) 5	34627800	6925560	66.827***	174.32
Site-treatment interaction	(s-1)(t-1) 40	18420350	460509	4.444***	524.96
Residual (Error)	s(t-1)(r-1) 90	9327119	103635		
Total	sr(t-1) 135	62375272	462039		
GRAND TOTAL	(rts)-1 161	238964064			

SED:
Treatments = 87.6
Site = 139.9
Site-trts = 277.8

Appendix 12: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Kuru.

Source of variation	Degrees of freedom, Df		Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates, r	(r-1)	2	13749	6874	0.554 ns	
			REPLICATES - YEARS STRATUM			
Years, y	(y-1)	1	2850520	2850520	316.924***	135.97
Residual (Error)	(r-1(y-1)	2	17989	8994	0.725 ns	
Total	r(y-1)	3	2868509	956170	77.119***	
			TREATMENTS - YEARS STRATUM			
Treatments, t	(t-1)	5	13322281	2664456	214.899***	134.13
Years-treatments	(y-1)(t-1)	5	845702	169140	13.642***	185.24
Residual	y(r-1)(t-1)	20	247973	12399		
Total	yr(t-1)	30	14415956	480532		
GRAND TOTAL	(yrt)-1	35	17298214			

SED:
Treatments = 64.3
Site = 31.6
Treatments-years = 88.8

Appendix 13: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Bokkos.

Source of variation	Degrees of freedom, Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	83988	41994	0.508 ns	
		REPLICATES - YEARS STRATUM			
Years	1	66663	66663	2.615 ns	
Residual	2	50976	25488	0.308 ns	
Total	3	117638	39213	0.474 ns	
		TREATMENTS - YEARS STRATUM			
Treatments	5	12730129	2546026	30.771***	346.48
Years-treatments	5	3580412	716082	8.655***	460.80
Residual	20	1654795	82740		
Total	30	17965336	598845		
GRAND TOTAL	35	18166962			

SED:
Treatments = 166.1
Site = 53.2
Treatments-years = 220.9

Appendix 14: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Sabon Gida.

Source of variation	Degrees of freedom, Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	47244	23622	0.297 ns	
		REPLICATES - YEARS STRATUM			
Years	1	804450	804450	17.953 ns	
Residual	2	89615	44808	0.564 ns	
Total	3	894065	298022	3.748*	
		TREATMENTS - YEARS STRATUM			
Treatments	5	31566698	6313340	79.403***	339.60
Years-treatments	5	1257628	251526	3.163*	462.47
Residual	20	1590198	79510		
Total	30	34414524	1147151		
GRAND TOTAL	35	35355832			

SED:
Treatments = 162.8
Site = 70.6
Treatments-years = 221.7

Appendix 15: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Wamba.

Source of variation	Degrees of freedom, Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	79780	39890	0.277 ns	
		REPLICATES - YEARS STRATUM			
Years	1	38949	38949	0.149 ns	
Residual	2	521515	260758	1.808 ns	
Total	3	560464	186821	1.295 ns	
		TREATMENTS - YEARS STRATUM			
Treatments	5	5491184	1098237	7.614***	**457.46**
Years-treatments	5	573848	114770	0.796 ns	
Residual	20	2884735	144237		
Total	30	8949767	298326		
GRAND TOTAL	35	9590011			

SED:
Treatments = 219.3
Site = 170.2
Treatments-years = 330.3

Appendix 16: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Laminga.

Source of variation	Degrees of freedom, Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	1070118	535059	4.340*	
		REPLICATES - YEARS STRATUM			
Years	1	3257171	3257171	95.377*	265.06
Residual	2	68301	34150	0.277 ns	
Total	3	3325472	1108491	8.992***	
		TREATMENTS - YEARS STRATUM			
Treatments	5	9780725	1956145	15.868***	422.83
Years-treatments	5	12048209	2409642	19.547***	560.72
Residual	20	2465451	123273		
Total	30	24294384	809813		
GRAND TOTAL	35	28689974			

SED:
Treatments = 202.7
Site = 61.6
Treatments-years = 268.8

Appendix 17: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Obi.

Source of variation	Degrees of freedom, Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	68712	34356	0.619 ns	
		REPLICATES - YEARS STRATUM			
Years	1	580952	580952	130.604*	95.53
Residual	2	8896	4448	0.080 ns	
Total	3	589848	196616	3.540*	
		TREATMENTS - YEARS STRATUM			
Treatments	5	14956004	2991201	53.855***	283.90
Years-treatments	5	3620805	724161	13.038***	369.43
Residual	20	1110844	55542		
Total	30	19687652	656255		
GRAND TOTAL	35	20346212			

SED:
Treatments = 136.10
Site = 22.20
Treatments-years = 177.10

Appendix 18: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Ankpa.

Source of variation	Degrees of freedom, Df	Sum of squares. SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	5814	2907	0.042 ns	
		REPLICATES - YEARS STRATUM			
Years	1	3962821	3962821	306.932***	**163.08**
Residual	2	25822	12911	0.187 ns	
Total	3	3988643	1329548	19.223***	
		TREATMENTS - YEARS STRATUM			
Treatments	5	4297918	859584	12.428***	**316.65**
Years-treatments	5	464531	92906	1.343 ns	
Residual	20	1383317	69166		
Total	30	6145767	204859		
GRAND TOTAL	35	10140223			

SED: Treatments = 151.8
Site = 37.9
Treatments-years = 199.6

Appendix 19: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Yandev.

Source of variation	Degrees of freedom Df	Sum of squares, SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	666036	333018	1.402 ns	
		REPLICATES - YEARS STRATUM			
Years	1	3015235	3015235	4.897 ns	
Residual	2	1231402	615701	2.593 ns	
Total	3	4246637	1415546	5.960**	
		TREATMENTS - YEARS STRATUM			
Treatments	5	5768562	1153712	4.858**	587.0
Years-treatments	5	3112940	622588	2.622 ns	
Residual	20	4749816	237491		
Total	30	13631318	454377		
GRAND TOTAL	35	18543990			

SED: Treatments = 281.4
Site = 261.6
Treatments-years = 447.6

Appendix 20: Field fertilizer rate studies: Analysis of variance of grain yields of maize for the two years combined for Katsina-Ala.

Source of variation	Degrees of freedom Df	Sum of squares. SS	Mean squares MS	Variance Ratio VR (F)	LSD(0.05)
Replicates	2	106082	53041	0.353 ns	
		REPLICATES - YEARS STRATUM			
Years	1	29119262	29119262	115.947**	
Residual	2	502287	251143	1.670 ns	
Total	3	29621548	9873849	65.667***	
		TREATMENTS - YEARS STRATUM			
Treatments	5	13588863	2717773	18.075***	467.06
Years-treatments	5	2378477	475695	3.164*	696.31
Residual	20	3007238	150362		
Total	30	18974578	632486		
GRAND TOTAL	35	48702208			

SED:
Treatments = 223.9
Site = 167.0
Treatments-years = 338.8

Appendix 21: Comparison of yields of maize for the 19-site years (two-year averages).

Fertilizer Rate (kg P_2O_5/ha)	Relative yield of maize (%)										
	Kuru	Bokkos	Sabon Gida	Wamba	Laminga	Obi	Ankpa	Yandev	Katsina-Ala	Ayangba*	Mean
0	0	19	16	60	59	15	32	77	40	38	36
20	9	30	47	79	82	38	43	79	77	45	53
40	18	47	70	86	84	36	49	96	72	36	59
60	26	49	60	78	87	54	49	84	74	38	60
80	35	50	79	89	96	57	57	97	84	37	68
100	39	60	76	79	94	55	53	100	67	45	67

* = Cropped only 1988.

Appendix 22: Field fertilizer rate studies: Nutrient concentration in index leaves (ear leaves) of maize (gkg^{-1}).

Nutrient	1988												1989											
	Total N		Total P		Total K		Total Ca		Total Mg		Total Zn		Total N		Total P		Total K		Total Ca		Total Mg		Total Zn	
Block	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Treatment													KURU											
1	21.8	31.9	1.5	2.5	21.0	16.2	2.9	1.9	1.5	1.2	0.10	0.06	27.4	24.1	2.0	2.0	14.6	18.4	1.5	1.4	1.7	1.4	0.07	0.07
2	33.0	30.8	1.5	5.5	18.3	19.4	2.0	1.8	1.0	1.0	0.08	0.07	26.4	25.2	3.0	2.0	18.9	16.7	1.7	1.6	2.0	1.6	0.07	0.07
3	31.2	26.9	1.0	2.5	15.3	20.0	2.4	2.1	1.0	1.0	0.08	0.07	38.0	28.6	2.5	2.0	16.7	16.2	1.3	3.5	1.3	1.3	0.07	0.08
4	31.9	34.7	2.0	2.5	17.8	19.4	2.5	2.3	0.9	1.0	0.08	0.08	38.0	28.3	2.0	3.0	15.7	17.3	2.0	1.8	1.9	1.3	0.07	0.09
5	26.9	30.2	2.0	2.0	16.7	16.7	2.5	2.3	1.1	1.0	0.11	0.06	35.0	35.0	2.5	4.5	17.3	18.9	1.6	2.5	2.1	1.7	0.07	0.08
6	30.2	31.6	1.5	3.0	15.7	16.7	2.2	2.3	1.2	1.2	0.06	0.07	20.2	31.4	2.0	2.5	16.3	17.8	1.3	2.2	0.9	1.5	0.06	0.07
													BOKKOS											
1	29.7	33.6	3.0	1.5	13.5	11.3	2.3	2.3	2.2	1.6	0.11	0.06	24.1	26.3	2.5	2.0	17.3	16.0	2.5	2.6	1.3	1.3	0.08	0.08
2	32.2	23.8	2.05	2.5	14.0	15.1	2.4	3.1	2.1	2.2	0.09	0.07	32.5	26.9	2.0	2.5	16.0	17.3	2.1	2.2	1.1	1.3	0.07	0.09
3	33.6	30.8	2.0	2.5	14.6	16.7	2.3	2.9	2.2	2.1	0.10	0.07	27.7	29.1	3.0	2.5	16.7	15.7	2.9	2.0	1.7	1.1	0.08	0.08
4	28.8	34.2	2.0	2.0	13.5	12.4	2.5	2.4	1.9	1.7	0.08	0.07	27.4	26.6	2.5	2.5	9.2	17.8	1.7	3.1	0.9	1.5	0.06	0.08
5	35.8	34.4	2.5	2.5	13.5	12.4	2.3	2.2	2.3	1.7	0.15	0.06	30.8	38.0	2.5	2.0	16.2	18.4	2.4	2.5	1.4	1.5	0.08	0.09
6	33.0	33.6	2.0	2.0	13.5	11.3	3.1	2.9	2.3	2.3		0.07	29.4	29.1	2.5	2.5	16.7	18.9	2.2	2.2	1.3	0.8	0.07	0.09
													SABON GIDA											
1	32.2	20.4	1.0	2.0	18.4	13.5	1.6	1.9	2.1	1.7	0.06	0.06	30.8	31.9	2.0	2.5	17.3	16.2	2.8	2.3	1.1	0.8	0.07	0.07
2	20.4	35.8	2.0	2.0	15.7	14.0	1.7	1.6	1.8	1.7	0.06	0.06	32.8	28.0	2.5	2.5	14.6	14.6	2.7	1.9	1.2	0.7	0.07	0.08
3	28.6	30.8	2.0	2.5	12.4	17.3	1.5	1.7	1.7	1.7	0.06	0.05	33.9	30.8	2.0	2.0	17.3	15.7	2.8	2.5	1.1	0.7	0.07	0.08
4	31.1	30.5	2.5	2.0	14.6	13.5	1.9	1.7	2.0	1.7	0.06	0.05	35.3	31.4	2.0	2.5	16.2	16.7	2.7	2.5	1.3	0.9	[illegible]	
5	31.4	34.2	2.0	2.5	16.7	13.5	1.8	1.7	2.0	1.9	0.05	0.05	30.2	29.4	2.0	2.0	15.1	17.3	3.6	2.9	1.4	0.9	0.06	0.08
6	31.6	32.2	2.0	2.0	15.7	13.5	1.5	1.7	2.1	1.5	0.06	0.07	31.6	32.5	2.5	2.0	16.2	16.7	3.3	3.6	1.4	1.5	0.06	0.07

Appendix 22: continued.

Nutrient	1988												1989											
	Total N		Total P		Total K		Total Ca		Total Mg		Total Zn		Total N		Total P		Total K		Total Ca		Total Mg		Total Zn	
Block	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Treatment													WAMBA											
1	30.8	31.9	2.0	2.5	17.3	16.2	2.8	2.3	1.1	0.8	0.07	0.07	35.3	29.9	1.0	1.5	23.2	11.1	2.2	2.0	0.9	0.9	0.10	0.10
2	32.8	28.0	2.5	2.5	14.6	14.6	2.7	1.9	1.2	0.7	0.07	0.05	35.8	22.9	1.5	2.0	17.3	18.9	2.0	2.1	0.8	0.5	0.07	0.08
3	33.9	30.8	2.0	2.0	17.3	15.7	2.8	2.5	1.1	0.7	0.07	0.06	35.3	29.7	2.8	2.0	20.5	18.9	2.3	2.7	0.9	1.3	0.09	0.09
4	35.3	31.4	2.0	2.5	16.2	16.7	2.7	2.5	1.3	0.9	0.07	0.06	35.0	24.9	2.0	2.0	18.9	17.3	2.8	2.8	1.1	0.6	0.10	0.09
5	30.2	29.4	2.0	2.0	15.1	17.3	3.6	2.9	1.4	0.9	0.06	0.07	30.8	26.9	2.0	2.0	21.1	20.5	3.2	2.9	1.1	1.2	0.07	0.09
6	31.6	32.5	2.5	2.0	16.2	16.7	3.3	3.6	1.4	1.5	0.06	0.07	30.2	29.4	2.5	3.0	21.6	16.2	1.0	2.6	0.7	1.5	0.10	0.07
													LAMINGA											
1	30.2	31.4	1.0	1.5	13.5	12.4	1.7	1.5	1.3	1.3	0.07	0.10	34.4	34.2	3.5	4.0	17.8	18.9	3.4	2.2	1.8	1.2	0.09	0.08
2	31.9	30.8	2.5	2.5	13.0	19.4	2.0	1.6	1.3	1.1	0.09	0.10	26.6	32.5	3.0	3.0	17.3	16.2	2.3	2.5	1.1	1.4	0.08	0.09
3	31.4	35.0	2.0	2.5	9.4	10.8	1.9	2.0	1.3	1.4	0.06	0.06	32.2	35.8	3.0	3.5	18.9	18.4	3.2	2.7	1.7	1.5	0.09	0.10
4	33.6	32.2	2.5	2.0	13.0	9.4	2.4	3.5	1.4	1.9	0.08	0.07	32.8	36.4	4.0	3.5	17.8	21.1	2.7	2.6	1.5	1.3	0.09	0.11
5	33.9	33.0	2.0	2.0	13.0	10.8	2.5	2.0	1.5	1.3	0.10	0.05	30.8	32.2	4.5	3.0	20.5	25.4	3.2	1.5	1.4	2.1	0.08	0.08
6	35.0	34.2	2.5	2.5	12.0	13.5	2.5	3.0	1.4	2.0	0.11	0.10	31.1	30.2	4.5	3.0	20.0	16.7	2.0	2.2	1.3	1.6	0.09	0.10
													OBI											
1	28.0	30.0	1.0	2.0	11.3	11.9	2.0	1.6	2.0	1.7	0.07	0.06	25.8	34.2	2.5	1.5	24.8	19.4	1.3	1.3	1.9	1.4	0.10	0.07
2	39.2	34.2	2.0	2.5	13.0	10.8	2.0	2.0	1.9	1.7	0.08	0.05	25.7	34.2	2.0	2.5	21.6	23.8	1.5	1.9	1.9	2.0	0.10	0.08
3	34.4	32.5	2.0	2.0	11.3	11.9	2.5	1.8	2.6	1.5	0.07	0.05	28.2	35.3	2.0	2.0	23.2	21.1	1.5	1.8	1.6	1.9	0.09	0.08
4	33.3	23.8	2.5	2.0	13.0	10.8	2.0	1.9	1.4	1.8	0.06	0.05	33.9	36.4	1.5	2.5	23.8	19.4	1.6	1.6	1.5	1.4	0.09	0.06
5	30.6	40.6	2.5	2.0	11.3	10.8	2.0	1.8	1.6	1.7	0.05	0.05	29.7	33.9	1.5	2.0	22.1	19.4	1.6	1.5	1.7	1.5	0.09	0.06
6	37.2	34.2	2.5	2.5	12.4	9.4	2.0	2.4	1.6	2.2	0.04	0.07	33.6	32.8	1.0	2.5	21.6	18.4	1.5	1.5	2.0	2.0	0.08	0.08

Appendix 22: continued.

Nutrient	1988												1989											
	Total N		Total P		Total K		Total Ca		Total Mg		Total Zn		Total N		Total P		Total K		Total Ca		Total Mg		Total Zn	
Block	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Treatment																								
													ANKPA											
1	29.7	34.4	2.5	1.5	11.9	21.6	1.9	1.1	1.6	1.1	0.05	0.07	32.2	33.0	2.0	3.5	16.7	17.3	2.3	2.8	1.4	1.4	0.06	0.06
2	37.8	30.8	2.0	2.5	10.8	14.6	2.1	2.2	1.6	1.2	0.11	0.07	30.2	33.6	2.0	3.0	16.2	16.2	2.3	2.6	1.4	1.2	0.06	0.07
3	42.0	34.4	2.0	2.0	15.1	13.5	1.9	2.6	1.3	1.1	0.07	0.08	33.6	31.8	2.5	4.0	16.2	18.4	2.4	3.2	1.4	1.6	0.06	0.07
4	38.1	37.8	2.0	2.5	12.4	13.5	1.9	2.3	1.5	1.0	0.05	0.06	31.6	26.6	2.0	3.0	16.2	17.8	2.5	3.2	1.2	1.7	0.06	0.07
5	35.0	24.4	2.5	2.5	13.5	13.0	2.5	2.7	1.5	1.4	0.07	0.07	35.0	21.6	3.0	3.5	16.2	17.3	2.7	3.3	1.6	1.5	0.06	0.06
6	33.6	36.1	2.5	2.0	16.2	13.5	2.1	2.0	1.1	1.0	0.07	0.06	25.0	21.2	2.5	3.5	17.8	16.2	3.3	3.8	1.6	1.7	0.07	0.06
													YANDEV											
1	39.9	28.6	1.5	2.0	15.7	16.7	1.5	1.3	0.9	1.0	0.06	0.06	34.8	31.8	3.0	4.0	15.1	16.2	2.9	2.8	2.4	2.5	0.06	0.06
2	35.3	31.4	2.0	2.0	13.5	16.7	1.6	1.4	1.0	0.7	0.07	0.05	29.9	24.3	4.0	3.5	15.7	15.7	2.6	3.2	2.0	2.3	0.06	0.06
3	37.5	33.0	2.0	2.0	14.0	15.7	2.2	2.0	1.1	1.1	0.06	0.06	33.5	35.7	4.5	2.5	15.7	17.3	2.4	2.8	2.2	2.5	0.06	0.06
4	28.6	31.4	2.5	2.5	14.0	16.2	2.0	1.5	1.0	0.9	0.05	0.06	23.2	23.5	3.5	2.5	16.2	16.2	3.4	3.2	2.5	2.4	0.06	0.06
5	24.6	33.6	2.0	2.5	15.1	15.1	2.0	1.5	0.9	0.8	0.05	0.05	30.6	36.7	3.0	4.0	14.6	18.9	3.5	3.0	2.3	2.1	0.06	0.06
6	25.8	26.3	3.0	2.5	13.5	17.3	2.9	2.5	1.4	1.0	0.07	0.06	25.9	29.9	2.0	2.5	16.2	18.9	2.7	3.2	2.4	2.6	0.05	0.05
													KATSINA-ALA											
1	27.4	27.4	1.0	1.5	13.5	16.2	1.8	1.4	1.5	1.6	0.06	0.06	28.2	27.9	2.5	1.5	15.7	16.7	1.8	1.5	2.0	1.5	0.06	0.07
2	26.0	28.0	2.0	2.0	13.5	13.5	1.6	2.7	1.7	1.8	0.06	0.08	27.4	23.4	2.8	2.0	16.2	17.8	1.9	1.8	2.0	1.5	0.09	0.06
3	26.6	31.6	2.5	2.0	14.0	12.4	2.0	2.1	2.4	1.6	0.06	0.08	23.8	24.3	2.5	2.5	16.2	17.3	2.3	2.0	1.1	1.8	0.06	0.07
4	29.6	30.8	2.5	2.5	13.0	14.6	1.5	2.2	1.5	1.8	0.06	0.07	23.7	29.6	3.0	2.5	16.2	15.6	2.2	1.8	2.1	1.5	0.07	0.06
5	27.4	23.4	2.5	2.5	10.8	14.6	1.8	1.8	1.7	1.9	0.05	0.06	29.2	25.4	2.5	2.5	17.8	17.3	2.6	2.7	2.3	1.7	0.05	
6	26.6	23.8	2.0	3.5	14.0	20.5	2.4	1.6	2.4	1.7	0.06	0.07	21.2	23.2	2.5	2.5	17.8	17.3	2.3	2.2	2.3	1.7	0.05	

Appendix 22: continued

Nutrient	1988												1989											
	Total N		Total P		Total K		Total Ca		Total Mg		Total Zn		Total N		Total P		Total K		Total Ca		Total Mg		Total Zn	
Block	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
										AVANGBA														
Treatment																								
1	35.0	40.0	1.5	3.0	8.1	10.8	1.5	1.8	1.1	1.8	0.04	0.06												
2	33.6	35.0	3.0	2.5	11.9	15.1	2.1	1.1	2.1	1.0	0.06	0.07												
3	32.5	25.2	2.5	2.5	12.4	13.0	2.0	2.0	1.9	1.9	0.06	0.05												
4	26.6	32.2	3.0	2.5	12.4	13.0	2.3	2.0	1.8	1.9	0.05	0.05												
5	25.3	29.4	2.0	2.5	10.8	10.8	2.6	2.3	2.2	2.1	0.06	0.06												
6	36.4	30.2	2.5	2.0	11.3	10.8	2.1	2.0																

Appendix 23: Field fertilizer rate studies: Dry grain yields of maize in Kuru site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	0	0	0	0	0
2	20	491.05	730.40	531.32	584.26	26.73
3	40	989.69	1120.56	1183.61	1097.95	50.22
4	60	1412.75	1373.66	1435.27	1407.23	64.37
5	80	2152.19	1928.77	1785.71	1955.56	89.45
6	100	2158.95	2092.22	2307.26	2186.14	100.0

Variance ratio: (i) Block = 0.006 ns; ; (ii) Treatment = 139.753*** (LSD 5% = 220.35)

Appendix 23 continued: Kuru site for the 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	0	0	0	0	0
2	20	168.92	183.69	167.68	173.43	13.99
3	40	458.15	521.04	385.43	454.87	36.69
4	60	943.58	844.52	787.54	858.55	69.25
5	80	1208.00	995.76	1179.67	1127.81	90.97
6	100	1386.55	1004.87	1327.92	1239.78	100.00

Variance ratio: Block = 1.557 ns; Treatment = 77.391*** (LSD 5% = 183.14)

Appendix 23 continued: Bokkos site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	581.53	532.87	604.26	572.89	17.87
2	20	931.66	974.90	849.21	918.59	28.65
3	40	1896.21	1926.93	2290.83	2037.99	63.55
4	60	2100.30	2161.55	1961.95	2074.60	64.70
5	80	1597.57	2445.70	2087.83	2043.70	63.73
6	100	3699.96	2903.26	3016.94	3206.72	100.00

Variance ratio: Block = 0.012 ns; Treatment = 31.064***

Appendix 23 continued: Bokkos site for 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	845.81	1291.62	1128.51	1088.65	46.53
2	20	1548.92	1939.68	1684.35	1724.32	73.69
3	40	1615.29	2414.11	2093.53	2040.98	87.23
4	60	2520.82	2036.05	1929.93	2162.27	92.[illegible]
5	80	2636.89	2270.39	2112.41	2339.90	100.00
6	100	1783.39	2145.20	2115.71	2014.77	86.10

Variance ratio: Block = 0.836 ns; Treatment = 7.431***(LSD 5% = 512.80)

Appendix 23 continued: Sabon Gida site for 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	767.61	718.05	544.33	676.66	19.86
2	20	2097.07	1657.30	1983.14	1912.50	56.13
3	40	3039.04	2823.10	3536.09	3132.74	91.94
4	60	2026.87	2444.43	2040.56	2170.62	63.71
5	80	3402.34	3129.13	3690.21	3407.23	100.00
6	100	3416.80	3320.98	2209.03	2982.27	87.53

Variance ratio: Block = 0.183 ns; Treatment = 20.388***(LSD = 708.06)

Appendix 23 continued: Sabon Gida site for 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	734.25	686.96	849.04	756.75	[illegible]
2	20	2182.86	2038.64	2225.18	2148.89	58.99
3	40	2843.73	2822.19	3211.02	2958.98	81.23
4	60	3020.93	3089.98	3151.88	3087.60	84.77
5	80	3558.93	3424.14	3460.27	3481.11	95.57
6	100	3615.74	3590.10	3721.71	3642.52	100.0

Variance ratio: Block = 5.427* (LSD = 157.74); Treatment = 462.879***

Appendix 23 continued: Wamba site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	2899.84	2755.03	2592.45	2749.11	71.41
2	20	4098.69	3194.87	3621.12	3638.23	94.50
3	40	4391.68	2936.15	4221.55	3849.79	100.00
4	60	3145.65	3337.58	3555.56	3346.26	86.92
5	80	3807.07	3629.50	4050.09	3828.89	99.46
6	100	3635.96	3720.27	2457.34	3271.19	84.97

Variance ratio: Block = 1.021 ns; Treatment = 2.180ns

Appendix 23 continued: Wamba site for the 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	2458.25	2626.42	2403.03	2495.90	64.47
2	20	3291.88	3465.50	2987.43	3248.27	83.90
3	40	3466.84	3658.84	3675.15	3600.28	92.99
4	60	3322.11	3503.37	3562.92	3462.80	89.44
5	80	4092.42	3817.49	3705.11	3871.67	100.00
6	100	3154.61	3845.33	3829.57	3609.84	93.24

Variance ratio: Block = 1.145 ns; Treatment = 14.291***(LSD = 399.48)

Appendix 23 continued: Laminga site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	2040.78	2007.10	1874.35	1974.08	39.0
2	20	3534.39	3136.36	3186.01	3285.59	64.91
3	40	4304.72	3440.49	3789.37	3844.86	75.96
4	60	4328.85	4701.98	4135.53	4388.79	86.70
5	80	5082.04	5225.13	4878.85	5062.01	100.0
6	100	4882.25	5686.50	4498.25	5022.33	99.22

Variance ratio: Block = 1.709 ns; Treatment = 38.513***(LSD = 597.77)

Appendix 23 continued: Laminga site for the 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	3445.29	2918.32	3116.05	3159.89	83.11
2	20	3279.79	4381.01	3746.0	3802.27	100.00
3	40	3854.58	3633.23	2897.59	3461.80	91.05
4	60	3545.32	3196.57	2796.61	3179.50	83.62
5	80	3584.22	3037.87	3108.14	3243.41	85.30
6	100	3588.68	3126.81	2648.29	3121.26	82.09

Variance ratio: Block = 2.776 ns; Treatment = 1.486 ns

Appendix 23 continued: Obi site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	459.17	557.87	619.85	545.63	17.56
2	20	2033.59	1286.81	1700.12	1673.51	53.86
3	40	1300.03	1667.03	1750.99	1572.68	50.61
4	60	2640.87	2823.83	3005.78	2823.49	90.87
5	80	2900.94	3460.76	2959.80	3107.17	100.00
6	100	2245.59	2080.78	2012.92	2113.10	68.01

Variance ratio: Block = 0.139 ns; Treatment = 38.440***(LSD = 472.11)

Appendix 23 continued: Obi site for the 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	531.82	903.83	806.17	747.27	28.23
2	20	1576.87	1747.73	1491.98	1605.53	60.66
3	40	1178.69	1736.51	1849.99	1588.31	60.01
4	60	1788.69	1770.22	1997.70	1852.20	69.98
5	80	1872.0	1945.51	1796.14	1871.20	70.70
6	100	2879.82	2482.70	2577.40	2646.64	100.00

Variance ratio: Block = 0.673ns; Treatment = 25.749***(LSD = 380.32)

Appendix 23 continued: Ankpa site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	1634.71	1851.11	1721.22	1735.68	60.58
2	20	1809.89	1948.66	2403.97	2054.17	71.70
3	40	2492.23	2214.79	2505.92	2404.31	83.92
4	60	2391.54	2383.70	2571.85	2449.03	85.48
5	80	2597.33	3096.77	2900.84	2864.98	100.00
6	100	3116.53	2887.80	2475.60	2826.64	98.66

Variance ratio: Block = 0.203 ns; Treatment = 9.505***(LSD = 448.05)

Appendix 23 continued: Ankpa site for the 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	1455.66	1007.52	703.09	1055.42	50.25
2	20	1889.70	1512.06	1774.77	1725.51	82.16
3	40	2079.79	1864.47	1705.40	1883.22	89.67
4	60	1611.0	1982.97	1900.95	1831.64	87.21
5	80	1907.40	1921.96	2471.48	2100.28	100.00
6	100	1568.06	1937.64	1766.44	1757.38	83.67

Variance ratio: Block = 0.045 ns; Treatment = 4.840*(LSD = 507.09)

Appendix 23 continued: Yandev site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	3826.71	3845.82	4274.69	3982.41	83.68
2	20	3704.25	2783.99	3533.96	3340.73	70.20
3	40	4896.20	3809.74	4177.44	4294.46	90.24
4	60	3689.22	4158.75	5131.06	4326.34	90.91
5	80	4170.06	4260.19	4239.19	4223.15	88.74
6	100	5171.38	4666.30	4439.33	4759.00	100.00

Variance ratio: Block = 1.200 ns; Treatment = 3.197ns

Appendix 23 continued: Yandev site for the 1989 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	2364.58	2888.79	2982.54	2745.30	64.69
2	20	3301.85	3280.17	3886.28	3489.43	82.23
3	40	3607.87	4624.53	3925.28	4052.56	95.50
4	60	2862.68	3342.80	2750.73	2985.40	70.35
5	80	3504.77	3802.08	5423.98	4243.61	100.00
6	100	3449.48	4613.13	3748.08	3936.90	92.77

Variance ratio: Block = 2.621 ns; Treatment = 4.164*(LSD = 939.10)

Appendix 23 continued: Katsina-Ala site for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	1161.41	1196.99	1177.28	1178.56	46.12
2	20	2602.83	2359.80	2703.36	2555.33	100.0
3	40	2474.0	2442.07	2386.12	2434.06	95.25
4	60	2213.76	2553.47	2294.97	2354.07	92.12
5	80	2384.01	2160.78	2846.08	2463.62	96.41
6	100	1851.56	1397.42	1698.36	1649.11	64.54

Variance ratio: Block = 1.047 ns; Treatment = 23.653***(LSD = 362.72)

Appendix 23 continued: Katsina-Ala for the 1988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	2217.93	3294.85	1353.80	2288.86	46.88
2	20	4477.88	3797.10	4217.11	4164.03	85.29
3	40	3712.09	3709.12	4012.58	3811.26	78.06
4	60	3764.80	4606.08	3980.63	4117.17	84.33
5	80	4867.16	5011.12	4768.23	4882.17	100.00
6	100	4724.45	4061.03	3705.67	4163.72	85.28

Variance ratio: Block = 1.006 ns; Treatment = 8.633***(LSD = 929.30)

Appendix 23 continued: Ayangba site for the 988 cropping season.

Treatment No.	Amount of P_2O_5 added (kg/ha)	Dry Grain Yields (kg/ha)			Mean yield (kg/ha)	Relative yield (%)
		Block A	Block B	Block C		
1	0	1825.56	1198.54	1908.65	1644.25	83.11
2	20	1931.98	2426.20	1576.80	1978.33	100.00
3	40	1569.71	2064.86	1127.03	1587.20	80.23
4	60	1978.67	1741.88	1229.85	1650.13	83.41
5	80	2326.72	1361.89	1092.83	1593.81	80.56
6	100	1835.81	2032.09	2039.13	1969.01	99.53

Variance ratio: Block = 1.63 ns; Treatment = 0.60 ns