EVALUATION OF MEHLICH - 3 AS A MULTIPURPOSE EXTRACTANT OF PHOSPHORUS AND POTASSIUM USING BELL PEPPER *(Capsicum annuum* L.) IN SOME NIGERIAN SOILS

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BY

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ABSTRACT

Use of single soil specific extractants to determine plant available phosphorus and exchangeable potassium for crops such as bell pepper, are costly, laborious and time wasting. Bell pepper, rich in antioxidants, requires phosphorus and potassium for high quality fruit yield. Mehlich-3 (M3), a multi-purpose extractant could extract phosphorus and potassium simultaneously. However, M3 has not been evaluated and adapted for Nigerian soils. Therefore, M3 as a multi-purpose extractant of P and K from soil for bell pepper was evaluated.

Phosphorus and potassium extractions were carried out on soil (0–15 cm) samples from 12 purposively selected sites belonging to eight soil series across three agro-ecological zones (derived savanna, humid forest and northern guinea savanna) of Nigeria. Bray 1 (B1), Bray 2 (B2) and Olsen were used to extract phosphorus; 1M Ammonium acetate pH 7.0 (AAc) was used to extract potassium, while M3, Ammonium hydrogen flouride+DTPA (ABD) and modified M3 (MM3) were used to extract phosphorus and potassium simultaneously. Concentrations of phosphorus and potassium extracted by different extractants were determined using standard procedures. In the screenhouse, pots were filled with 3 kg each of the 12 soil samples and laid in a completely randomised design (n=108). Bell pepper was grown at one plant per pot for four weeks. Phosphorus and potassium uptakes were determined. Field experiment was conducted on Egbeda, Apomu and Jago soil series for three cropping seasons to determine critical range of soil phosphorus and potassium and optimum fertiliser rates using M3. Phosphorus (0, 30, 45 and 60 kg/ha) and potassium (0, 15, 30 and 45 kg/ha) were applied in a split plot arrangement in a randomised complete block design, replicated thrice. Fruit yield of bell pepper was measured. Data were analysed using descriptive statistics, correlation and quadratic regression at $\alpha_{0.05}$.

Phosphorus extracted by B1, B2, Olsen, ABD, MM3 and M3 were 8.34±1.22, 11.19±2.62, 5.11±1.68, 30.33±4.32, 15.68±3.48 and 14.41±4.32 mg/kg, respectively, while potassium extracted by AAc, ABD, MM3 and M3 were 0.47±0.02, 0.21±0.02, 0.36±0.05 and 0.59±0.09 cmol/kg, respectively. Phosphorus and potassium uptakes were 2.34±0.5 and 22.62±2.28 g/kg, respectively. Significant correlations exist between extracted phosphorus and potassium with their uptakes, except ABD for potassium. Correlations of phosphorus and potassium extracted by M3 with their uptakes were the highest (r=0.95), while the lowest was in B1 (0.78) for phosphorus and MM3 (0.93) for potassium. The yields (t/ha) of bell pepper across seasons were 15.02±0.51 (Egbeda), 14.19±0.36 (Apomu) and 5.15±0.40 (Jago). Fruit yield was significantly influenced by applied fertilisers with phosphorus lowest in Apomu (r^2=0.65) and highest in Jago (r^2=0.99), for potassium, the least was in Jago (r^2=0.52) and highest in Egbeda (r^2=0.99). Critical ranges of phosphorus and potassium in the soils were 15 (Apomu) to 20 (Jago) mg/kg and 0.20 (Apomu) to 0.25 (Jago) cmol/kg, respectively. Optimum phosphorus and potassium concentrations for bell pepper were 45 kg/ha and 30 kg/ha, respectively.

Mehlich-3 is a good simultaneous extractant of phosphorus and potassium across the agro-ecological zones. It is therefore recommended for evaluating soil phosphorus and potassium.

Keywords: Multipurpose soil extractants; Mehlich-3 extractant; Phosphorus uptake; Bell pepper yield;

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I pray for all the known and unknown people that have contributed to my academic progress that God's blessings shall locate them and manifest in their lives in Jesus name. Amen.

CERTIFICATION

I certify that this work was carried out by Mr Oluwayombo Olawale Olufunmi in the Department of Agronomy, University of Ibadan.

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DEDICATION

This work is dedicated to the glory of God the Father, the Son and the Holy Spirit, who have without measure, been my strength and guide from ages past; the author and the finisher of this work.

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CHAPTER ONE

INTRODUCTION

Phosphorus (P) is the next most limiting nutrient after Nitrogen (N) in essentiality to crop production followed by Potassium (K). Adequate supply of P and K to crops requires assessing the fertility status of the soil. Soil fertility refers to the inherent biological, chemical and physical capacity of a soil to support profitable crop yield. Maintaining soil fertility is often one of the challenges of profitable agricultural production. For this, there is need for adequate supply of essential nutrients to the crop. Soil fertility assessment is the determination of the ability of a soil to produce maximally, which is necessary in modern day agricultural enterprise for profitability. There are many methods of assessing soil fertility status. They include: use of deficiency symptoms, field trial, plant analysis, soil analysis, tissue analysis, microbiological assay and greenhouse trial.

Among the above listed methods, soil analysis is rated as the best way of assessing the fertility status of the soil due to its advantages of being rapid, accurate and timely. Soil testing is defined as the assessment of chemical properties of a soil for predicting accurately its fertiliser requirement (Sobulo and Adepetu, 1987). Through soil testing, a relative measure of the amount of nutrients in the soil is obtained (Matula, 2009). Although, physical properties like texture, bulk density, water holding capacity and infiltration rate are important indices in predicting productivity of soils, they do not form the basis for fertiliser recommendation (Sobulo and Adepetu, 1987).

Soil testing has the advantage of ensuring balanced nutrient application thus helping to avoid soil pollution and nutrient imbalance which result from indiscriminate and imprecise fertiliser application. One of the advantages of a soil test is that plant nutrient disorder resulting from soil nutrient deficiency can be detected before they are visible in the plant. It ensures high net return per unit cost of fertiliser applied by predetermining the rate of fertiliser needed to sustain crop production and guarantees high yield in such a system. It also incorporates other management practices in a technological package for extension workers and field agents. Soil fertility studies thus focus on adequate and balanced supply of nutrients to satisfy the needs of plants, avoiding toxic concentration. It evaluates the soil status with respect to its ability and capacity to supply nutrients for plant growth. Developing a soil testing programme involves: Background research, field sampling, extraction and chemical analysis, correlation, calibration, data interpretation and fertiliser recommendation. Based on such a programme, many extractants have been developed for different elements and specific soils. Efficiency of soil testing programme could be improved by eliminating the need for multiple or separate extractants for P and K.

The main concern of this work is the evaluation (correlation and calibration) of Mehlich-3 extractant for Phosphorus and Potassium using bell pepper as test crop. Correlation enables the selection of an appropriate extractant that would extract a nutrient in vitro the same way in which the plant in the field does, while calibration gives the quantity of fertiliser nutrient to be added to the soil per unit area at a particular soil test value for a specific yield. Correlating P and K uptake by bell pepper with amount extracted by Mehlich-3 would confirm the suitability or otherwise of Mehlich-3 extractant for P and K (Self, 2004). On the other hand, calibration would enable the prediction of bell pepper yield at a given soil P or K level thereby ensuring application of appropriate quantity of the nutrients.

Current soil test measurements of available P and exchangeable K for fertiliser recommendation on Nigerian soils involve the use of separate soil extractants (Nzewi, 1979), which makes extraction of P and K for subsequent determination by colorimetric and Flame Photometry methods laborious, time consuming and expensive. Bray’s 1, 2 and Olsen extractants are recommended to measure available P depending on the agro-ecological zones where the soil is collected from, while 1M Ammonium acetate pH 7.0 is for K across all agro-ecological zones. The high cost of soil analysis in Nigeria is a major factor why farmers do not carry out soil testing before planting out their crops in the field and this eventually results in low economic returns. In situations where fertiliser application is inevitable, blanket application is adopted. Such a generic fertiliser use in crop production does not only result in low yield and crop quality due to nutrient imbalance but also soil degradation and pollution.

Bray 1 and 2 soil extractants are single element extractants as developed for Phosphorus extraction by Bray and Kurtz (1945) although Ayodele and Agboola

(1981) and Adeoye (1986) used it for both P and K) while 1M Ammonium acetate pH 7.0 (Schollenberger and Simon, 1945) is a multipurpose extractant used in the extraction of exchangeable bases (Na, K, Ca, Mg) and micronutrient such as Mn. The use of a multipurpose extractant such as the Mehlich-3 (Mehlich, 1984) affords soil chemists and commercial laboratories the luxury of extracting more than one element from the soil in their available form in one single extraction. However, M3 has not been evaluated and adapted for Nigerian soils. Therefore having a multipurpose extractant for simultaneous extraction of P and K will be beneficial to rapid and routine analysis. Mehlich-3 is a modification of Mehlich-2 extractant to include Cu among the extractable nutrients, retain or enhance the wide range of soils for which it is suitable and minimize its corrosive properties. The substitution of nitrate for chloride anions and the addition of EDTA accomplished those objectives (Mehlich, 1984). It was intended to extract P, K, Ca, Mg, Zn, Cu, and Mn.

Mehlich-3 extractant has already been adopted in many countries. For national standardisation there is a need therefore to evaluate and adapt it to Nigerian soils in different agro-ecological zones. Evaluating and adapting Mehlich-3 to Nigerian soils requires soil specific experimentation on a specific crop which this study addresses. The objectives of this study therefore are to:

1. compare single and multipurpose extractants of P and K including Mehlich-3,
2. relate Mehlich-3 extracted soil P and K to P and K uptake of bell pepper,
3. derive conversion equations between Mehlich-3 and recommended extractant(s) of P and K,
4. determine relationships between P and K soil test values by Mehlich-3 and yield of bell pepper.
5. establish critical range of soil P and K and optimum fertiliser rates using M3

CHAPTER 2

LITERATURE REVIEW

2.0 History of development of extractants

The awareness of the need for extractant, its development and use began as early as late nineteenth century when the interest of man for agriculture began. Tisdale *et. al.* (1975) corroborated an earlier work that plants excrete weak acids – a thought that led to the theory that weak acids could be used to assess soil nutrient status.

The search for the principle and knowledge of plant nutrition and feeding habits led to the development of soil chemistry and extractant. Various solutions such as water, mineral acids, organic acids, bases, salt solution or combination of acids have been used in the development of extractants. Lots of works have also gone into investigation of extractant from Daubeny in 1845, which used carbonated water as an extractant and Liebig (1873) that used dilute solutions of hydrogen chloride (HCl) and nitric acid (HNO_3) to extract different quantities of phosphorus and potassium. In 1894 Dyer used 1% nitric acid as a solvent. Morgan (1941) noted that it is difficult to have a solution/extractant that will extract the same quantity of nutrients from the soil as the plant. The important thing then is to get high correlation between the amount of nutrients extracted from the soil and plant uptake. A solution or extractant, whether organic, inorganic, base, acid, salt or a combination of any of these becomes suitable when it can remove nutrients elements from the soil in their available forms. It is also important that there should be a significantly positive high correlation between available nutrients in soil and plant uptake of nutrients or relative yield.

In Nigeria a lot of information has been obtained on extractant development. Sobulo (1983) recommended 1M NH_4OAc pH 7 for K among other four extractants that he worked on (0.1M HNO_3, 0.13N HCl, Morgan solution and 0.01M $CaCl_2$). Wild (1971) recommended both 0.01M and 0.001M $CaCl_2$ for K in Northern soils while Ekpete (1972) recommended 0.01M $CaCl_2$ for K in Eastern soils. Other workers like Oko (1974) used Ammonium hydrogen flouride ($NH_4F.HF$) extractant to estimate P availability in Rice in the rain forest sedimentary soils of Western Nigeria. Ayodele (1980) also recommended 0.1M $NH_4F.HF$ at pH of 4.1, 4.3 and 5.0 as a suitable extractant for P evaluation in Savannah soils of South-Western Nigeria. Akinrinde (1987) observed significant correlation between K extracted by Electro-Ultrafiltation (EUF) Technique and 1M NH_4OAc but not with P extracted by EUF and Bray P1 on soils covering various ecological zones and parent materials within Nigeria.

Developments of extractant involve correlation and calibrations studies or tests which are either carried out in the screenhouse or field. A reliable soil test correlates soil nutrients to plant use and fertiliser recommendations, calibrates tests to field conditions for individual crop, specific soil and agro-ecology. Once the relationship between soil test values, fertiliser rates and crop yield is known, it is possible to determine the most economic fertiliser rate. Soil testing requires not only reliable methods of analysis but also reliable field calibration data over some years.

Plants can only use certain forms of nutrients, which is a very small portion of the total amount of that nutrient in the soil. Therefore, test results are often called "availability indices". Such an index relates specific laboratory test values to availability (Self, 2004).

A suitable soil extractant must (i) extract nutrient from the labile pool which supplies nutrients to plant roots (ii) be rapid, reproducible and economical (Havlin and Soltanpour, 1981). Matula (2009) considers an extractant to be suitable if it satisfies the following conditions: simultaneous extraction of all important nutrients from the soil, efficient in all soil types, accurate and reproducible, simple, not expensive, good for expeditious detection and relate soil available nutrients to plant nutrients.

2.1 Chelates

Chelates, also known as ligands have been in use solely or added to other extractants to enhance extraction of metals from the soil. Usually these ligands are organic compounds, and are called chelants, chelators, chelating agents, or sequestering agents. In general, ligands are viewed as electron donors and the metals as electron acceptors. This is because the ligand and central metal are bonded to one another, and the ligand is providing both electrons to the bond instead of the metal and ligand each providing one electron.

The process whereby chelates extract metals from a medium such as the soil is referred to as chelation. Chelation describes ways that ions and molecules bind metal ions. Chelation involves the formation or presence of two or more separate coordinate bonds between a polydentate (multiple bonded) ligand and a single central atom. Chelate effect describes the enhanced affinity of chelating ligands for a metal ion compared to the affinity of a collection of similar non-chelating (monodentate) ligands for the same metal. The most commonly used chelating agents in combination with other extractants are ethylene diamine triacetic acid (EDTA) and diethylene triamine penta acetic acid.

2.1.1 Ethylene diamine triacetic acid (EDTA)

It is a white, water-soluble solid with Molecular formula $C_{10}H_{16}N_2O_8$ and Molar Mass 292.24 g mol^{-1}. In coordination chemistry, $EDTA^{4-}$ is a member of the aminopolycarboxylic acid family of ligands. $EDTA^{4-}$ usually binds to a metal cation through its two amines and four carboxylates. Many of the resulting coordination compounds adopt octahedral geometry. Although of little consequence for its applications, these octahedral complexes are chiral. The anion $[Co(EDTA)]^{-}$ has been resolved into enantiomers Kirchner (1957). Many complexes of $EDTA^{4-}$ adopt more complex structures due to (i) the formation of an additional bond to water, i.e. seven-coordinate complexes, or (ii) the displacement of one carboxylate arm by water. Ferric complex of EDTA is seven-coordinate (López-Alcalá et al,1984). EDTA forms especially strong complexes with Mn(II), Cu(II), Fe(III), Pb(II) and Co(III) as described by Holleman et al (2001).

Several features of EDTA's complexes are relevant to its applications. First, because of its high denticity, this ligand has a high affinity for metal cations (Fig.2.1):

$$[Fe(H_2O)_6]^{3+} + H_4EDTA \rightleftarrows [Fe(EDTA)]^{-} + 6\ H_2O + 4\ H^{+}\ (\underline{K_{eq}} = 10^{25.1})$$

Written in this way, the equilibrium quotient shows that metal ions compete with protons for binding to EDTA. Because metal ions are extensively enveloped by EDTA (Fig.2.2), their catalytic properties are often suppressed. Finally, since complexes of $EDTA^{4-}$ are anionic, they tend to be highly soluble in water. For this reason, EDTA is able to dissolve deposits of metal oxides and carbonates.

2.1.2 Diethylene triamine pentaacetic acid (DTPA)

Pentetic acid or diethylene triamine pentaacetic acid (DTPA) is anaminopolycarboxylic acid consisting of a diethylenetriamine backbone with five carboxymethyl groups (Fig.2.3). The molecule can be viewed as an expanded version of EDTA and is used similarly. It is a white, water-soluble solid with Molecular formula $C_{14}H_{23}N_3O_{10}$ and Molar Mass 393.35 g mol^{-1}.

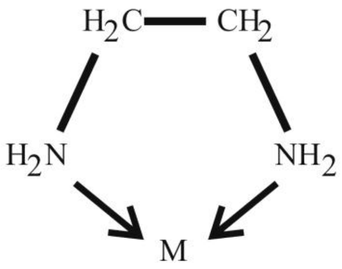

Fig. 2.1 Ethylene diamine triacetic acid ligand, binding to a central atom with two bonds

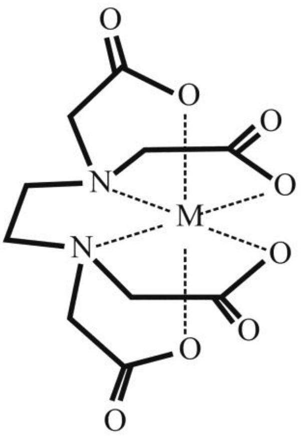

Fig. 2.2 Metal-EDTA chelate

The conjugate base of DTPA has a high affinity for metal cations. Thus, the penta-anion $DTPA^{5-}$ is potentially an octadentate ligand assuming that each nitrogen centre and each COO^{-}-group counts as a centre for coordination. The formation constants for its complexes are about 100 greater than those for EDTA (Hart, 2005). As a chelating agent, DTPA wraps around a metal ion by forming up to eight bonds. Transition metals, however, usually form less than eight coordination bonds. So, after forming a complex with a metal, DTPA still has the ability to bind to other reagents, as is shown by its derivative pendetide. For example, in its complex with Copper (II), DTPA binds in a hexadentate manner utilizing the three amine centres and three of the five carboxylates (Fomenko et al, 1973).

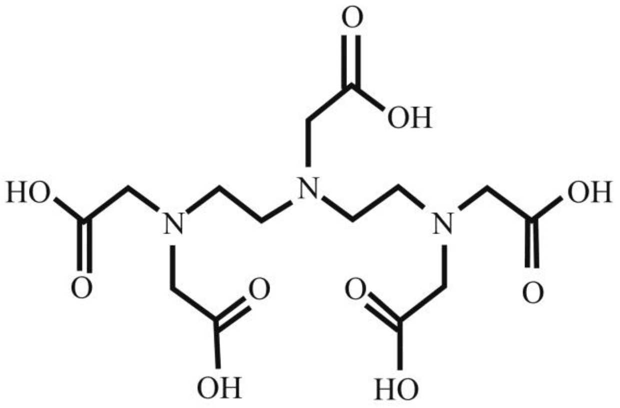

Fig. 2.3 Structure of Diethylene triamine pentaacetic acid (DTPA)

The use or inclusion of Chelating chemicals/agents such as Ethylenediamine tetraacetic acid (EDTA) and Diethylene triamine pentaacetic acid (DTPA) has been well documented for micronutrient soil test by Lindsay and Norvell, (1969,1978); Lindsay et al, (1967); Lindsay, (1974, 1979) and Norvell, (1972).

Hunter (1972) modified Olsen's NaHCO3 with the addition of 0.01M EDTA to predict Cu, Mn, Fe and Zn. According to Provin and McFarland (1998) addition of the EDTA-H_4 in acidified ammonium acetate-EDTA extractant for the prediction of plant available phosphorus is to reduce calcium-phosphorus precipitation following extraction. The highly buffered acidic nature of the extraction can dissolve significant quantities of calcium carbonate. This dissolution of carbonates may be liberating bound phosphates, which are not readily available to the plant.

A comparative study by Njukeng et al. (2013) on the use of Calcium Acetate Lactate, Calcium Chloride and Acidic Ammonium Acetate- Ethylene Diaminetetra Acetic Acid (AAAc-EDTA) for the Quantification of Extractable, P, K and Mg from Acidic Soils, revealed that the extraction methods were poorly correlated to each other except the methods for P. However, the AAAc-EDTA extracting solution offers the advantage of extracting many nutrients and can save time and energy. Thus, the presence of EDTA in Mehlich-3 extractant and substitution with DTPA in another extractant in this study is to investigate further, the roles of chelates in extractants of P and K.

2.2 Soil test correlation

Correlation is the process through which extractants are selected as being suitable for the extraction of a nutrient in forms available to plants in a soil. Corey (1972) defined correlation as the establishment of a relationship between a quantity of extractable nutrients and plant uptake under screenhouse or field conditions. It was expressed as the relationship between soil test values and crop growth from field of unknown response by Thomas and Hanway (1968). Nevertheless, correlation is better carried out in the screenhouse where other growth parameters are kept constant apart from the ones of interest.

Correlation coefficient denoted by “r” indicates how best extractants predict plant uptake. The higher the r value the better the extractant.

Many types of chemical solutions may be used to extract nutrients from soil in the laboratory. The key is to find one that will extract an amount of a nutrient proportional to what a plant extracts. To determine this, experiments are carried out in the screenhouse where plants are grown in pots on soils collected from sites that fertiliser recommendations is intended.

After the desired growth period, the plants are harvested and analyzed. The amount of nutrient extracted by the plants is then compared with that extracted by the extractant. If the extractant correlates (compared) well with plant uptake, it is selected. Bray (1937) observed that different plants exhibit varying ability to absorb identical forms of a nutrient. Introduction of the concept of relative yield (RY) makes correlation studies a useful analytical tool. Sims (1989) comparing Mehlich 1 and 3 extractants for P, K, Ca, Mg, Mn, Cu and Zn in Atlantic coastal plain soils, observed high significant correlations between M3 and M1 for P and K.

2.3 Soil test calibration

Soil test calibration refers to the determination of relationship between laboratory test values and yields response due to fertiliser application and indicates the test values at which response are expected. From the yield curve soil test values are classified into low, medium, high and very high on the basis of responses to fertiliser application.

Soil and climate can greatly influence the reliability of fertiliser recommendations based on a soil test. For instance, a recommendation that is satisfactory in semi-arid areas where alkaline, calcareous soils are common may not be satisfactory for other parts of the country where soil and climate are very different. Once a test has been selected, it must be calibrated (related) to field conditions for individual crops.

This involves growing crops on fields treated with different rates of nutrients being evaluated. Nutrient rates range from zero to more than adequate for optimum yields. By conducting a series of experiments usually over several years, on a wide range of soils, it is possible to relate the laboratory soil test value to actual field yields and rates of fertiliser necessary to achieve optimum yields.

In calibration study, the term critical or highest level, plateau yields, sufficiency and toxicity levels are very useful deductions that could be made from a graphical representation of crop yield against soil test values. A typical calibration yield curve is shown in Fig. 2.4. Beegle and Oravec (1990) in comparison of field calibrations for Mehlich 3 P and K with Bray-Kurtz P1 and ammonium acetate K for corn, found high correlations with the Bray-Kurtz P1 extractant (r=0.99) and neutral 1M ammonium acetate K extractant (r=0.96). While P field calibrations for the Mehlich-3 P and Bray-Kurtz P1, Mehlich 3 and the neutral, 1M ammonium acetate K were similar.

2.4 Critical level

Critical level is defined by Waugh et al. (1973) as the soil test value above which response is not expected and below which a large yield response can be obtained with adequate supply of a given nutrient. Hunter (1972) said it is the variability below and above which plant growth is retarded depending on how far removed from the critical limits the element is. It was defined by Ulrich (1952) in terms of nutrient concentration that is just deficient for optimum growth or that which is just adequate for optimum growth or as nutrient concentration in the tissue associated with a 10% reduction from optimum growth due to deficiency. Critical levels are crop and extractant specific. The critical concentration of available K at which deficiencies occur, could be up to 0.45 cmol/kg in most tropical soils, but Adeoye (1986) observed critical level of K to be 0.20 cmol/kg.

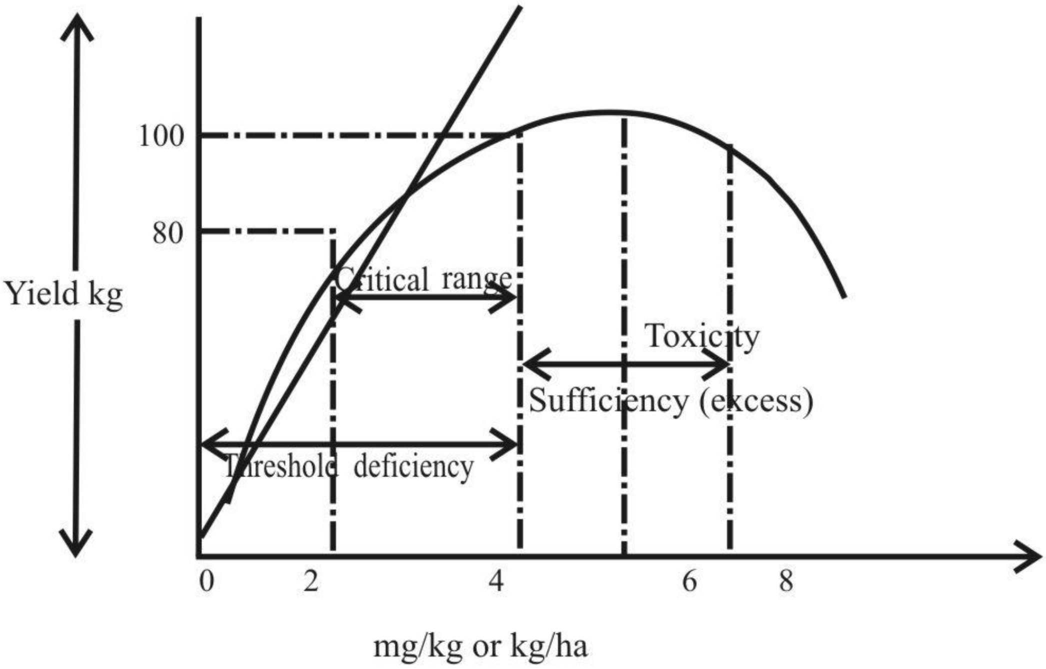

Fig.2.4 Typical calibration curve of yield against applied/available nutrient

However, in an earlier work by Heathcote and Stockinger (1970), responses were found in cereal crops to potassium fertiliser in the savannah area where the soils contained up to 0.20 cmol/kg K. Also, Lombin and Mustafa (1981), on cotton, observed significant response to K where available K in soil was 0.10 cmol/kg. Values of K as high as 1.92 cmol/kg was reported by Akinyede (1988) while Amao (1991) reported 3.07 – 2.41 cmol/kg for savannah and forest soils. Beegle and Oravec (1990) reported critical levels of 43 and 45 kg P ha^{-1} for the Bray-Kurtz P1 and Mehlich-3 P extractants respectively and 0.20 and 0.24 cmol kg^{-1} for Mehlich 3 and neutral, 1M ammonium acetate extractants of K respectively.

Critical levels for P are based on Bray 1 or 2 and Olsen extractants while K is on 1M Ammonium Acetate pH 7.0. There is dearth of information on the critical levels of Phosphorus and Potassium based on Mehlich-3 extractant for crops on Nigerian soil and therefore needs to be done for optimal production of this high valued commercial crop. Fertiliser recommendations based on soil test correlation, calibration and interpretations with Mehlich-3 have to be carried out in many locations cutting across different agro-ecological zones, soil types and classes. Results obtained from these tests will be used to rate soils into fertility classes (critical levels) such as defined below:

Low:	A soil test value is classified as low when the result is below the critical level resulting into nutrient deficiencies and low yield. Low soil test value is an indication that fertiliser should be applied.
Medium:	This is the range of soil test values above the critical level where different responses to fertiliser application is expected. Soil test values in this range require less fertiliser to attain optimum yield than when the test value is low.
High:	This is the range of soil test values where responses to fertiliser application are unlikely. Fertiliser application may lead to yield depression and nutrient toxicity.

The recommended existing soil fertility ratings (Chude et al. 2004) for P and K are shown below

Available Phosphorus (P)

(i) Bray P1

Low: < 8ppm
Medium: 8 – 20ppm
High: > 20ppm

(ii) Bray P2
Low: < 15ppm
Medium: 15 – 25ppm
High: >25ppm

(iii) Mehlich-1
Low: < 7.30ppm
Medium: 7.30 – 15ppm
High: >15ppm

Exchangeable Potassium (K)

(i) 1M Ammonium Acetate pH 7.0
Low: < 0.20 cmol/kg
Medium: 0.20 – 0.40 cmol/kg
High: >0.40 cmol/kg

2.5 Relative yield concept

Relative yield concept is a tool used to interpret the yield of a crop in relation to rate of fertiliser applied. Relative yield (% RY) is the crop yield in the absence of a given nutrient expressed as a percentage of the crop yield with complete nutrients.

$$\text{RY}(\%) = \frac{crop\ yield\ (complete\ nutrient) - x}{crop\ yield\ (complete\ nutrient)} \times 100$$

where x = crop yield without N, P, K e.t.c.

it could also be

$$\frac{yield\ with\ no\ fertilizer}{yield\ with\ adequate\ fertilizer} \times 100$$

In this study RY is calculated as

$$\mathrm{RY}(\%) = \frac{\text{yield of a treatment}}{\text{yield of a treatment with highest P or K}} \times 100$$

and

$$\mathrm{RNUP} = \frac{\text{P or K uptake in a treatment}}{\text{P or K uptake in treatment with highest P or K}} \times 100$$

where RNUP is the relative nutrient (P or K) uptake of Bell Pepper

The RY therefore provides a basis for comparing yields from different sites when yield varies due to measurable factors. It can be used to compare yield from one year to another. Waugh *et al*. (1973) ascribe positive yield to the correction of a deficiency. The lower limits of origin of the response curve are due to the level of the available soil nutrient and it is termed threshold or traditional yield level. The upper limit or end of the response curve represents the optimum yield.

2.6 Available phosphorus

Phosphorus is the next most limiting nutrient after N to crop production. It exists principally in organic and inorganic forms. The total amount of P in South Western Nigeria seems to be influenced by parent rock, vegetation and cropping history (Okeya, 1979).

Phosphorus is important to plant growth for various reasons listed below (Chude *et. al*. 2004): It is a constituent of certain amino acids, phosphatide, nuclei acids, proteins, phospholipids and coenzymes NAD, NADP and ATP, it is necessary for cell division, a constituent of chromosomes and stimulation of root development as well as meristematic growth; seed and fruit development and stimulates flowering. Deficiencies of Phosphorus result into: delayed maturity and lack of or poor seed and fruit development, stunted appearance with mature leaves having dark to blue-green coloration and restricted root development and in acute deficiency of P purpling of leaves and stems with spindly growth do occur.

Forest soils on basement complex have higher total P than forest soils on sedimentary materials (Uzu *et al*., 1975). On newly cleared land, large quantities of P may be available from organic form or from plant ash following burning of vegetation (Kang and Juo, 1979). Organic P which constitutes a significant part of total P in the plough layer of South Western Nigeria soils had been found to range from 36 – 79% (Adepetu and Corey, 1975). Inorganic P exits in the form and order Fe – P (49%). Occluded – P (26%), Al – P (20%) and Ca – P (5%). Most of the mineralized P and added P (fertiliser) were to Fe – P and Al – P. Kang and Juo (1979) explained that P plays an important role in balanced fertiliser application for food crop production with deficiency resulting in limited crop growth and sometimes crop failure. Furthermore, P deficiency in soil is known to retard nitrification thereby reducing the efficiency of ammonium nitrogen fertilisers.

Distilled water has been employed as an extractant of P from the soil (Obigbesan, 1970; Agboola, 1973 and Sorn Srivichal *et al*. 1988). As observed, small quantity of P was extracted while the extract was cloudy for colourimetric determination. Distilled water extraction of P would have been an environmentally friendly option if not for the disadvantages. Phosphorus is absorbed by plants in either the monovalent phosphate ion ($H_2PO_4^{1-}$), or as the divalent phosphate ion (HPO_4^{2-}). The ion absorbed is determined by the pH of the soil. The $H_2PO_4^{1-}$ predominates in soil less than 7.2 and HPO_4^{2-} of pH greater than 7.2. Soil inorganic P consists of labile, active and stable pools. The labile pool, which is about twice the active pool, is in rapid equilibrium with the active pool. Mengel (1985) noted that phosphate concentration of the soil solution is influenced by plant uptake, assimilation or release of inorganic PO_4^{3-} from the pool of organic PO_4^{3-}, quantity of P adsorption sites and the potentials of the equilibrium with calcium phosphate. Knowledge of quantity intensity relationship i.e. P buffering capacity or fixing capacity of the soils is required for the interpretation of the available P values and fertiliser recommendation from established critical plant requirement.

Many extractants have been developed for P analysis. They include Bray- P1 and P2 (Bray and Kurtz, 1945), Sodium Bicarbonate (Olsen *et al.*, 1954), Ammonium hydrogen flouride (Agboola and Omueti, 1980, Agboola, 1981 and Adeoye, 1986) and Mehlich-3 (Mehlich, 1984).

2.6.1 Bray extractants

Bray 1 extractant is prepared by adding 15 ml of 1.0M NH_4F and 25 ml of 0.5M HCl to 460 ml of distilled water to obtain a solution containing 0.03 M NH_4F and 0.025 M HCl. The soil/extracting solution ratios and shaking time vary among users. Soil solution ratio of 1:5 or 1:10 and a shaking time of 1 minute (Nzewi, 1979). For acid soils, Flourine promotes P desorption by decreasing Al activity through the formation of Al and Fe complexes. Fluoride also is effective in suppressing the re-adsorption of Aluminium P by soil colloids. However, the Bray P1– test (Bray & Kurtz, 1945) performs unsatisfactorily in highly calcareous soils due to the neutralization of the acid by calcium carbonate ($CaCO_3$ and formation of CaF_2, which reacts with dissolved P to form secondary precipitates (Tran *et al.*, 1990). This is the main reason why this method is not used on soils of Eastern and Northern Nigeria. Bray 2 extractant is almost the same with Bray-P1 but the HCl concentration is increased by a factor of 4 to 0.1M. It is more suitable for acid soils.

2.6.2 Olsen extractant (0.5M $NaHCO_3$)

About 42.0 g of $NaHCO_3$ is dissolved in about 950 ml of distilled water and the pH adjusted to 8.5 and diluted to 1L with distilled water.

The OH^- and CO_3^{2-} anions in $NaHCO_3$ solution decrease the concentration or activity of Ca^{2+} and Al^{3+},resulting in increased P solubility in soils. The extractant is useful for both acid and calcareous soils. In calcareous soils, increased calcium phosphate solubility results from the decreased Ca concentration by the high concentration of CO_3^{2-} and the precipitation of $CaCO_3$. In acid or neutral soils, the solubility of Aluminium and iron phosphates increases as increased OH^- concentration decreases Al^{3+} by aluminate complex formation and of Fe^{3+} by precipitation as the oxide. The increased surface negative charges and /or decreased number of sorption sites on Fe and Al oxide surfaces at high pH levels could be responsible for the desorption of sorbed P as well.

2.6.3 Mehlich-3 extractant

Mehlich-3 extracting solution contains 0.2 M CH_3COOH + 0.25 M NH_4NO_3 + 0.015 M NH_4F + 0.013 M HNO_3 + 0.001 M EDTA. This extractant has been shown to be effective at predicting crop response to P across soils with acid to alkaline pH ($CaCO_3$ –affected soils) and varying organic carbon levels by Tran et al (1990) and Mallarino (2003). Atia and Mallarino's work in 2002 found linear correlations between soil P measured by Olsen, Mehlich-3, Fe-P and Resin membrane soil P test across Iowa calcareous and non-calcareous soils. Mallarino and Atia (2005) reported P extracted by Bray and Mehlich-3 to be highly correlated with exceptions on high calcareous soils in a study of "Correlation of Resin Membrane Soil and Phosphorus Test with Corn Yield and Routine Soil Test" on Iowa soils.

2.6.4 Ammonium hydrogen flouride ($NH_4F.HF$) extractant

This extractant was investigated at Agronomy Department, University of Ibadan in 1986 by Adeoye, in his Ph.D work which emanated from a preliminary work of Agboola and Omueti (1980) and Agboola (1981) on the assessment of P, K, and Mg. He compared Ammonium hydrogen flouride Chelate extractant and some conventional extractants on sedimentary soils of Western Nigeria. Ammonium hydrogen flouride was prepared in different concentrations (buffered and unbuffered) in combination with either EDTA or DTPA. He discovered that Bray P1 extracted more P than Ammonium hydrogen flouride and that the amount of P extracted increases with Ammonium hydrogen flouride concentrations while more P was extracted when combined with EDTA than DTPA. A negative correlation was also observed between pH and amount of P extracted while more P was extracted at lower pH.

In a work on response of pepper cultivar to N and P fertiliser application by Olanrewaju and Sowemimo (2003) on a Sandy Loam Alfisol, highest yield was obtained at 24.2 kg P/ha. In a similar earlier work by Aliyu et al. (1996) optimum economic yield was recorded at 24 kg P/ha. There was consistency on rate of P fertiliser requirement of 24 kg P/ha.

2.7 Exchangeable potassium (K)

The primary sources of K in the soil are the K-bearing minerals such as the Micas and Feldpars (Eshett and Omueti, 1994).

Potassium is the major nutrient required by plant after phosphorus and plays important roles in plant metabolic activities (Fujiwara, 1964; Chevailer, 1971; Chude et al, 2004)

Potassium as a macro nutrient:

1. improves utilization of light during cool and cloudy weather and thereby enhances plant ability to resist cold, diseases and other adverse conditions.
2. increases the size of grains or seeds and improves the quality of fruits and vegetables.

3. activates enzyme involved in photosynthesis and protein and carbohydrate metabolism.
4. assists carbohydrate translocation; synthesis of protein and maintenance of its stability; membrane permeability and pH control; water utilization by stomata regulation.
5. increases utilization of light even in cool and cloudy weather and
6. promotes respiration in rice plants.

Expression of potassium deficiencies include shrivelled seeds of fruits, slow and stunted growth of plants, weak stalk and easy lodging of plants, chlorosis along the leaf margins followed by scorching and browning of tips of older leaves gradually progressing inwards.

2.8 Exchangeable potassium extractants

Extracted Potassium (K) from the soil, referred to as the extractable K is the K fraction of the soil used in estimating K abundance in soil. The exchangeable K is defined as K which is free to exchange with cations of salt solutions added to soils. But since the amount of K exchanged from the soil depends on the nature of the replacing solutions, the exchangeable K is defined more specifically as that which is extracted with neutral 1M Ammonium Acetate (NH_4OAc) minus the water-soluble K (Black, 1965).

In soils that are not saline, levels of water-soluble K are minimal and can be ignored which is not so on saline soils. However, in saline soils, the levels of water-soluble K should be determined from saturated extract or some similar extract and subtracted from the amount of K determined using NH_4OAc. Wild (1971) found exchangeable potassium as the best indices of availability of potassium in the soil – potassium which is exchangeable with ammonium acetate as the easiest to make and that it gives good correlation with potassium uptake.

A number of extractants are used to measure extractable K. These include: Mehlich-1 (1953) and Mehlich-3 (1984), the Morgan (1941) and modified Morgan (McIntosh, 1969) procedures, the 1M NH_4Oac pH 7.0 (Schollenberger and Simon 1945) and the ammonium bicarbonate-DTPA (Soltanpour and Schwab, 1977) extractants. Morgan's extractant was developed by Morgan in 1941. It contains 0.72 M NaOAc + 0.52 M CH3COOH. The pH of the solution should be adjusted to 4.8 with sodium acetate or acetic acid.

1M Ammonium Acetate pH 7.0 extractant was developed by Schollenberger and Simons in 1945. It is a preparation of mixture of glacial acetic acid (99.5%) and concentrated ammonium hydroxide adjusted to pH 7.0 with either glacial acetic acid or concentrated ammonium hydroxide. Alternatively, reagent-grade ammonium acetate may be used.

Mehlich-1 extractant, also referred to as dilute double acid or the North Carolina extractant was developed in 1953,. The solution contains 0.05 M H_2SO_4 + 0.05 M HCl.

Modified Morgan was developed in 1969 as a modification to the earlier extractant developed by Morgan in 1941. The Ammonium acetate was changed to Ammonium Hydroxide and the concentration of the acetic acid was changed to 1.25 M. The solution should be adjusted to pH 4.8

Ammonium hydrogen flouride ($NH_4F.HF$) extractant was investigated by Adeoye (1986), Agboola (1981) and Agboola and Omueti (1980) as a possible suitable extractant for K. Adeoye found out that modified $NaHCO_3$ extracted more K than Ammonium hydrogen flouride followed by 1M Ammonium Acetate.

2.8.1 Mehlich-3 extractant

Mehlich-3 as an extractant of soil K has received attention from several researchers. Sims (1989) in comparison of Mehlich 1 and 3 extractants for P, K, Ca, Mg, Mn, Cu and Zn in atlantic coastal plain soils, observed high significant correlations between M3 and M1 for K. Also, in a study by Beegle and Oravec (1990) comparing field calibrations for Mehlich 3 P and K with Bray-Kurtz P1 and ammonium acetate K for corn, found high correlations with the Bray-Kurtz P1 extractant (r=0.99) and neutral 1M ammonium acetate K extractant (r=0.96). While P field calibrations for the Mehlich-3 P and Bray-Kurtz P1, Mehlich 3 and the neutral, 1M ammonium acetate K were similar. Cate-Nelson partitioning of observed data resulted in critical levels of 43 and 45 kg P ha^{-1} for the Bray-Kurtz P1 and Mehlich-3 P extractants, respectively while K were 0.20 and 0.24 cmol kg^{-1} for the Mehlich 3 and neutral, 1M ammonium acetate extractants, respectively.

2.9 Extractants recommended for P and K in Nigeria

Different extractants have been recommended for P on different soils in Nigeria due to differences in the physical and chemical properties. The National Soil

Correlation Committee constituted in 1974, recommended Bray P1 for slightly acidic to neutral soils of Western Nigeria, Bray P2 for acidic Eastern soils and Olsen for the alkaline soils of Northern Nigeria. 1M ammonium acetate pH 7.0 is accepted as universal extractant for K on all Nigerian soils. Existing fertiliser recommendations are based on these extractants. Development of a field calibration data base for a new soil testing extractant is an essential, but expensive and time-consuming process (Sims, 1989). Deriving conversion equations between M3 and current extractants would allow for the use of the new extractant with existing field calibration data.

2.10 Bell pepper *(Capsicum annuum* L.)

The genus Capsicum originated in Central and South America (Grubben and Denton, 2004). The approximately 25 species all occur in the area. Mexico was probably the centre of origin of the chilli and sweet pepper (*Capsicum annuum*). *Capsicum annuum* is cultivated so widely in Africa that African people consider hot pepper as a traditional African vegetable or spice, while the much less popular sweet pepper is seen as an exotic, newly introduced European vegetable (Grubben and Denton, 2004).

Sweet pepper (Bell pepper), one of the most important glasshouse and summer vegetables in Western industrialised countries such as Europe, Canada and Mexico (Hartz *et al*., 2008), is more adapted to temperate climate than hot pepper. bell pepper (*Capsicum annuum L.*) is a crop of high economic and nutritional value in Nigeria. Nigeria as the largest producer of the crop in Africa accounts for about 50% of the African production (Erinle, 1989) and was adjudged second in the world in 1979 (Yamaguchi, 1983) although FAO in 2001 put China as the largest producer with 10 million tons, followed by Mexico (1.9 million tons) and Turkey with 1.5 million tons.

Bell pepper is well adapted to wide range of soil texture but yield higher in sandy soils because of warmth of such soils (Hartz et al. 2008). The FAO 2001 statistics, estimated world production of capsicum pepper at 21.3 million tons from a harvested area of 1.6 million ha with average yield of 13.4 t/ha. Bell pepper may yield up to 30 t/ha in the field and up to 100 t/ha in protected cultivation. The yield level in African countries is generally very low as a consequence of extensive cultivation technology.

It is an erect herb or subshrub that grows up to 2.5 m tall as an annual crop but sometimes a short-term perennial with strong taproot and numerous lateral roots. Leaves are alternate, simple, and very variable. Fruit colour varies from red, orange, yellow, purple, white, blue or brown when mature with mild, sweet aroma and taste.

Bell pepper is normally raised from seeds which germinate between 6 – 21 days after sowing depending on temperature which are later transplanted as seedlings between 4 – 6 weeks. At temperatures below 25 °C rate of seed germination decreases rapidly, but at above 38 °C there is reduction in effective pollination, fruit set and yield. Its cultivation is difficult in hot and humid tropical lowland and grows at a wide range of altitude from lowland up to 3000 m above sea level.

It grows on almost all soil types but most suited to well-drained sandy or loamy soil. Water logging causes poor fruit setting, diseases and fruit rotting. They are generally indeterminate in their flowering and fruiting habits after 60 – 90 days after sowing. Bell pepper fruiting period is from 30 – 45 days. Harvesting starts from between 3 – 4 months after planting and may last for 2 - 3 months if there is enough moisture and nutrient supply in the soil. It is grown under rain fed or irrigated conditions, requiring at least 600 mm water during its growing period. Capsicum is susceptible to varying diseases when humidity is high.

Nutrient requirement of bell pepper varies depending on cultivation technology. Harvesting bell pepper green stimulates more flowering and fruiting. It is rich in vitamin C and Capsaicin - the active ingredient, stimulates the mucous membrane of the mouth, stomach and bowels, causing strong peristalsis. Capsicum fruits could be consumed fresh, dried or processed. The non-pungent fruits, usually called sweet pepper, are eaten raw in salads, but more commonly cooked, fried or processed together with other foods. Bell Pepper is cholesterol free with the following nutritional values per 100g fruit: Energy 31 Kcal, Carbohydrates 6.03g, Protein 0.99g, Total Fat 0.30g, Dietary Fiber 2.1g, Vitamin A 3131 IU, Vitamin C 127.7 mg, Vitamin E 1.58 mg, Vitamin K 4.9 Âµg, Sodium 4 mg, Potassium 211 mg, Calcium 7 mg, Copper 0.017 mg, Iron 0.43 mg, Magnesium 12 mg, Manganese 0.112 mg, Phosphorus 26 mg, Selenium 0.1 Âµg and Zinc 0.25 mg among others.

Major area of pepper production in Nigeria is the savannah agro ecological zones (Erinle, 1989). Nigeria lies between latitudes 4°16^1 and 13°53^1 North and between longitudes 2°40^{1}and 14°411 East and has a total land area of 923,738 square kilometres in which 34% is occupied by crops, 23% by grassland, 16% by forests and the remaining 27% by rivers and lakes (World Fact Book, 2007).

2.11 Agro-ecological zones of Nigeria

Nigeria is currently divided into nine agro-ecological zones which are Arid/Sahel, derived savannah, high altitude, humid forest, mid-altitude, northern guinea savannah, semi arid/sudan zones, southern guinea savannah and water bodies. (IITA, 2015)

Humid forest zone - Mbato in Imo State falls under this zone. The humid forest zone covers Bayelsa, Rivers, Imo, Akwa Ibom, and part of Cross Rivers, Ebonyi, Anambra, Edo, Ondo, Lagos, Abia, Osun, Delta and Ogun States (NAERLS and NPAFS, 2010). Of all the zones the humid forest contains the most valuable species of vegetation (NAERLS and NPAFS, 2010). However due to human activities, this age-old forested area has been drastically reduced. Bush fallows, villages and farms are found scattered throughout the zone. Presently the drier end of its inland is becoming reduced to derived guinea savanna because of felling of trees and land clearings. In the humid rain forest are found economic cash crops such as Oil Palm (*Elaeis guineensis*), cocoa (*Theobroma cacao*), Rubber (*Hevea brasiliensis*) banana/plantain (*Musa* spp.) and cola nut (*Cola nitida*). Also found are some principal staple food crops such as yam, cocoyams, sweet potato, maize, rice, groundnut, cowpeas and beans as well as a number of fruits. A number of timber trees such as the African mahogany (*Khaya ivorensis* and *K. grandifoliola*), the scented Sapele wood (*Entandrophragma cylindricum*) and Iroko (*Chlorophora excelsa*). Crops cultivated in the humid forest zone include Cassava, Cocoa, Coconut, Oil Palm, Yam, Plantain/Banana, Pineapple, Pepper, Tomato, Okro, Amaranthus, Avocado, Irvingia and Egusi-Melon.

Derived savannah zone – Ibadan, a location where soil was collected for the correlation study falls under this agro-ecological zone. Derived savannah includes Oyo, Ogun, Ondo, Southern Kwara, Enugu, Ekiti, Kogi, Benue, Nassarawa, Southern Taraba, Southern Plateau States and part of the Federal Capital Territory (FCT). Crops such as Cassava, Maize, Cocoa, Plantain/Banana, Pineapple, Pepper, Tomato, Okro, Amaranthus, Celosia, Corchorus and Egusi-Melon are cultivated in the derived savanna agro-ecology. This was originally the drier part of the high forest. Due to bush burning and overgrazing, cultivation and hunting activities over a long period in the zone, the high forest trees were destroyed and the forest that used to exist is now replaced with a mixture of grasses and scattered trees. However, along the streams and in wet low-lying areas were surface water accumulates there are still some traces of forests. The soil is classified as an Alfisol – a soil of Basement complex rocks under forest vegetation. The soils are typically deep and with a fine surface layer (sandy loam) over heavier sandy clay loam or sandy clay. The soils contain moderate levels of nutrients and are sometimes described as ferruginous soils. The soils are friable and permeable because of good structure thus reducing the problem of erosion (Enwezor, 1999).

Guinea savannah zone - This zone consists of the larger part of the savanna zone and is sometimes divided into the southern Guinea savanna and northern Guinea savanna. It is the broadest vegetation zone in the country and it occupies almost half of its area. It is located in the middle of the country, extends southwards to southern Nigeria and pushes northward beyond Zaria. It covers an area that has 100 – 150 cm of annual rainfall. Comparatively, there are fewer trees in the northern Guinea savanna than in the southern and the trees are not as tall as those found in the southern Guinea savanna. Most of the tall grasses found in the derived Guinea savanna, are also found in the Guinea savanna, however, they are less luxuriant. The appearance of this zone differs from season to season. During the rainy season, the whole zone is green covered with tall grasses that grow and reach maturity rapidly and thus become fibrous and tough. In the dry season they tend to die and disappear. This clearing is due to several periodical bush-burning that occurs during the dry season between November and April, carried out to either assist in land clearing or hunting. The Guinea savanna is characterized by grasses such as *Pennisetum*, *Andropogon*, *Panicum*, *Chloris*, *Hyparrhenia*, *Paspalum* and *Melinis*. These tall grasses are characteristic of the Guinea savanna. The soils are generally slightly or mildly acidic, less leached, derived from Pre-cambian crystalline Basement Complex rocks with rainfall averaging about 1, 600 mm annually. They are generally coarse-textured with pH (H_2O) ranging from 5.5 to near 7.0. Organic matter content in the surface soils is generally low and total content rarely exceeds 0.1%. Available P is low often less than 10 ppm but moderate in exchangeable cations. The dominant clay is Kaolinite; therefore cation and water retention capacities are low. The CEC is also often very low usually falling below 5 cmol/kg of soil.

Southern guinea savanna covers parts of Niger, Northern Taraba, Kwara, Adamawa, Gombe, Southern Borno, Northern Oyo and the Federal Capital Territory (FCT). Yam, Cassava, Soybean, Pepper, Onion, Tomato, Okro, Cucumber, Water Melon Garlic and Ginger are some of the plants grown in the zone. Northern guinea savanna cuts across parts of Kaduna, Bauchi, Gombe, Zamfara, Niger, Southern Kebbi, parts of Kano, Borno, Kwara and Kastina States. Maize, millet and cowpea are common crops in the zone. Bagauda (Kano State), where soil samples was also taken is in this zone.

The mid-altitude zone includes parts of Plateau, Bauchi, Adamawa and Taraba States where rice, cassava and yam are the commonly grown crops in this zone. Yobe, Borno, Sokoto, Kebbi, Zamfara and parts of Katsina, Kano and Jigawa States make up the Sahel/Sudan or arid/semi-arid zone (NAERLS and NPAFS, 2010). Millet, Sorghum and Cowpeas are part of the cropping system in the arid/semi-arid agro ecology (Manyong *et. al.*, 2005).

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CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the selected study areas

Twelve (12) composite purposively selected surface soil samples (0 – 15 cm) belonging to eight soil series and two soil orders (Alfisols and Ultisols) from 12 locations across three agro-ecological zones of Nigeria were collected. The soil series were Egbeda, Apomu and Jago from Ibadan, Alagba, Afia Mkpo, Ugbolu and Oji from Mbato, and Gadau from Bagauda. The locations were at the National Horticultural Research Institute (NIHORT) headquarters, Ibadan, Oyo State (Derived Savannah zone) and its substations at Mbato, Imo State (Humid forest zone) and Bagauda in Kano State (Northern Guinea Savannah zone) as shown in Fig.3.1. The soils were taken from four locations in each of the agro-ecological zones based on land use and vegetation cover (Table 3.1).

3.2 Cropping history of experimental sites

The cropping history of sites where soil samples were collected for correlation and screenhouse studies and sites selected for field experiments are shown in Table 3.1. Sites 1, 2, 3 and 4 were located at NIHORT headquarters, Ibadan, Oyo State. They are from the experimental plots of the Institute. The altitude is between 168 – 185 m above sea level with coordinates falling between N7.48° and E3.86° and an annual rainfall of 1300 mm. Site 1 is adjacent to a perennial stream which had been under fallow for more than two years while sites 2 and 3 were under continuous cropping of leafy and fruit vegetables. Site 4, which had also been under fallow for over two years had previously been grown with Pineapple. Sites 1, 2 and 3 were selected for field experiments. Sites 5, 6, 7 and 8 were located at NIHORT, Bagauda, Kano State, Bagauda lies within N11°55’ and E8°39’ at an altitude of 510 m above sea level with annual rainfall of 1200 mm. Site 5 was a eucalyptus plantation of more than 20 years

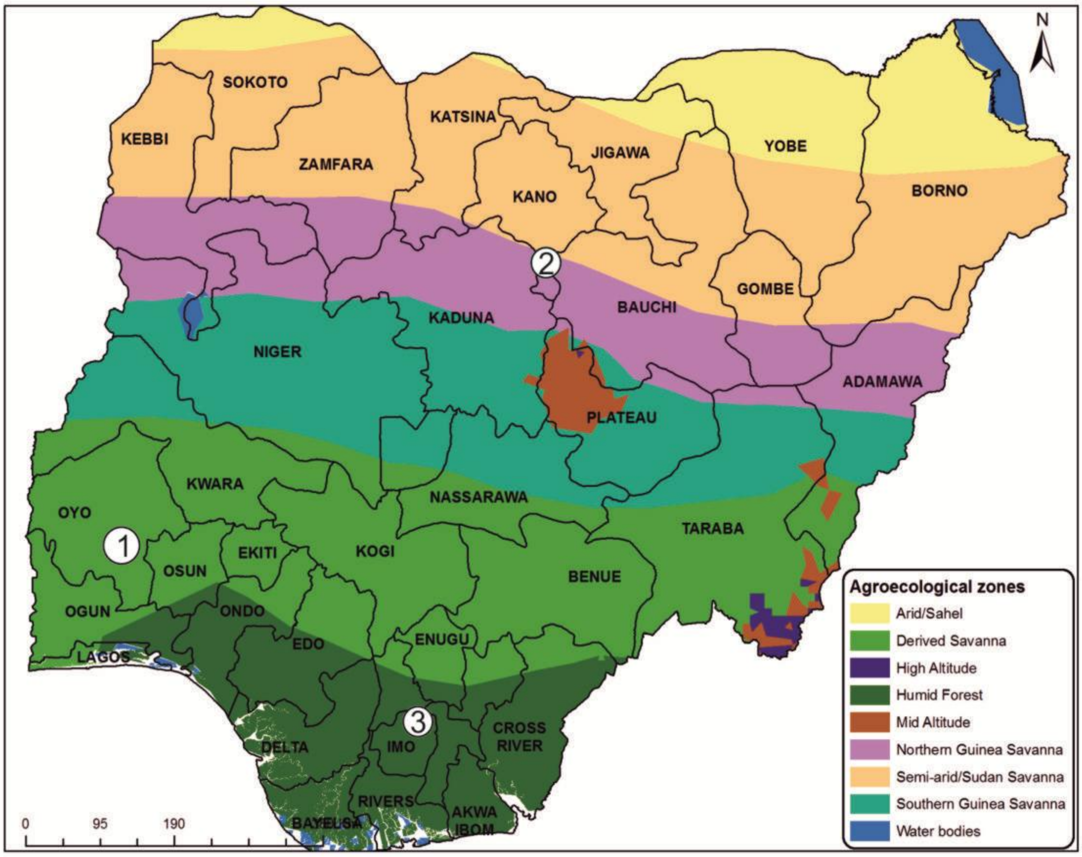


Fig 3.1: Map of Nigeria showing the agro-ecological zones (IITA, 2015) where soil samples were taken for correlation and screenhouse studies.

Location 1 – Derived savannah zone, Ibadan, Oyo State

Location 2 - Northern Guinea savannah, Bagauda, Kano State

Location 3 – Humid Forest zone, Mbato, Imo State

Table 3.1 Site description of soils used for correlation studies

Location	Site	Elevation(m)	Coordinates	History/Land use
Ibadan	1	168	N7.40211°, E3.84562°	Fallow (2 years)
	2	173	N7.40173°, E3.84774°	Previously cultivated with annual leafy and fruit vegetables
	3	185	N7.40721°, E3.84833°	Previously cultivated with annual leafy and fruit vegetables
	4	178	N7.4070°, E3.8450°	Fallow (2 years)
Bagauda	5	518	N11.55684°, E8.39103°	Eucalyptus Plantation>15yrs
"	6	515	N11.55776°, E8.03911°	Maize, Millet & G/Corn>15yrs
"	7	510	N11.55866°, E8.39125°	Maize, Millet & G/Corn>15yrs Close to Irrigation Pump
"	8	511	N11.55954°, E8.39133°	Maize, Millet & G/Corn>15yrs Animal ploughed after herbicide Spraying
Mbato	9	149	N5.87207°, E7.29830°	Bounds between experimental field covered by Elephant grass
"	10	159	N5.87490°, E7.30679°	Old Citrus Orchard
"	11	164	N5.87784°, E7.30790°	Fallow >15yrs. Dominated by small trees, shrubs & dense climbers
"	12	160	N5.88119°, E7.31230°	Close to Ibii river. Fallow >3years High water table(122cm)

while sites 6, 7 and 8 were fields grown with arable crops such as millet, maize, cowpea and guinea corn for more than 15 years. The last operation on site 8 was by animal ploughing after spraying with herbicide. Site 7 was adjacent to an irrigation water pump.

Sites 9, 10, 11 and 12 were located at NIHORT, Mbato, Imo State. Mbato is within N5°87' and E7°30' at an altitude of about 149 m above sea level with annual rainfall of 1300 mm. Site 9 was the bound of vegetable experimental field of the Institute dominated with elephant grass cover while site 10 was an old citrus orchard. Sites 11 and 12 had been under fallow for more than 15 and three years respectively. Site 11 was dominated with small trees, shrubs and dense climbers while site 12 with a water table of about 122 cm was located very close to Ibii river.The soils are also classified as Alfisol. The parent material from which the soils of the field experiment were formed, the mode of formation, soil association, soil series and the drainage classes are contained in Table 3.2, while Table 3.3 contains the classes and series of soils used for screenhouse studies.

3.3 Extractants used for correlation studies

Available phosphorus was determined using six extractants listed below;

1. Bray P1: 0.03N $NH_4.F$ + 0.025N HCl (Bray and Kurtz, 1945),
2. Bray P2: 0.03N $NH_4.F$ + 0.10N HCl (Bray and Kurtz, 1945),
3. Olsen P: 0.5M $NaHCO_3$ (Olsen *et al*., 1954),
4. Mehlich-3: 0.2M CH_3COOH + 0.25M NH_4NO_3 + 0.015M NH_4F + 0.013M HNO_3 + 0.001M EDTA (Mehlich, 1984)
5. Ammonium hydrogen flouride extractanct: 0.05M NH4F.HF + 0.01M DTPA (Adeoye, 1986)
6. Modified Mehlich-3 (substituted EDTA with DTPA): 0.2M CH_3COOH + 0.25M NH_4NO_3 + 0.015M NH_4F + 0.013M HNO_3 + 0.001M DTPA

Exchangeable potassium was determined using four extractants listed below;

1. 1M Ammonium acetate pH 7.0 (Black, 1965),
2. Mehlich-3: 0.2M CH_3COOH + 0.25M NH_4NO_3 + 0.015M NH_4F + 0.013M HNO_3 + 0.001M EDTA (Mehlich, 1984)
3. Ammonium hydrogen flouride extractant: 0.05M NH4F.HF + 0.01M DTPA (Adeoye,1986)

Table 3.2 Description of soils and sites at Ibadan where field experiment was carried out.

Soil Series	Elevation (m)	Parent Material	Mode of Formation	Drainage class
Jago	168 m	Alluvium	Hill Wash	Poorly draindeded to swampy
Apomu	173 m	Colluvial-alluvial materials derived from the basement Complex	Hill Wash	Well drained class 4
Egbeda	185 m	Precambian Basement Complex comprising mainly granite and Gneisses, Biotite Gneisses and Quartz Schist	Sedentary	Well drained class 4

Source: Adapted from Askira (2000)

Table 3.3 Locations, classes and series of soils used for correlation studies.

Location	Agro-ecological zones	Soil Classes	Soil Series
Ibadan, Oyo State	Derived Savanna	Alfisol	
Ib1			Jago
Ib2			Apomu
Ib3			Egbeda
Ib4			Apomu
Bagauda, Kano State	Northern Guinea Savannah	Ultisols	
B1			Gadau
B2			Gadau
B3			Gadau
B4			Gadau
Mbato, Imo State	Humid Forest	Alfisol	
M1			Alagba
M2			Afia Mkpo
M3			Ugbolu
M4			Oji

Source: Askira, 2000 and Okafor, 2016

Denotations

Ib1 – Ib4	Soils from Ibadan, Oyo State
B1-B4	Soils from Bagauda, Kano State
M1-M4	Soils from Mbato, Imo State

4. Modified Mehlich-3 (substituted EDTA with DTPA)): 0.2M CH_3COOH + 0.25M NH_4NO_3 + 0.015M NH_4F + 0.013M HNO_3 + 0.001M DTPA

Diethylene triamine pentaacetic acid (DTPA) was substituted for EDTA in the modified Mehlich-3 extractant because of the ability of DTPA to extract nutrients without the destruction of the carbonate.

3.4 Soil Analysis

Soil samples taken were composite of each sampling unit (sites, locations and treatments) for extractant correlation and suitability, and field experiment. Laboratory analysis of the soil samples were done in duplicates.

3.4.1 pH Determination

Soil pH was determined in both distilled water and 1M KCl. About 10 g of air dried soil (<2 mm fraction) were put into separate 50 ml beakers and 10 ml of distilled water and 1M KCl solution were added into each beaker to attain 1:1 ratio and allowed to equilibrate for 30 minutes with occasional stirring The electrode was calibrated with pH buffers 4.0 and 7.0, before insertion into the suspension and the reading taken with digital Corning pH meter Model 220 when reading stabilized. Average of two readings taken to one decimal place was recorded as the pH of the soil in water and 1M KCl.

3.4.2 Particle size distribution

Particle size distribution was according to Bouyoucos (1951), where 100 g of air dried 2 mm sieved soil was weighed into a dispersion cup, 50 ml of 5 % sodium hexametaphosphate (Calgon) solution and 200 ml of distilled water were added followed by stirring with a glass rod. After 30 minutes the suspension was stirred for 15 minutes with mechanical stirrer and was poured into a 1000 ml glass cylinder and made up to 940 ml mark with distilled water. The cylinder was vigorously shaken in a back-and-forth manner, placed on a table and the hydrometer inserted. The first hydrometer reading was taken after 40 seconds and the temperature was also recorded. After two hours, the second hydrometer and temperature reading was taken and the percentages of sand, silt and clay were determined thereof. The textural class of the soils was determined by using the USDA soil textural triangle (NSSC, 1995).

First hydrometer reading = concentration of silt + clay particles.

Second hydrometer reading = concentration of clay

Temperature correction at 40 seconds and 2 hours = 0.3 (Temperature – 20)^{0}C

$$\% \text{ silt + clay} = \frac{(\text{temperature correction factor + hydrometer reading) at 40 seconds} \times 100}{\text{weight of sample (100 g)}} = A$$

% Sand = 100 - A

$$\% \text{ clay} = \frac{(\text{temperature correction factor + hydrometer reading) at 2 hours} \times 100}{\text{weight of sample (100 g)}} = B$$

% silt = A - B

3.4.3 Organic Carbon

Walkley Black method (1934) as modified by Heanes (1984) was employed, where 0.5 g of 0.5 mm sieved soil was weighed into 50 ml glass beaker and 5 ml of 1M potassium dichromate was added and swirled to mix thoroughly. Thereafter, 10 ml of concentrated sulphuric acid was added into the suspension, and the mixture heated for exactly 30 minutes on a hot plate at 150 °C. After the mixture has cooled down it was diluted to 50 ml with distilled water and allowed to stand overnight. This is to allow for a clear supernatant solution. Standard Carbon solutions were prepared from oven dried Sucrose, mixed with the same volume of potassium dichromate and concentrated sulphuric acid and digested as the soils. The standards and samples were read on Labomed 20D spectrophotometer at a wavelength of 600 nm using a 1 cm cell. Amount of C in the samples were determined from a standard curve and calculated as follows

$$\text{Carbon content (g/kg)} = \frac{\text{absorbance} \times \text{slope} \times \text{dilution factor}}{1,000}$$

Where

absorbance = meter reading of a sample

slope = obtained from calibration curve of standards and their absorbances

dilution factor = final volume of digest ÷ weight of soil sample

1, 000 = conversion factor to %

3.4.4 Total nitrogen

Nitrogen was determined by macro - Kjeldahl method of Jackson (1962). About 0.5 g of 0.5 mm sieved soil was weighed into digestion flask together with 0.5 g of salt/catalyst mixture of sodium sulphate and copper sulphate (ratio 10:1) in 5 ml concentrated sulphuric acid and digested for about 3 hours (Amin and Flowers, 2004)

The digested solution was made up to 50 ml mark with distilled water and shaken in a back-and-forth manner. Thereafter, an aliquot of the digest was taken and the N content determined by colorimetric Technicon auto analyser method with Labomed 20D spectrophotometer at 630 nm. Nitrogen content was calculated as stated below

$$\text{Nitrogen (g/kg)} = \frac{\text{absorbance} \times \text{slope} \times \text{dilution factor}}{1,000}$$

Where

absorbance = meter reading of a sample

slope = obtained from calibration curve of standards and their absorbances

dilution factor = final volume of digest ÷ weight of soil sample × aliquot

aliquot = volume taken from digested solution

1, 000 = conversion factor to %

3.4.5 Available phosphorus

Available phosphorus was determined by extractants as enumerated earlier in section 3.3. For Bray P-1 and P-2, $NH_4F.HF$, Mehlich-3 and modified Mehlich-3 tests, 1 g of soil was extracted with 10 ml of the extractants (ratio 1:10) on a reciprocating shaker for five minutes, while for Olsen, 1 g of soil was extracted with 20 ml of the extractant (ratio 1:20) and shaken for 30 minutes. All extracts were filtered through Whatman No. 42 filter paper. About 5 ml aliquot of the extracts were taken into 25 ml volumetric flask, 5 ml of Ascorbic acid (Watanabe and Olsen, 1965) was added, shaken and made to mark with distilled water. Phosphorus content was determined with the aid of Labomed 20D spectrophotometer on wavelength of 882 nm (Bray and Kurtz, 1945).

$$\text{Available P (mg/kg)} = \text{absorbance} \times \text{slope} \times \text{dilution factor}$$

Where

absorbance = meter reading of a sample

slope = obtained from calibration curve of standards and their absorbances

dilution factor = final volume of suspension ÷ weight of soil sample × aliquot

aliquot = volume taken from filtered solution.

3.4.6 Exchangeable bases

Exchangeable potassium was determined in 1M ammonium acetate extraction method of Black (1965), $NH_4F.HF$, Mehlich-3 and modified Mehlich-3. For 1M ammonium acetate extraction, 2.5 g of 2 mm sieved soil was weighed into a beaker and 25 ml of NH_4OAC (ratio 1:10) was added and stirred for 5 minutes on reciprocating shaker. For $NH_4F.HF$, Mehlich-3 and modified Mehlich-3, 1 g of soil was extracted with 10 ml of the extractants (ratio 1:10) on a reciprocating shaker for five minutes. All extracts were filtered through Whatman No. 42 filter paper. Calcium, Mg and Na were also determined in the 1M ammonium acetate filtrate. Buck Scientific Atomic Absorption Spectrophotometer (AAS) Model 210 VGP was used to determine Ca and Mg in the filtrate while K and Na were read using Jenway PFP Flame Photometer. Calculations for the bases are stated below

$$\text{Ca, Mg, K and Na (cmol/kg)} = \frac{\text{absorbance} \times \text{slope} \times \text{dilution factor}}{\text{equivalent weight of cation}}$$

Where

absorbance = sample reading from flame Photometer

slope = obtained from calibration curve of standards and their absorbances

dilution factor = final volume of filtrate ÷ weight of soil sample

$$\text{equivalent weight of cation} = \frac{\text{relative atomic mass}}{\text{no of charge}}$$

3.4.7 Micronutrients (Zn, Cu, Mn and Fe)

Zinc and Cu were determined in 0.1M HCl extraction (Tucker and Kurtz, 1955; Osiname, 1972) where 2.00g of soil was weighed and extracted with 20 ml of 0.1M HCl (ratio 1:10) and stirred on a reciprocating shaker for 45 minutes and afterwards filtered through Whatman No. 42 filter paper. Zinc and Cu was then determined in the filtrate on Buck Scientific Atomic Absorption Spectrophotometer (AAS) Model 210 VGP. Iron was determined in solution of 1M ammonium acetate pH 4.8 and Ethylene Diamine Triacetic acid (EDTA) followed by extraction procedure as for Zn and Cu. Manganese was determined in the 1M ammonium acetate extract on Buck Scientific Atomic Absorption Spectrophotometer (AAS) Model 210 VGP. Calculations for the micronutrients are shown below

$$\text{Zn, Cu, Mn or Fe (mg/kg)} = \text{absorbance} \times \text{slope} \times \text{dilution factor}$$

Where

absorbance = meter reading of a sample

slope = obtained from calibration curve of standards and their absorbances

dilution factor = final volume of filtrate ÷ weight of soil sample × aliquot

3.4.8 Exchangeable acidity

Exchangeable acidity ($Al^{3+} + H^{+}$) was determined using 1 N KCl extraction method and titrated with 0.01 N NaOH (Black, 1965). About 2 g of 2 mm sieved soil was weighed into a beaker while 20 ml of 1 N KCl was added and stirred with reciprocating shaker for 5 minutes. It was filtered with Whatman No. 42 filter paper, to get the filtrate. Two drops of phenolphthalein was added and it was titrated with 0.01 N NaOH until pink colour was observed. Exchange acidity = $H^{+} + Al^{+}$

3.4.9 Effective cation exchange capacity

Effective cation exchange capacity (ECEC) was calculated by summation of exchangeable bases and exchangeable acidity. ECEC = TEB + EA

Where TEB = total exchangeable bases (Ca + Mg + K + Na)

EA = exchangeable acidity ($H^{+} + Al^{+}$)

3.4.10 Base saturation

Base saturation (BS) was calculated from the formular

$$BS\ (g/kg) = \frac{\text{ECEC} - \text{exchangeable acidity (Al} + \text{H)}}{\text{ECEC}} \times 1000$$

3.5 Determination of suitability of Mehlich-3

Three kilogram soils were weighed into perforated plastic pots lined with tissue paper with trays at the bottom of the pot. Soils from each location were replicated three times in a completely randomized design (CRD). Bell pepper seeds (var. California Wonder) were raised in the nursery for four weeks before transplanting into the pots. The pots were watered to field capacity and allowed to equilibrate for 48 hours before transplanting. Two seedlings of the test crop were transplanted per pot and thinned to one after one week. Nitrogen fertiliser (Urea) at 40 kg N/ha was applied in a single dose one week after transplanting (WAT).

3.6 Plant analysis for nutrient uptake

Whole bell pepper plants were harvested at 4 WAT, packed into well labelled envelopes, oven dried at 75 ^{0}C to constant weight and weighed for their dry matter yield that was used to calculate the nutrient uptake. Oven dried plant samples were blended and analysed for their P and K contents. Plant samples were analysed for their P and K contents according to the procedure outlined in Selected Methods for Soil and Plant Analysis Manual of International Institute of Tropical Agriculture, Ibadan (IITA, 1979). A 5.0ml Nitric/Perchloric acid mixture (ratio 2:1) was added into 0.2 g of each sample contained in a 25 ml conical flask and left overnight. The plant samples were heated until white fuming stage, the point at which 1.0 ml of hydrochloric acid/distilled water mixture (ratio 1:1) was added and heated for further 30 minutes. Distilled water was added to the digest and shaken before cooling down to room temperature to avoid formation of insoluble perchlorate compounds. The digest was washed into 50 ml volumetric flasks and made up to mark with distilled water. Phosphorus and K were determined in the digest. Total phosphorus was determined by vanadomolybdate yellow colorimetric method (A.O.A.C, 1970) while K was determined by Flame Photometry method.

Nutrient uptake was calculated as shown below

Nutrient uptake (g/kg) = content in plant tissue (g/kg) × dry matter yield (g/)

Extracted P, K and nutrient uptake values obtained from laboratory soil extractions and nutrient uptake determination respectively were subjected to statistical analysis using SAS 9.0 to determine the relationships and significant differences between extractants as well as between extractants and uptakes. Also conversion equations from Mehlich-3 extracted P and K soil values to existing extractants of P and K were derived through regression equations. This will be an interim measure between new and current extractant(s), allowing for use of the new extractant with existing field calibration data.

3.7 Field soil test calibration

Field calibration was carried out in the wet seasons of 2011 and 2012 and the dry season of 2012 to determine the critical level and the highest P and K requirements of bell pepper on three soil series. Three sites representing three soil classes out of the four locations at NIHORT headquarters Ibadan (a derived savannah agro-ecological zone) were selected for this study. Routine soil tests were carried out on the composite soil samples taken for

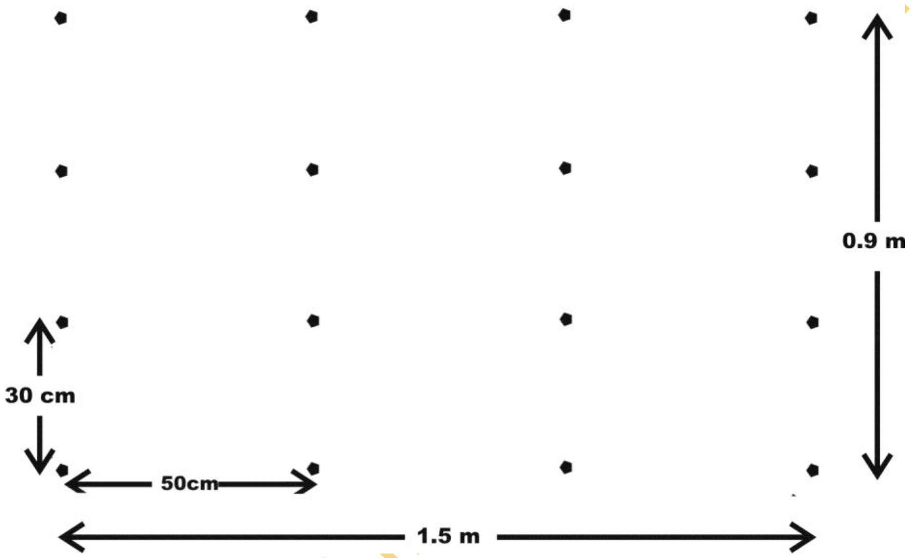


Fig. 3.2 Plant arrangement on the plot

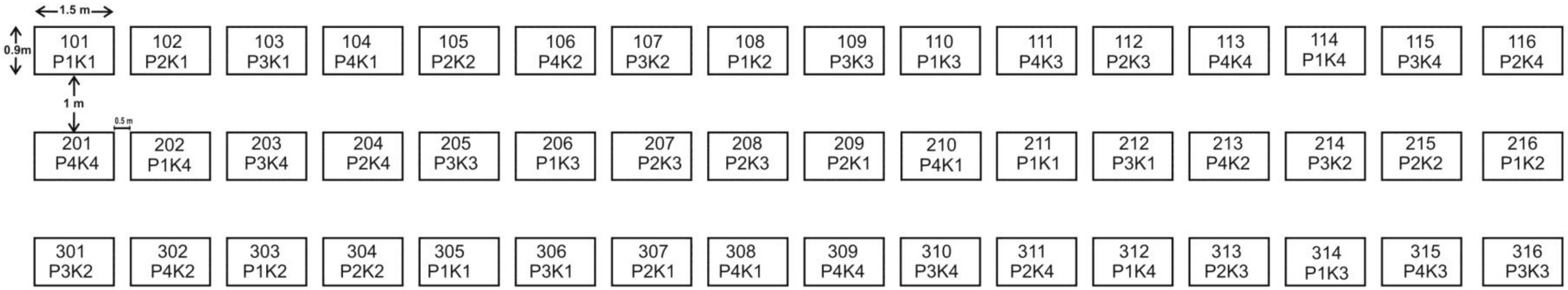
- Plants on the plot

pre-planting soil analysis. Bell pepper (*Capsicum annuum* L.) seedlings were raised in the nursery for four weeks before transplanting into the field at a spacing of 30 cm within rows and 50 cm between rows on 0.9 x 1.5 m plot size as shown in Figure 3.2, giving a plant population of 16 plants per plot (66, 666 plants/ha).

Single Superphosphate (SSP, 18% P_2O_5) was the source of phosphorus and was applied at four rates of 0, 30, 45 and 60 kg P/ha in a single dose at two weeks after transplanting (2 WAT). Murate of Potash (MOP, 60 % K_2O) was the source of potassium (K) fertiliser applied at the same time interval as for P in a single dose at rates of 0, 15, 30 and 45 kg K/ha to the plants by banding. Nitrogen fertiliser in form of Urea (46% N) at 40 kg N/ha was applied in two equal split doses at 2 WAT and at flowering by banding. There were 16 treatments combinations replicated three times to give 48 plots per site (Figure 3.3). The experimental design was a 4 x 4 randomized complete block in a split plot arrangement replicated three times, where potassium was assigned to the main plot and phosphorus to the sub plot because of mobility of K. The quantity of fertilisers applied per plot and the application time are contained in Table 3.4.

Fruits were harvested, counted and weighed at weekly intervals from 6 WAT until senescence. Using standard procedure, three plants (leaf, stem and root) were harvested per plot before flowering at 5 WAT for nutrient uptake determination. Yield per plot (kg/1.35 m^2) were taken and extrapolated to tons per hectare (t/ha).The Weather data collected for the three seasons were the monthly minimum and optimum temperature, Relative Humidity and the Total Rainfall as shown in Table 3.5. The minimum temperature range for 2011 was 20 – 25 °C with the lowest in January and the highest in March while the optimum temperature was between 28 – 35 °C with the lowest in the month of July/August and the highest in December. The relative humidity (RH) ranged between 80 and 92%. The lowest RH of 80% was recorded in January while the highest was recorded in September with 92%. The monthly total rainfall ranged between 0.0 – 471.4 mm with the lowest occurring in January with 0.0 mm and the highest of 471.4 mm in October. The minimum temperature range for 2012 was 22 – 25 °C with the lowest in January/August/December and the highest in March while the optimum temperature was between 28 – 36 °C with the lowest in the month of July and the highest in January. The relative humidity (RH) ranged between 83 and 92%. The lowest RH of 83% was recorded in January while the highest was recorded in September/October with 92%. The monthly total rainfall ranged between 0.0 – 283.3 mm with the lowest occurring in January/December with 0.0 mm and the highest of 283.3 mm in October.

Bell pepper fruit yield data were subjected to analysis of variance using Statistical System Software 9.0 (SAS 9.0) to determine differences in yield of bell pepper at different P and K rates. Duncan’s Multiple Range Test was used to separate treatment means. Furthermore, relative yield concept was also used to explain yield results while critical and highest levels were deduced from regression equations of yield curves of Bell pepper.



101 P1K1	102 P2K1	103 P3K1	104 P4K1	105 P2K2	106 P4K2	107 P3K2	108 P1K2	109 P3K3	110 P1K3	111 P4K3	112 P2K3	113 P4K4	114 P1K4	115 P3K4	116 P2K4
201 P4K4	202 P1K4	203 P3K4	204 P2K4	205 P3K3	206 P1K3	207 P2K3	208 P2K3	209 P2K1	210 P4K1	211 P1K1	212 P3K1	213 P4K2	214 P3K2	215 P2K2	216 P1K2
301 P3K2	302 P4K2	303 P1K2	304 P2K2	305 P1K1	306 P3K1	307 P2K1	308 P4K1	309 P4K4	310 P3K4	311 P2K4	312 P1K4	313 P2K3	314 P1K3	315 P4K3	316 P3K3

Fig. 3.3 Field layout of experimental plots

Phosphorus rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
Potassium rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Table 3.4 Quantity of fertilisers applied to bell pepper on the field.

Treatments	N	P	K
P1K1	12	0	0
P2K1	12	22.5	0
P3K1	12	33.75	0
P4K1	12	45.0	0
P1K2	12	0	3.375
P2K2	12	22.5	3.375
P3K2	12	33.75	3.375
P4K2	12	45.0	3.375
P1K3	12	0	6.75
P2K3	12	22.5	6.75
P3K3	12	33.75	6.75
P4K3	12	45.0	6.75
P1K4	12	0	10.125
P2K4	12	22.5	10.125
P3K4	12	33.75	10.125
P4K4	12	45.0	10.125

Nitrogen was applied at 6g/plot, each at 2 weeks after transplanting and flowering stage.

Phosphorus rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
Potassium rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Table 3.5 Weather data for 2011, 2012 and 2013 at NIHORT experimental Station, Ibadan.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011												
Mean Max Temp (°C)	34	34	34	33	33	31	28	28	30	31	33	35
Mean Min Temp (°C)	20	24	25	24	24	23	23	24	23	21	23	20
Mean R. Humidity (%)	80	88	89	87	88	89	92	91	92	90	90	85
Total Rainfall (mm)	0.0	212.3	44.9	104.7	241.2	221.9	236.6	177.7	198.7	471.4	51.3	0.0
2012												
Mean Max Temp (°C)	36	34	35	33	31	30	28	28	30	31	32	34
Mean Min Temp (°C)	22	24	25	24	23	23	23	22	23	22	24	22
Mean R. Humidity (%)	83	88	88	87	88	89	90	89	92	92	91	88
Total Rainfall (mm)	0.0	23.1	151.1	144.5	180.2	246.5	200	58.9	255.6	283.3	137.4	0.0
2013												
Mean Max Temp (°C)	34	34	32	33	32	28	28	28	30	32	NA	NA
Mean Min Temp (°C)	22	20	24	24	26	23	22	22	23	23	NA	NA
Mean R. Humidity (%)	81	68	88	89	93	88	92	91	95	91	NA	NA
Total Rainfall (mm)	0.0	0	180	230.3	80.9	252.9	417.8	20.3	254.6	150.8	NA	NA

Source: National Horticultural Research Institute Metrological station, Ibadan

NA – Not available

CHAPTER FOUR

RESULTS

Detailed results of the particle size and chemical properties of the soils across all sites are shown in Table 4.1. The properties include the pH in distilled water and 1M KCl, particle size analysis, exchangeable bases (Ca, Mg, K and Na), exchange acidity, base saturation, ECEC, available P, organic carbon, total N and the micronutrients (Zn, Cu, Fe and Mn).

The mean and range values of chemical properties of the soils are presented in Table 4.2. The range of soil pH in distilled water and 1M KCl was from 4.0 to 6.3 and 3.4 to 5.9 respectively while the mean values were 5.2 and 4.7 respectively. The soils from Mbato (Humid forest agro-ecological zone) are strongly acidic while those from Ibadan (Derived/Coastal Savannah) and Bagauda (Northern Guinea Savannah agro-ecological zone) were slightly acidic. The textural classes of the soils are loamy sand, sandy loam and silt loam respectively. There was high variability in the organic carbon content of the soils. The mean organic carbon content was 9.88 g/kg with a range between 3.5 and 23.3 g/kg. The N range of 0.25 – 1.92 g/kg was classified as very low to low respectively with a mean of 0.84 g/kg. The available P of the soils was from low to medium with an average of 8.34 mg/kg and within the range of 3.25 – 15.89 mg/kg. The exchangeable K levels in most of the locations were in the range classified as medium to high. The range of K across the locations was 0.16 – 0.96 cmol/kg soil with a mean of 0.47 cmol/kg soil. Mean value of Na was 0.12 cmol/kg and within the range of 0.04 – 0.21 cmol/kg was normal for soils collected from the indicated locations. The trend of the exchangeable bases in order of abundance was Ca > Mg > K > Na. The Ca and Mg contents averaged 2.56 and 0.73 cmol/kg soil respectively while the range were 0.98 – 7.36 and 0.25 – 1.85 respectively. Highest value of Ca and Mg were obtained in Bagauda soils. The exchangeable acidity varied between 0.10 and 0.30 cmol/kg with a mean value of 0.19 cmol/kg. The ECEC ranged

Table 4.1 Particle size distribution and chemical properties of soil used for correlation and calibration experiments.

Location	pH		Particle Size Distribution			Organic	Total	Available	Exchangeable Bases				Exc. Acidity	ECEC	Base	Micronutrients			
and site	H_2O	1M KCl	Sand	Silt	Clay	Carbon	Nitrogen	Phosphorus	Ca	Mg	K	Na	H^++Al		Saturation	Cu	Zn	Fe	Mn
	(1:1)	(1:1)	g/kg					mg/kg	cmol/kg						g/kg	mg/kg			
Ibadan																			
1	5.8	5.5	753	147	100	4.0	0.30	13.76	1.63	0.40	0.20	0.11	0.28	2.42	917.4	1.05	4.11	2.25	29.40
2	5.2	4.9	793	117	90	3.5	0.25	13.44	1.64	0.25	0.18	0.11	0.17	2.35	923.4	1.58	3.67	2.10	31.90
3	5.2	4.8	623	177	200	9.8	1.10	4.30	3.00	0.64	0.53	0.10	0.19	4.46	881.2	2.65	5.13	3.55	42.45
4	6.0	5.9	803	117	80	5.5	0.50	9.56	2.54	0.74	0.30	0.10	0.10	3.78	920.6	1.12	6.08	1.80	21.90
Bagauda																			
5	6.3	5.8	472	387	140	14.3	1.20	5.11	7.36	1.85	0.78	0.13	0.12	10.23	923.8	0.90	1.76	4.40	11.12
6	5.4	4.8	493	387	120	5.9	0.40	7.56	3.33	1.23	0.96	0.17	0.16	5.85	835.9	0.49	1.55	4.10	15.20
7	5.6	5.2	573	327	100	4.0	0.35	8.58	3.25	0.92	0.76	0.13	0.16	5.22	854.4	0.36	1.39	2.80	5.47
8	4.9	4.7	573	337	90	5.5	0.40	9.35	2.63	0.57	0.55	0.07	0.14	3.96	861.1	0.40	1.63	3.10	12.41
Mbato																			
9	4.9	4.3	743	117	140	9.8	1.00	15.89	1.96	0.54	0.16	0.04	0.14	2.84	943.7	0.79	2.03	3.90	10.76
10	4.0	3.4	653	137	210	19.4	1.50	5.50	1.04	0.54	0.50	0.11	0.30	2.49	799.2	0.42	2.38	12.90	6.86
11	4.2	3.5	593	177	230	23.3	1.92	3.32	1.35	0.59	0.45	0.21	0.28	2.88	843.8	0.60	2.37	68.00	14.99
12	4.4	3.5	753	117	130	13.5	1.19	3.75	0.98	0.45	0.30	0.15	0.27	2.15	860.5	0.26	2.34	22.30	8.27

Table 4.2 Mean and range of chemical properties of experimental soils across the agro-ecological zones.

Parameters	Units	Mean	sd	Cv	S.E	Range
pH in H_2O(1:1)		5.2	0.72	13.85	0.22	4.0 – 6.3
pH in 1M KCl(1:1)		4.7	0.87	18.51	0.26	3.4 – 5.9
Organic Carbon	g/kg	9.88	6.51	65.89	1.95	3.5 – 23.3
Total Nitrogen	“	0.84	0.55	65.48	0.16	0.25 – 1.92
Available P	mg/kg	8.34	4.23	50.72	1.27	3.25 – 15.89
Exchangeable Cations	cmol/kg					
Ca^{2+}	“	2.56	1.72	67.19	0.51	0.98 – 7.36
Mg^{2+}	“	0.73	0.44	60.27	0.13	0.25 – 1.85
K^{+}	“	0.47	0.26	55.32	0.08	0.16 – 0.96
Na^{+}	“	0.12	0.04	33.33	0.01	0.04 – 0.21
Exch. Acidity(Al^{3+} + H^{+})	“	0.19	0.07	36.84	0.02	0.10 – 0.30
ECEC	“	4.05	2.29	56.54	0.69	2.15 – 10.23
Base Saturation	g/kg	880.4	44.8	5.09	13.41	799.2 – 943.7
Micronutrients	mg/kg					
Mn^{2+}	“	17.57	11.51	65.51	3.45	5.47 – 42.45
Fe^{2+}	“	10.93	18.94	173.28	5.67	1.80 – 68.0
Zn^{2+}	“	2.87	2.57	89.55	0.77	1.55 – 6.08
Cu^{2+}	“	0.89	0.68	76.40	0.20	0.26 – 2.65

sd = standard deviation

cv = co-efficient of variation

S.E. = standard error

between 2.15 to 10.23 with a mean of 4.05 cmol/kg while base saturation ranged between 799.2 – 943.7 g/kg with a mean of 880.5 g/kg. Highest ECEC value was obtained in Bagauda soils while the lowest was from Mbato. The micronutrient levels were within normal range for most soils. Manganese values range between 5.47 and 42.45 mg/kg with a mean of 17.57 mg/kg while Fe varied between 1.80 and 68.0 mg/kg with a mean value of 10.93 mg/kg. The variation within Zn and Cu values of the soils were not as pronounced as in Mn and Fe. The mean value for Zn was 2.87 mg/kg and ranged between 1.55 and 6.08 mg/kg while the mean for Cu was 0.89 mg/kg and ranged between 0.26 and 2.65 mg/kg.

4.1 Correlation of P extractants

The values of P extracted by different extractants across all locations are shown in Table 4.3 while the means, sd, cv and the range values are shown in Table 4.4. Table 4.5 shows the correlation coefficient (r) among P extractants and the conversion factors of P values from M3 to values of recommended extractants. The mean value of P extracted by Bray P1 extractant across all locations was 8.34 mg/kg and ranged between 3.32 and 13.76 mg/kg while P extracted by Bray P2 extractant ranged between 3.72 and 31.97 mg/kg with a mean value of 11.19 mg/kg. The means of P extracted by Olsen and Mehlich-3 extractants were 5.11 and 14.41 mg/kg respectively while the values ranged between 0.21 to 20.15 mg/kg and 2.97 to 47.25 mg/kg respectively. Phosphorus values of soils extracted by $NH_4F.F$ + DTPA and Modified Mehlich-3 ranged between 7.5 to 45.0 mg/kg and 7.7 to 43.13 mg/kg respectively, while the means were 30.33 and 15.68 mg/kg respectively. There were significant correlations between P extracted by Mehlich-3 extractant and other conventional extractants of P ($\alpha_{0.01}$). Correlation coefficient (r) of the extractants ranged from 0.77 to 0.96. as shown in Table 4.5. The lowest correlation coefficient (r) of 0.77 was between Mehlich-3 and Bray P1 while the highest of 0.96 was between Mehlich-3 and $NH_4F.F$ + DTPA.

4.2 Correlation of K extractants

The values of K extracted by different extractants in all locations are shown in Table 4.6 while the means, sd, S.E, cv and the range values are shown in Table 4.7. The mean value of K extracted by 1M Ammonium Acetate pH 7.0 extractant across all

4.3 Phosphorus (mg/kg) extracted in the pre-planting soils of the three agro-ecological zones

Soil	Bray 1	Bray 2	Olsen	Mehlich-3	NH_4.HF+DTPA	Modified Mehlich-3
Ibadan						
1	13.76	9.54	5.22	14.58	22.50	18.75
2	13.44	31.97	20.15	47.25	45.00	51.00
3	4.30	5.40	0.58	2.70	11.25	9.00
4	9.56	9.50	5.94	12.15	22.50	18.13
Bagauda						
5	5.11	7.97	2.54	2.97	10.00	9.75
6	7.56	7.29	2.36	7.83	13.75	11.25
7	8.58	14.63	5.22	9.18	12.50	9.75
8	9.35	5.90	5.94	6.48	17.50	11.25
Mbato						
9	15.89	27.00	11.93	43.47	42.50	33.00
10	5.50	7.02	0.61	10.26	16.25	10.50
11	3.32	4.37	0.21	11.34	12.50	10.50
12	3.75	3.42	0.58	4.65	7.50	6.00

Table 4.4 Means and range of extracted available P.

Extractants	Mean (mg/kg)	sd	cv (%)	S.E	Range (mg/kg)
Bray P1	8.34	4.23	0.51	1.22	3.32 - 13.76
Bray P2	11.19	9.08	0.81	2.62	3.72 - 31.97
Olsen	5.11	5.83	1.14	1.68	0.21 - 20.15
Mehlich-3	14.41	14.93	1.04	4.32	2.97 - 47. 25
NH_4F.F + DTPA	30.33	14.93	0.49	4.32	7.5 - 45.0
Modified Mehlich-3	15.68	12.04	0.77	3.48	7.7 - 43.13

sd = standard deviation

cv = co-efficient of variation

S.E. = standard error

Table 4.5 Correlation co-efficients (r) and conversion equations relating Mehlich-3 and other P extractants

Extractant	Correlation co-efficient (r)	Conversion equation from Mehlich-3 P values
Bray 1	0.77*	y(B1) = 0.4939x + 3.0351
Bray 2	0.95*	y(B2) = 0.5755x + 2.9027
Olsen	0.90*	y(O) = 0.3514x + 0.0442
Ammonium hydrogen flouride + DTPA	0.96*	y(ABD) = 0.7724x + 9.2022
Modified Mehlich-3	0.95*	y(MM3) = 0.7652x + 4.6547

*Significant at 5%

where x = values of P extracted by Mehlich-3

and y(B1) = Phosphorus extracted by Bray 1
y(B2) = Phosphorus extracted by Bray 2
y(O) = Phosphorus extracted by Olsen
y(ABD) = Phosphorus extracted by $NH_4F.F$ + DTPA
y(MM3) = Phosphorus extracted by Modified Mehlich-3

Table 4.6 Potassium (cmol/kg) extracted by various K extractants in all locations.

Soil	Mehlich-3	Ammonium Acetate	NH_4.HF+DTPA	Modified Mehlich-3
Ibadan				
1	0.28	0.20	0.19	0.18
2	0.22	0.18	0.16	0.17
3	0.65	0.53	0.35	0.43
4	0.45	0.30	0.27	0.27
Bagauda				
5	0.92	0.78	0.39	0.59
6	1.10	0.96	0.14	0.66
7	1.00	0.76	0.22	0.52
8	0.70	0.55	0.14	0.43
Mbato				
9	0.24	0.16	0.12	0.18
10	0.58	0.50	0.21	0.36
11	0.58	0.45	0.20	0.33
12	0.38	0.30	0.18	0.24

Table 4.7 Means and range of extracted exchangeable K (cmol/kg) across all sites.

Extractants	Mean (cmol/kg)	sd	cv(%)	S.E	Range (cmol/kg)
Ammonium Acetate pH 7.0	0.47	0.06	12.77	0.02	0.18 - 0.96
Mehlich-3	0.59	0.3	50.85	0.09	0.22 - 1.10
NH4F.F + DTPA	0.21	0.08	38.10	0.02	0.12 - 0.39
Modified Mehlich-3	0.36	0.17	47.22	0.05	0.17 - 0.66

sd = standard deviation

cv = co-efficient of variation

S.E. = standard error

locations was 0.47 cmol/kg of soil and ranged between 0.18 and 0.96 cmol/kg while values by Mehlich-3 extractant ranged between 0.22 and 1.10 cmol/kg with a mean value of 0.59 cmol/kg. The means of K extracted by NH_4F.F + DTPA and Modified Mehlich-3 were 0.21 and 0.36 cmol/kg respectively while the values ranged between 0.12 to 0.39 cmol/kg and 0.17 to 0.66 cmol/kg respectively. There were significant correlations between K extracted by Mehlich-3, 1M Ammonium Acetate pH 7.0 and Modified Mehlich-3 extractants although there was no significant correlation between K extracted by Mehlich-3 and NH_4F.F + DTPA. ($\alpha_{0.05}$). Table 4.8 shows the correlation coefficient (r) between K extracted by Mehlich-3 extractant and the other extractants of K and the conversion factors of K values from recommended extractants to M3 K values.

4.3 Correlation between P uptake of bell pepper and P extractants

The means and range of P uptake by bell pepper in soils from different locations are contained in Table 4.9. There were significant correlations between all P extractants and P uptake of bell pepper. Mean P uptake was 2.34 g/kg and ranges from 1.15 to 6.12 g/kg. Highest P uptake of 6.12 g/kg was observed on soil 5 while the lowest with a value of 1.15 g/kg was observed on soil 2. Table 4.10 shows the correlation coefficient (r) between P uptake by Mehlich-3 extractant and other extractants of P. The lowest correlation coefficient (r) of 0.78 was observed between P uptake and Bray P1 while the highest of 0.95 was with Mehlich-3. The lowest 'r' was with Olsen P and the highest with Modified Mehlich-3.

4.4 Correlation between K uptake of bell pepper and K extractants

There were significant correlations between all K extractants and K uptake of Bell Pepper except with NH4F.F + DTPA (Table 4.11). The lowest correlation coefficient (r) of 0.93 was observed between P uptake and Modified Mehlich-3 while the highest (0.95) was observed with Mehlich-3. Mean K uptake was 22.62 g/kg and ranged from 12.80 to 35.78 g/kg. Highest K uptake was 35.78 g/kg while the lowest was 12.80 g/kg. The highest and the lowest correlations were observed with Mehlich-3 and Modified Mehlich-3 respectively.

Table 4.8 Correlation co-efficients (r) and conversion equations relating Mehlich-3 and K extractants

Extractant	Correlation co-efficient (r)	Conversion equation from Mehlich-3 K values
1M Ammonium acetate pH 7.0	0.99*	y (AAc) = 0.8665x - 0.0402
Ammonium hydrogen flouride + DTPA	ns	ns
Modified Mehlich-3	0.98*	y (MM3) = 0.5488x + 0.0386

* Significant at 5%, ns – not significant

where x = values of K extracted by Mehlich-3

and y(AAc) = Potassium extracted by 1M Ammonium acetate pH 7.0

y(MM3) = Potassium extracted by Modified Mehlich-3

Table 4.9 Means and range of P and K (g/kg) uptake by bell pepper**.**

Nutrient	Mean	sd	cv (%)	S.E	Range
P	2.34	1.74	74.36	0.50	1.15 - 6.12
K	22.62	7.88	34.84	2.28	12.80 - 35.78

sd – standard deviation

cv – co-efficient of variation

S.E. – standard error

Table 4.10 Correlation co-efficients (r) relating P uptake of bell pepper and amounts of P extracted by extractants

P extractant (mg/kg)	Correlation co-efficient (r)
Mehlich-3	0.95*
Bray P1	0.78*
Bray P2	0.89*
Olsen	0.85*
Ammonium hydrogen flouride + DTPA	0.89*
Modified Mehlich-3	0.95*

* Significant at 5%

Table 4.11 Correlation co-efficients (r) relating K uptake of bell pepper and amounts of K extracted by extractants

K extractants (cmol/kg)	Correlation co-efficient (r)
Mehlich-3	0.95*
Ammonium Acetate pH 7.0	0.94*
Ammonium hydrogen flouride + DTPA	ns
Modified Mehlich-3	0.93*

*Significant at 5%; ns - not significant at 5%

4.5 Effects of P and K fertiliser on the yield of bell pepper.

The effects of different rates of Phosphorus and Potassium fertiliser application on the yield of bell pepper in 2011 and the 1st and 2nd croppings of 2012 on different soil series are contained in Tables 4.12 – 4.14. Significant differences were observed between yield of bell pepper and the treatments. Highest bell pepper yield was obtained at 45 kg P/ha in all the 3 soil series in 2011 and the 2nd cropping of 2012. In the 1st cropping of 2012 highest yields were obtained at 60 kg P/ha on Egbeda and Jago soil series while it was on the control (0 kg P/ha) on Apomu soil series. Yield on Egbeda soil series as shown in Table 4.12 were 4.98, 7.02 and 8.11 t/ha in 2011 and 1st and 2nd cropping of 2012 respectively while it was 5.46, 5.52 and 12.21 t/ha (Table 4.13) on Apomu soil series in 2011 and the 1st and 2nd croppings of 2012 respectively. On Jago soil series yields were 2.60, 4.69 and 3.97 t/ha in 2011 and the 1st and 2nd croppings of 2012 (Table 4.14). On Egbeda soil series, highest bell pepper yield was obtained in the control (0 kg K/ha) in 2011 and 1st cropping of 2012 and at 15 kg K/ha in the 2nd cropping of 2012 while on Apomu soil series in 2011 and 1st cropping of 2012, highest yields were obtained at 30 kg K/ha and at 15 kg K/ha in the 2nd cropping of 2012. Yields of 8.3, 8.54 and 6.38 t/ha were obtained on Egbeda soil series in 2011 and the 1st and 2nd croppings of 2012 respectively. The yield on Apomu soil series were 5.69, 7.30 and 10.01 t/ha and on Jago series 2.40, 4.02 and 5.47 t/ha in 2011 and the 1st and 2nd croppings of 2012 respectively.

4.6 Effects of fertiliser application on P and K uptake of bell pepper

There were significant differences in uptake of P and K of bell pepper among the treatments. From Table 4.15 the uptake of P was highest at 30 kg P/ha on Egbeda and Apomu soil series with 1.40 and 1.42 g/kg P while on Jago soil series, highest P uptake was observed at 60 kg P/ha with a value of 1.28 g/kg P. Uptake of K was highest at 30 kg P/ha on the 3 soil series. The uptake values are 17.23, 19.13 and 17.31 g/kg on Egbeda, Apomu and Jago soil series respectively. As shown in Table 4.16 the highest uptakes of P were observed at the same K rate of 45 kg/ha. Phosphorus uptake values on Egbeda, Apomu and Jago soil series were 1.48, 1.59 and 1.37 g P/kg respectively while K uptake values were 22.66, 23.10 and 22.63 g K/kg respectively.

Table 4.12 Effects of P and K fertiliser application on the yield (t/ha) of bell pepper (*Capsicum annuum* L.) on Egbeda soil series.

Source	Year		
	2011 wet season	2012 wet season	2012 dry season
P (kg/ha)			
0	2.01c	3.55d	2.20d
30	3.85b	4.53c	4.15c
45	4.98a	5.08b	8.11a
60	4.71a	7.02a	5.71b
K (kg/ha)			
0	8.30a	8.54a	5.58b
15	2.98b	4.95b	6.38a
30	1.63d	3.54c	2.55c
45	2.64c	3.12d	5.66b
K*P	**	**	**

Means with the same letters in a column for each nutrient are not significantly different ($P<0.05$)

* significant at 5% ** significant at 1%

Table 4.13 Effects of P and K fertiliser application on the yield (t/ha) of bell pepper (*Capsicum annuum* L.) on Apomu soil series.

Source	Year		
	2011 wet season	2012 wet season	2012 dry season
P (kg/ha)			
0	1.99c	5.52a	6.24d
30	4.99b	4.79b	8.38c
45	5.46a	4.47c	12.21a
60	2.08c	3.74d	9.02b
K (kg/ha)			
0	2.41c	2.03d	10.33a
15	2.52c	5.23b	10.01a
30	5.69a	7.30a	9.43b
45	3.92b	3.96c	6.08c
K*P	**	**	**

Means with the same letters in a column for each nutrient are not significantly different ($P<0.05$)

* significant at 5% ** significant at 1%

Table 4.14 Effects of P and K fertiliser application on the yield (t/ha) of bell pepper (*Capsicum annuum* L.) on Jago soil series.

Source	Year		
	2011 wet season	2012 wet season	2012 dry season
P (kg/ha)			
0	0.548c	1.39c	2.68c
30	1.54b	1.54c	2.72c
45	2.60a	2.86b	5.45a
60	1.54b	4.67a	3.97b
K (kg/ha)			
0	1.93b	2.22b	2.81c
15	2.40a	1.65c	4.05b
30	0.79d	2.50b	2.55d
45	1.09c	4.02a	5.47a
K*P	**	**	**

Means with the same letters in a column for each nutrient are not significantly different (P<0.05)

* significant at 5% ** significant at 1%

Table 4.15 Effect of P fertiliser on P and K uptake (g/kg) of bell pepper (*Capsicum annuum* L.) on various soil series in the dry season of 2012.

Treatment	Egbeda	Apomu	Jago
P (kg/ha)		P uptake (g/kg)	
0	0.82d	1.19b	0.91d
30	1.39a	1.41a	1.17b
45	0.93c	1.17b	1.01c
60	1.25b	1.36a	1.27a
		K uptake (g/kg)	
0	14.39c	14.92c	17.30a
30	17.23a	19.13a	17.30a
45	14.60c	12.84d	12.20c
60	15.28b	15.59b	14.83b
K*P	**	**	**

Means with the same letters in a column for each nutrient uptake are not significantly different ($P<0.05$)

* significant at 5% ** significant at 1%

Table 4.16 Effect of K fertiliser on P and K uptake (g/kg) of bell pepper (*Capsicum annuum* L.) on various soil series in the dry season of 2012.

Treatment	Egbeda	Apomu	Jago
K (kg/ha)		P uptake (g/kg)	
0	1.13b	1.39b	1.07b
15	1.02c	1.12c	1.02b
30	0.78d	1.05d	0.91c
45	1.48a	1.59a	1.37a
		K uptake (g/kg)	
0	12.43c	10.44d	11.14c
15	12.94c	11.34c	14.16b
30	13.49d	17.25b	13.72b
45	22.66a	23.09a	22.63a
K*P	**	**	**

Means with the same letters in a column for each nutrient uptake are not significantly different ($P<0.05$)

* significant at 5% ** significant at 1%

4.7 Effects of P and K fertiliser combinations on the yield of Bell Pepper.

Effects of treatment combinations of P and K fertiliser on the yield of bell pepper are shown in Figures 4.1 – 4.9. There were significant differences among the yield. On Egbeda soil series, highest yield of 14.82 and 13.34 t/ha were obtained on P3K1 in 2011 and dry season of 2012 respectively, while highest yield of 16.70 t/ha was obtained on P4K1 in the wet season of 2012 (Figures 4.1 – 4.3). Highest yields of 15.01, 12.82 and 16.43 t/ha were obtained on Apomu soil series in the three cropping seasons consecutively on treatments P3K3, P1K3 and P4K1 respectively as shown in Figures 4.4 – 4.6. On Jago soil series, highest yield of 11.86 and 8.36 t/ha were obtained on P4K4 in the two croppings of 2012, while highest yield of 5.46 t/ha was obtained on P3K1 in 2011 (Figures 4.7 – 4.9).

4.8 Effects of P and K fertiliser combination on P and K uptake of bell pepper

Effects of treatment combinations of P and K fertiliser on the P and K uptake of bell pepper are shown in Figures 4.10 – 4.15. There were significant differences between treatments on P and K uptake of bell pepper. Phosphorus uptake was highest at P2K4 on Egbeda and Jago soil series while highest yield was observed on P1K4 on Apomu series. Phosphorus uptake values were 2.20, 2.35 and 1.52 g/kg on Egbeda, Apomu and Jago soil series respectively as shown in Figures 4.10 – 4.12. Highest K uptake was observed on P3K4 on all the soil series. Potassium uptake values were 26.56, 26.89 and 31.42 g/kg as shown in Figures 4.13 – 4.15.

4.9 Yield of bell pepper

Yields and relative yields of bell pepper on different soil series, seasons and treatments are shown in Tables 4.17 – 4.19 while P and K uptake and relative uptake are shown in Tables 4.20 – 4.21. An increase of 14, 26 and 12 times were observed on treatments

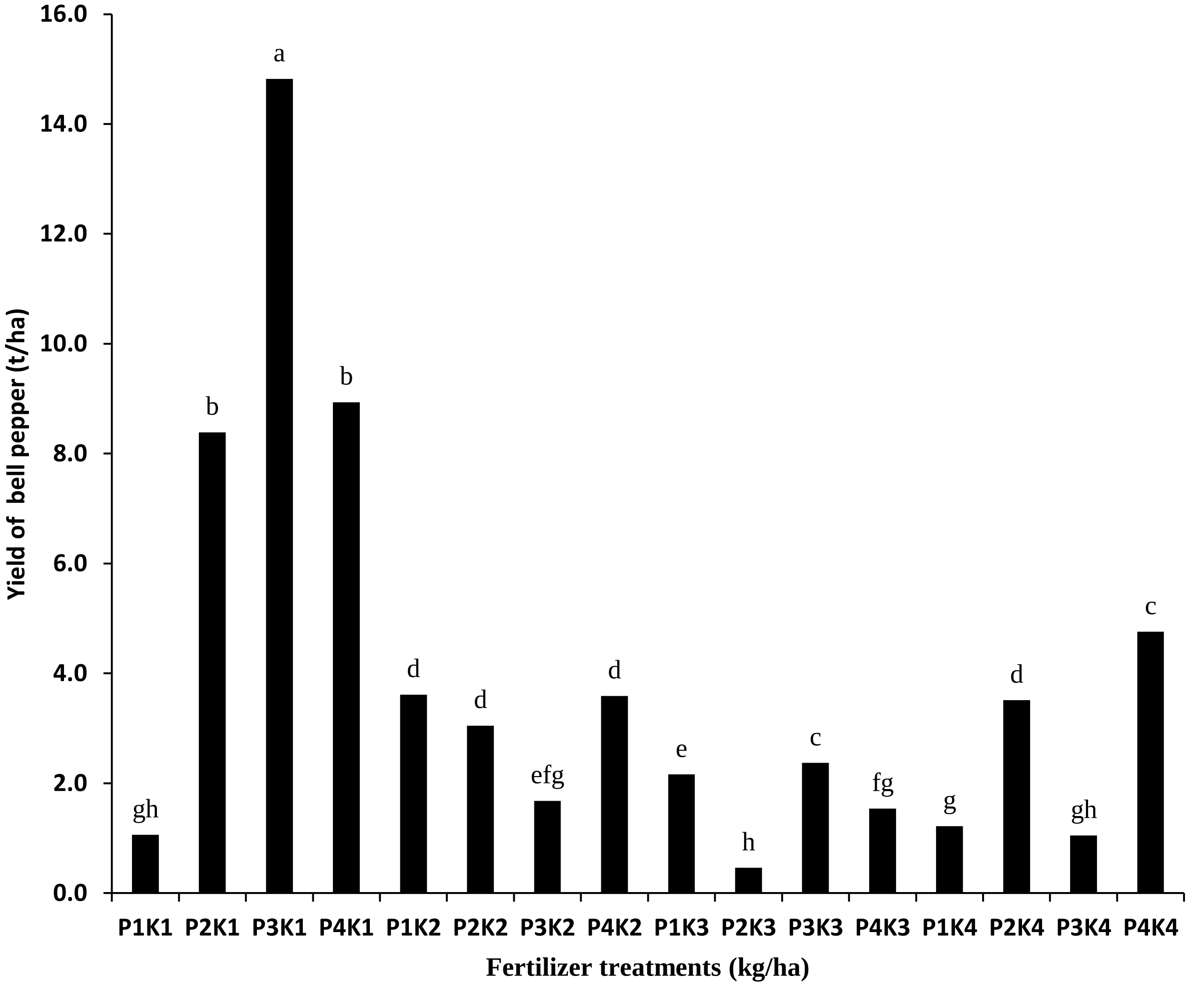


Fig. 4.1 Effect of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Egbeda soil series in 2011

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

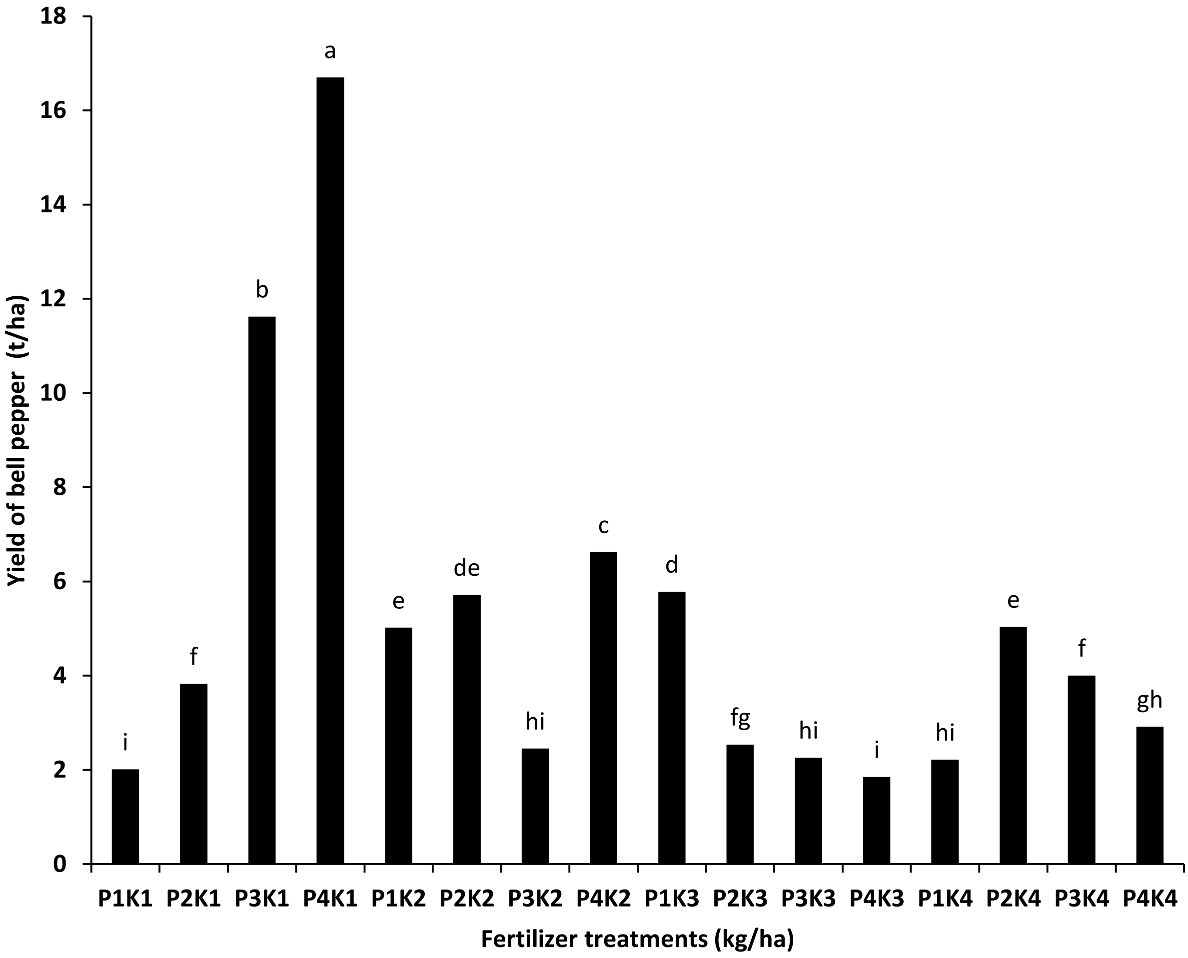
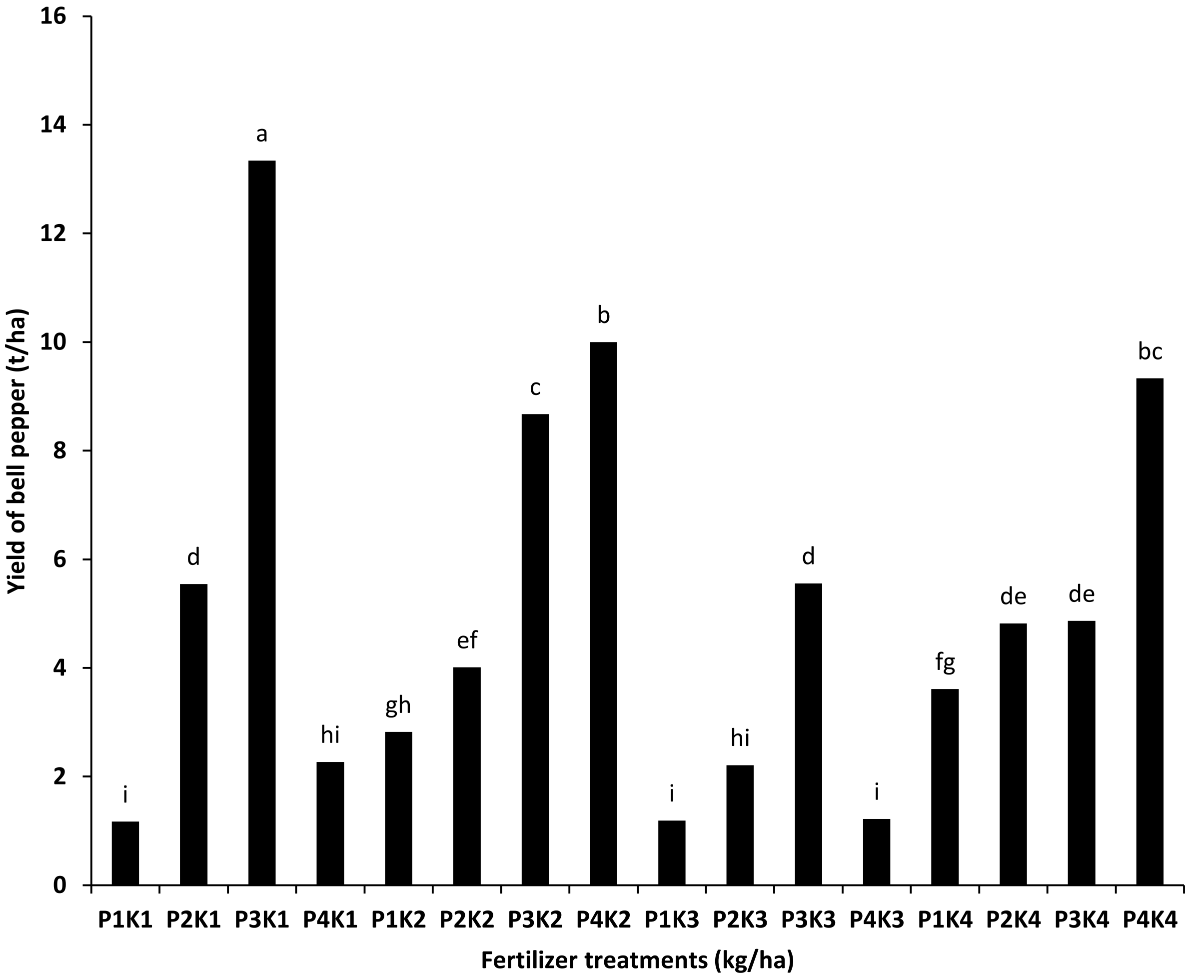


Fig. 4.2 Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Egbeda soil series in the wet season of 2012

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4



4.3 Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Egbeda soil series in the dry season of 2012

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

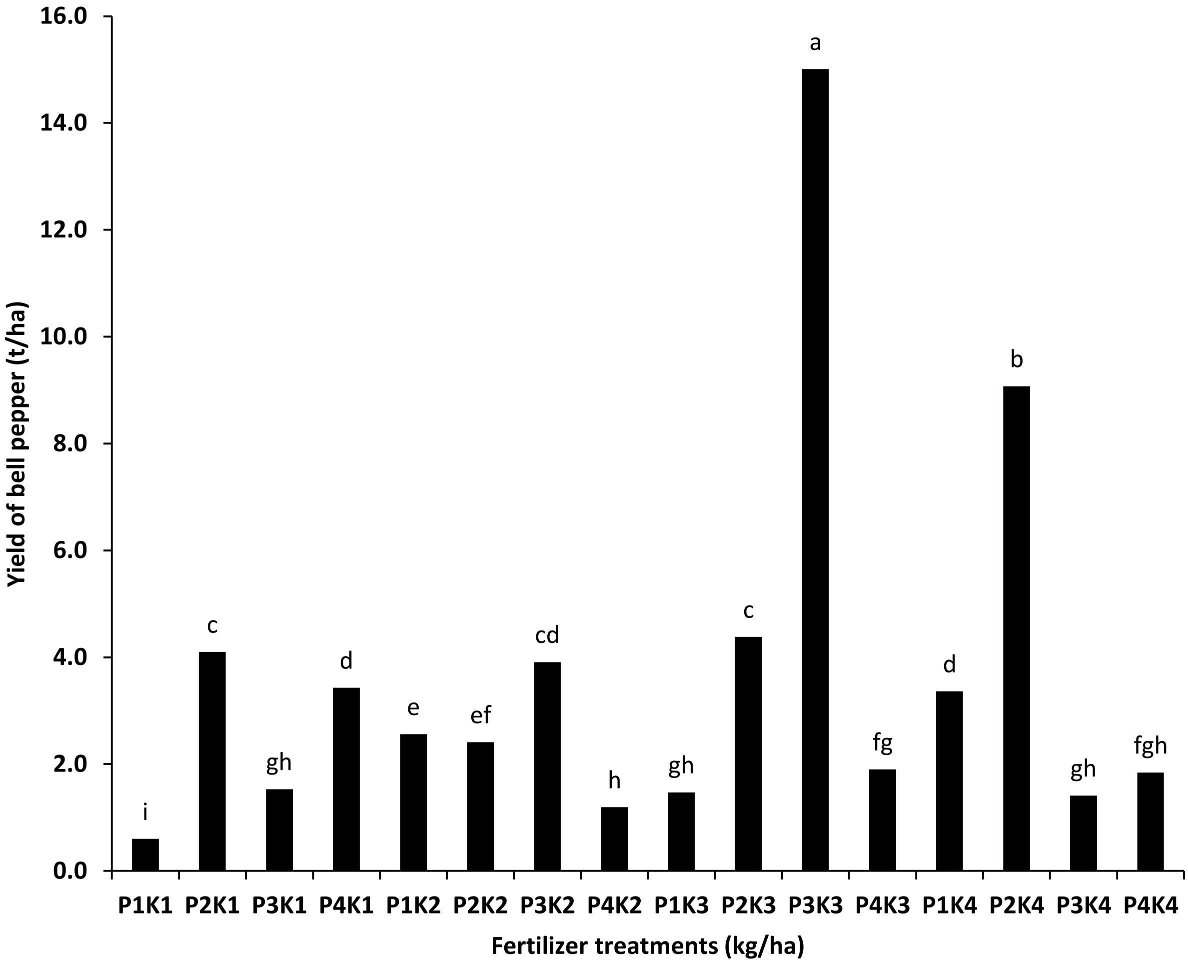


Table 4.4 Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Apomu soil series in 2011

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

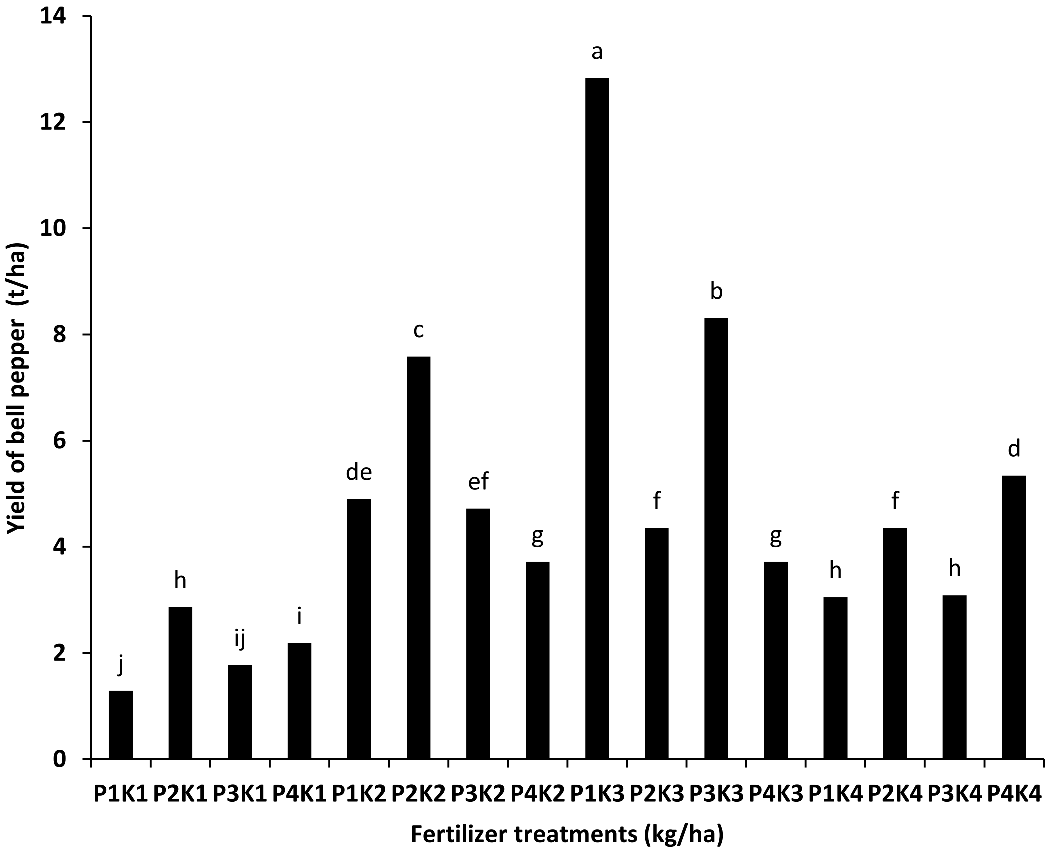


Fig. 4.5 Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Apomu soil series in the wet season of 2012

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

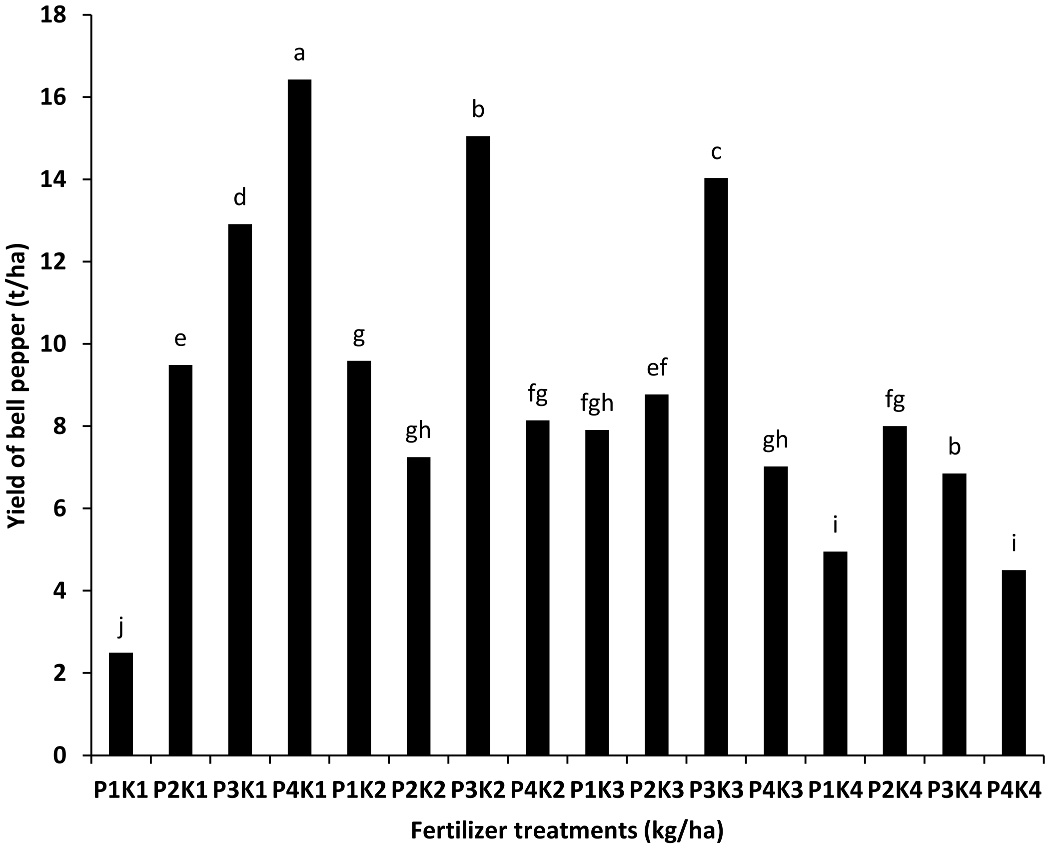


Fig. 4.6 **Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Apomu soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

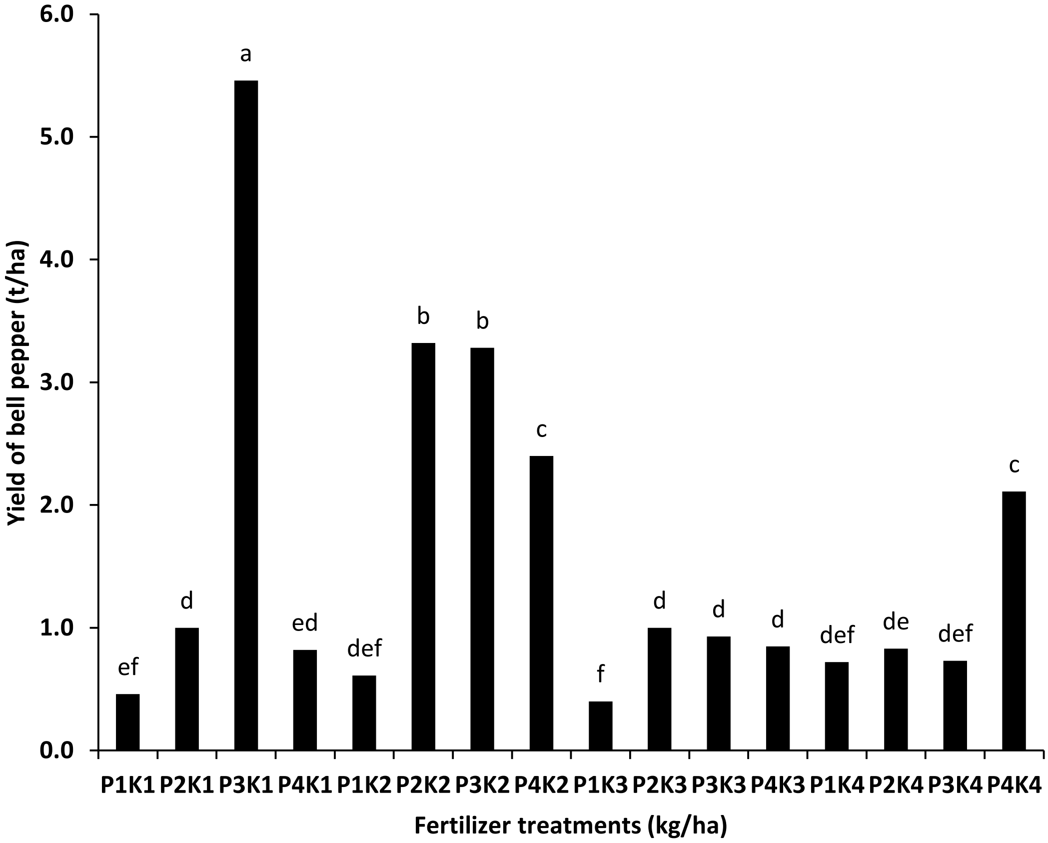


Fig. 4.7 Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Jago soil series in 2011

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

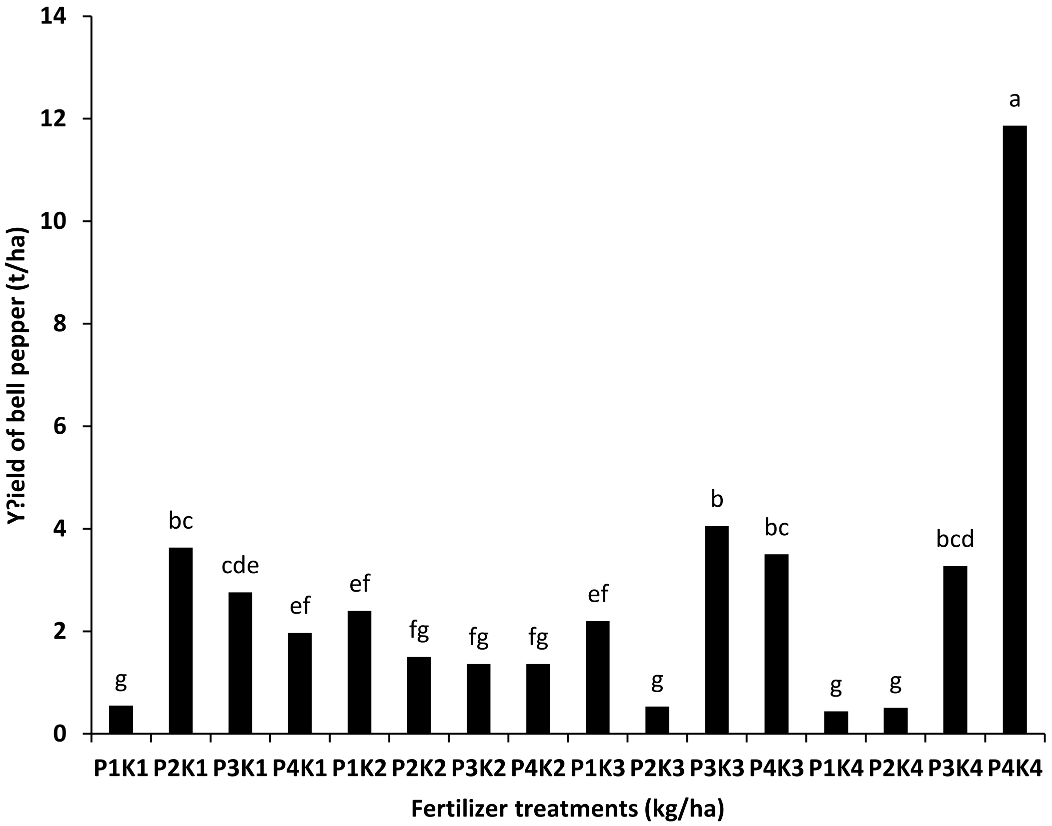


Fig. 4.8 **Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Jago soil series in the wet season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

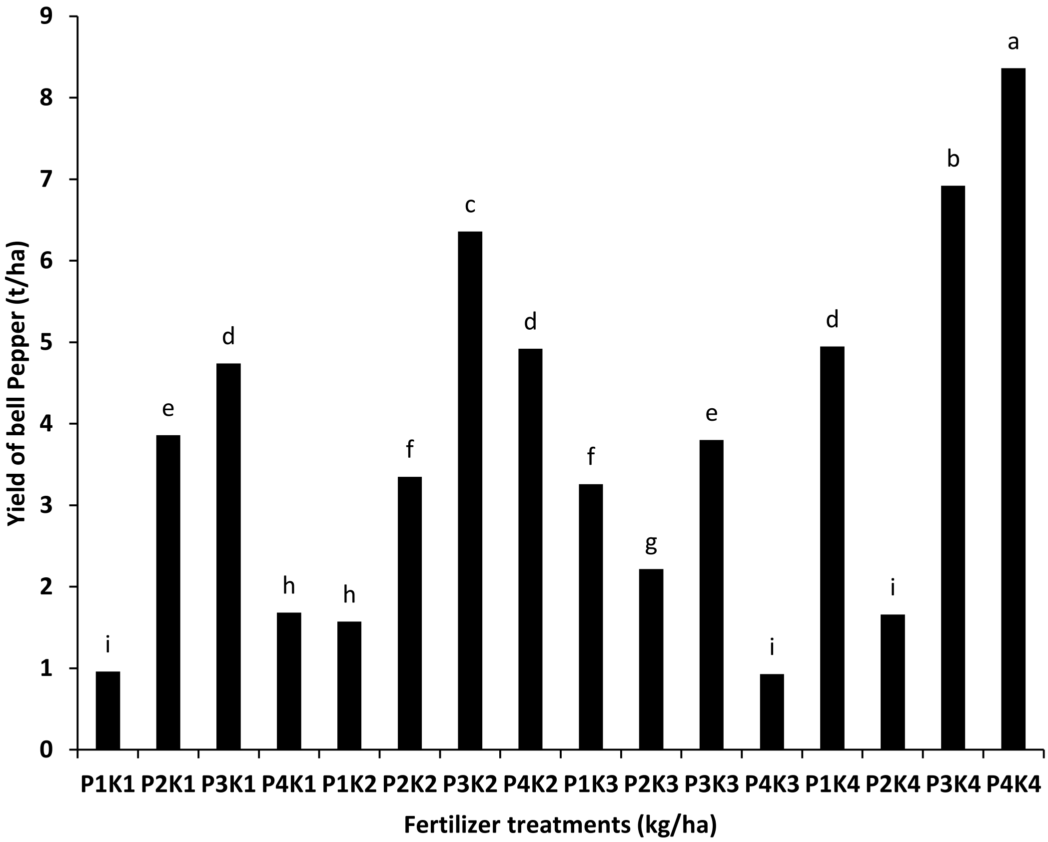


Fig.4.9 **Effects of P and K fertiliser combinations on the yield (t/ha) of bell pepper (*Capsicum annuum* L) on Jago soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

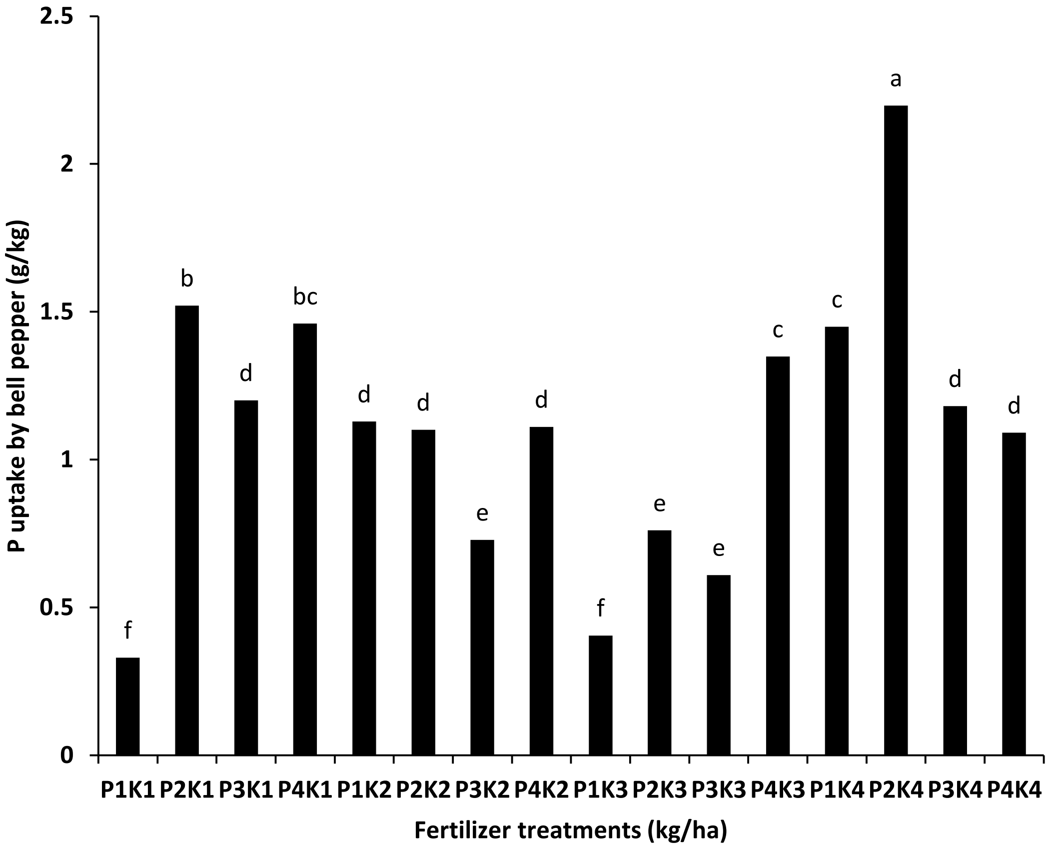


Fig.4.10 **Effects of P and K fertiliser combinations on P uptake (g/kg) of bell pepper (*Capsicum annuum* L) on Egbeda soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

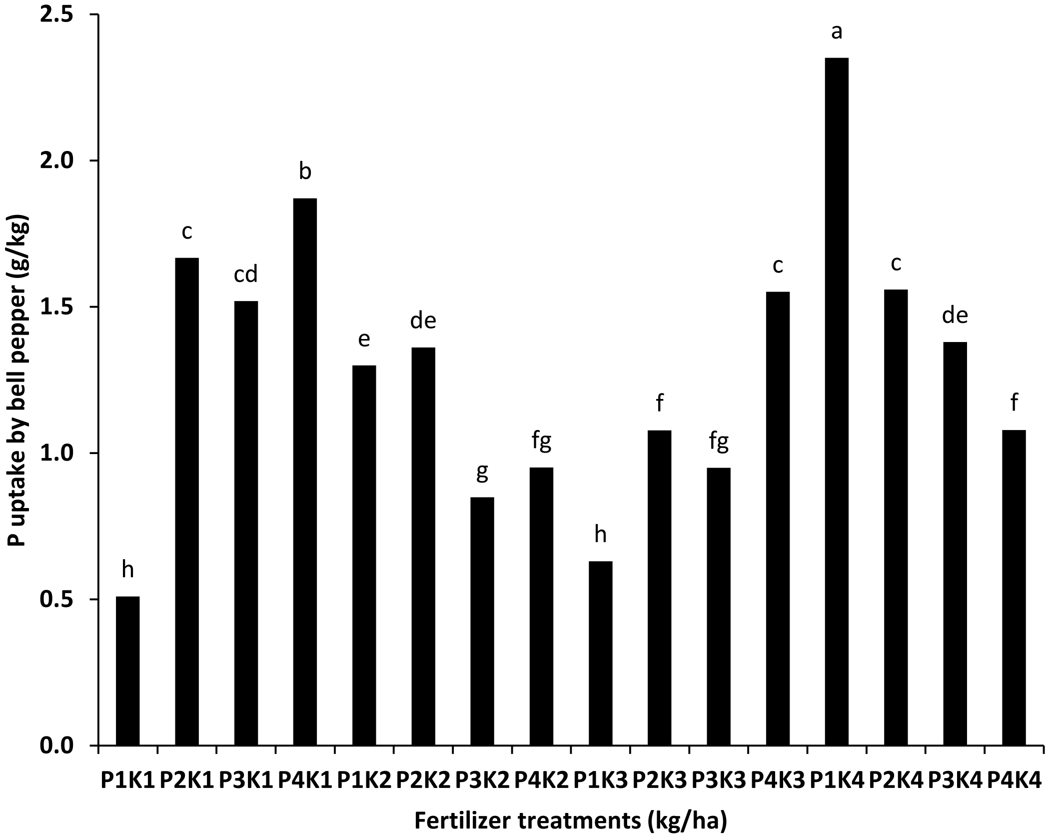


Fig.4.11 **Effects of P and K fertiliser combinations on P uptake (g/kg) of bell pepper (*Capsicum annuum* L) on Apomu soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

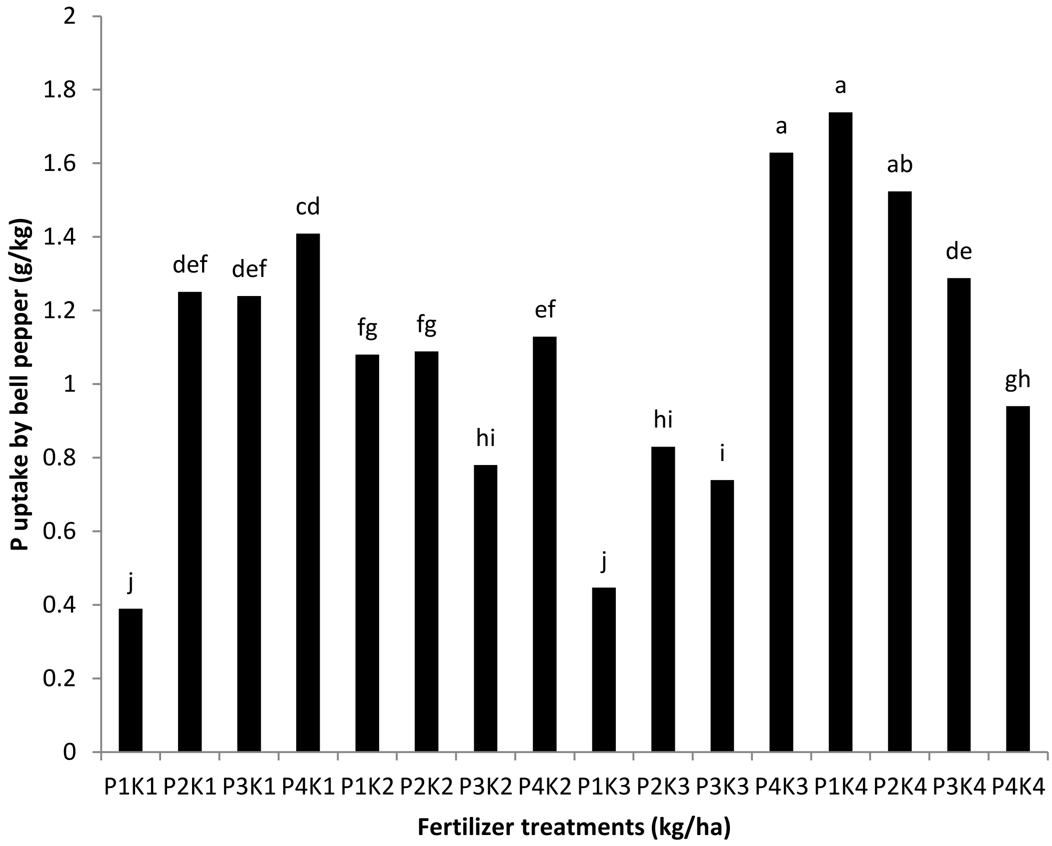


Fig.4.12 **Effects of P and K fertiliser combinations on P uptake (g/kg) of bell pepper (*Capsicum annuum* L) on Jago soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

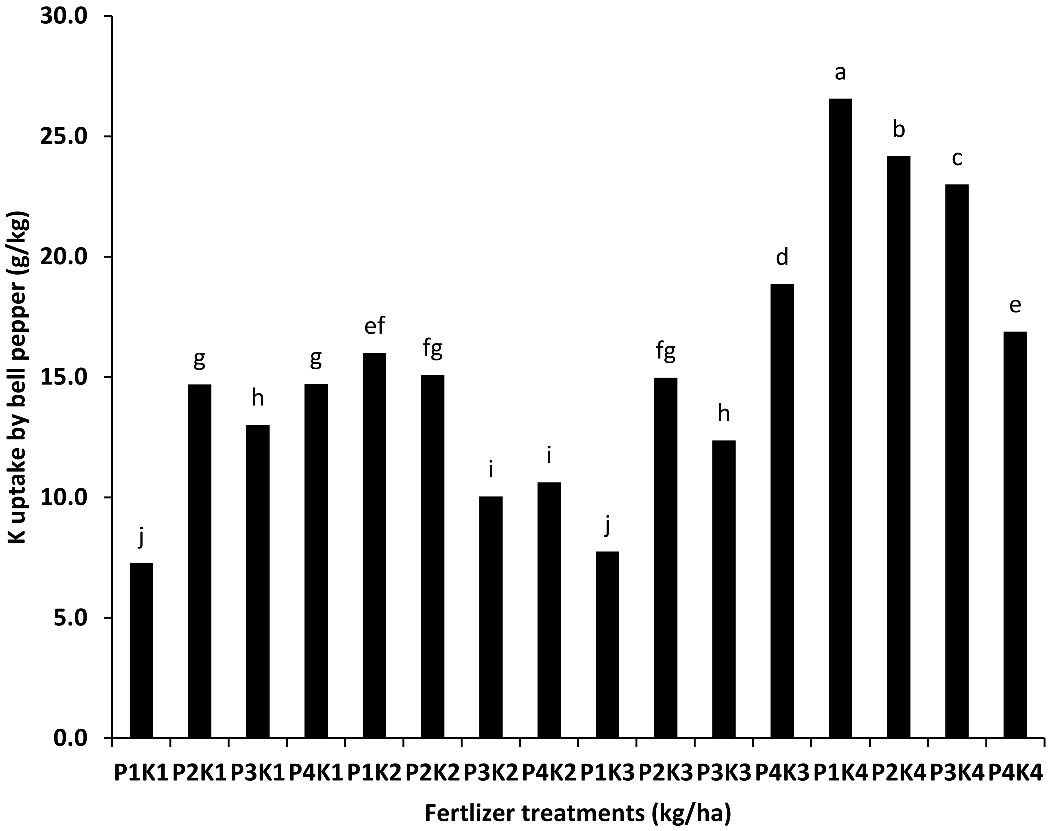


Fig.4.13 **Effects of P and K fertiliser combinations on K uptake (g/kg) of bell pepper (*Capsicum annuum* L) on Egbeda soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

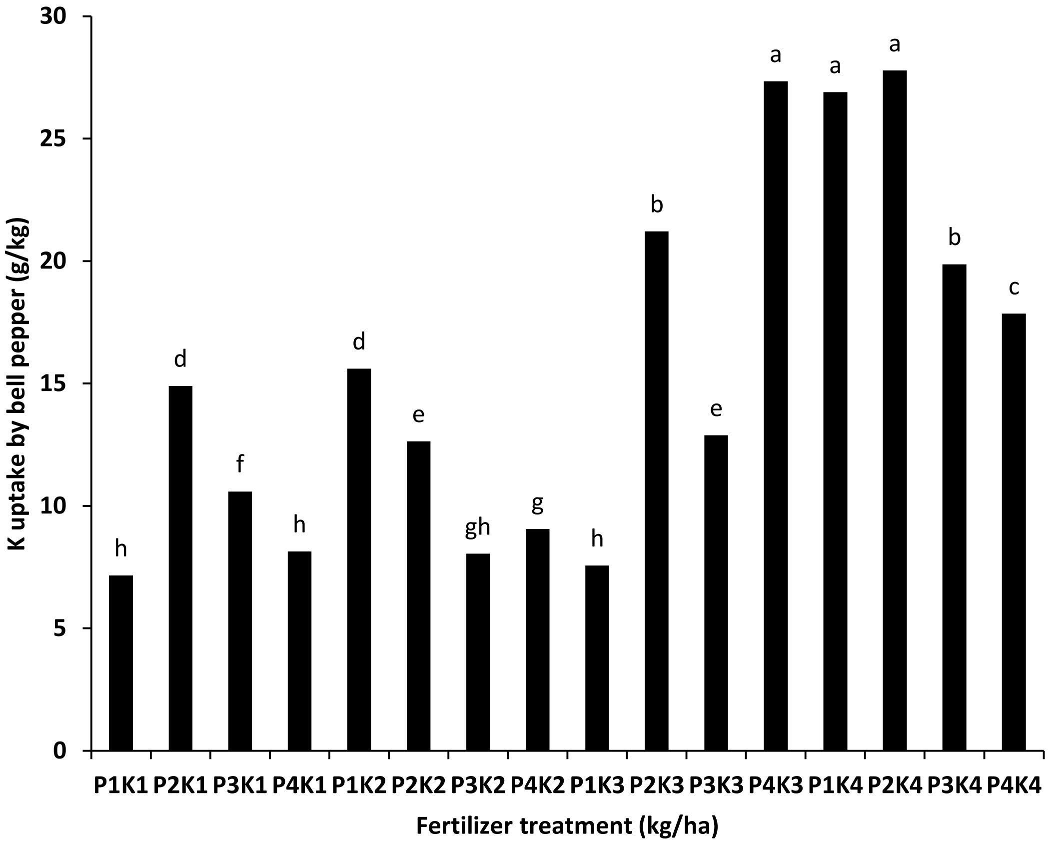


Fig.4.14 **Effects of P and K fertiliser combinations on K uptake (g/kg) of bell pepper (*Capsicum annuum* L) on Apomu soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

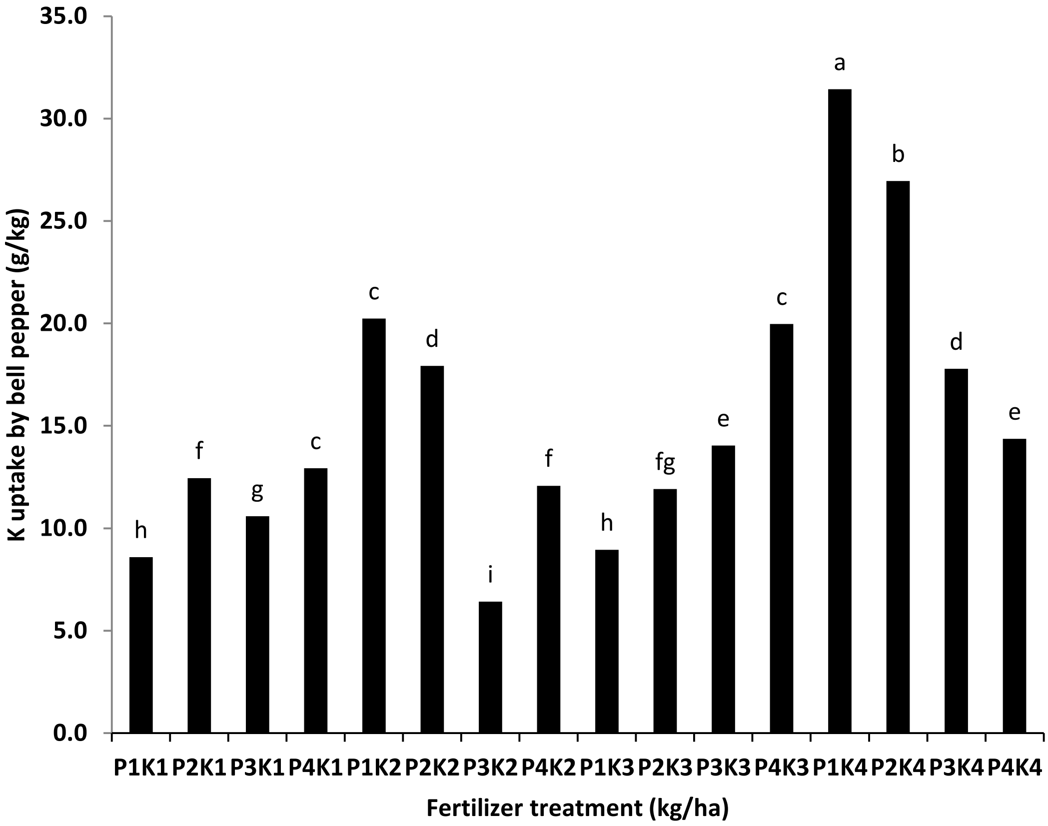


Fig.4.15 **Effects of P and K fertiliser combinations on K uptake (g/kg) of bell pepper (*Capsicum annuum* L) on Jago soil series in the dry season of 2012**

Treatments with the same letters are not significantly different ($\alpha_{0.05}$)

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Table 4.17 Yield of bell pepper on Egbeda soil series

Treatment	2011 wet season		2012 wet season		2012 dry season	
	Yield (t/ha)	Relative Yield (%)	Yield (t/ha)	Relative Yield (%)	Yield (t/ha)	Relative Yield (%)
P1K1	1.06	7.15	2.01	12.04	1.17	8.77
P2K1	8.39	56.59	3.82	22.86	5.58	41.81
P3K1	14.82	100.00	11.60	69.45	13.34	100.00
P4K1	8.97	60.54	16.70	100.00	2.27	17.00
P1K2	3.48	23.49	5.02	30.06	2.82	21.12
P2K2	3.05	20.58	5.38	32.24	4.01	30.07
P3K2	1.68	11.35	2.45	14.69	8.67	65.00
P4K2	3.59	24.20	6.62	39.66	10.00	74.93
P1K3	2.16	14.58	5.78	34.63	1.19	8.88
P2K3	0.46	3.12	3.51	21.04	2.21	16.58
P3K3	2.37	16.00	2.26	13.51	5.56	41.64
P4K3	1.53	10.30	1.85	11.08	1.22	9.16
P1K4	1.19	8.00	2.22	13.27	3.61	27.08
P2K4	3.51	23.66	5.07	30.36	4.82	36.16
P3K4	1.05	7.06	4.00	23.93	4.88	36.55
P4K4	4.76	32.11	3.25	19.46	9.33	69.93

P rates – 0, 30, 45, 60 kg P/ha

P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha

K1, K2, K3, K4

Table 4.18 Yield of bell pepper on Apomu soil series

Treatment	2011 wet season		2012 wet season		2012 dry season	
	Yield (t/ha)	Relative Yield (%)	Yield (t/ha)	Relative Yield (%)	Yield (t/ha)	Relative Yield (%)
P1K1	0.60	3.88	1.29	9.99	2.49	15.18
P2K1	4.10	26.73	2.86	22.26	9.49	57.75
P3K1	1.53	9.99	1.74	13.52	12.91	78.58
P4K1	3.36	21.89	2.19	17.01	16.43	100.00
P1K2	2.56	16.68	4.90	38.11	9.59	58.38
P2K2	2.47	16.12	7.61	59.15	7.25	44.12
P3K2	3.91	25.49	4.72	36.67	15.05	91.57
P4K2	1.19	7.78	3.72	28.93	8.14	49.57
P1K3	1.47	9.61	12.86	100.00	7.91	48.12
P2K3	4.38	28.53	4.35	33.86	8.77	53.39
P3K3	15.34	100.00	8.31	64.58	14.36	87.42
P4K3	1.90	12.36	3.72	28.93	7.02	42.72
P1K4	3.36	21.93	3.05	23.74	4.95	30.16
P2K4	9.07	59.14	4.35	33.86	8.00	48.68
P3K4	1.41	9.17	3.09	23.99	6.85	41.69
P4K4	1.84	11.97	5.34	41.56	4.50	27.41

P rates – 0, 30, 45, 60 kg P/ha

P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha

K1, K2, K3, K4

Table 4.19 Yield of bell pepper on Jago soil series

Treatment	2011 wet season		2012 wet season		2012 dry season	
	Yield (t/ha)	Relative Yield (%)	Yield (t/ha)	Relative Yield (%)	Yield (t/ha)	Relative Yield (%)
P1K1	0.46	8.36	0.55	4.67	0.96	11.47
P2K1	1.00	18.36	3.63	30.61	3.86	46.17
P3K1	5.46	100.00	2.76	23.26	4.74	56.70
P4K1	0.82	15.00	1.97	16.57	1.68	20.13
P1K2	0.61	11.22	2.41	20.29	1.57	18.80
P2K2	3.33	60.90	1.50	12.61	3.35	40.02
P3K2	3.28	60.10	1.32	11.15	6.36	76.04
P4K2	2.40	44.03	1.36	11.46	4.92	58.90
P1K3	0.40	7.37	2.20	18.54	3.26	39.03
P2K3	1.00	18.34	0.53	4.48	2.22	26.50
P3K3	0.93	17.06	4.05	34.17	3.80	45.49
P4K3	0.82	15.02	3.50	29.49	0.93	11.06
P1K4	0.72	13.19	0.44	3.68	4.95	59.15
P2K4	0.83	15.27	0.51	4.26	1.66	19.84
P3K4	0.73	13.44	3.27	27.57	6.92	82.74
P4K4	2.11	38.67	11.86	100.00	8.36	100.00

P rates – 0, 30, 45, 60 kg P/ha

P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha

K1, K2, K3, K4

Table 4.20 Phosphorus uptake of bell pepper in the dry season of 2012

Treatment	Egbeda		Apomu		Jago	
	Uptake (g/kg)	Relative uptake (%)	Uptake (g/kg)	Relative uptake (%)	Uptake (g/kg)	Relative uptake (%)
P1K1	0.33	15.00	0.51	21.70	0.39	22.41
P2K1	1.52	69.20	1.67	71.13	1.25	72.05
P3K1	1.20	54.65	1.52	64.49	1.24	71.04
P4K1	1.46	66.58	1.87	79.66	1.41	80.83
P1K2	1.13	51.27	1.30	55.20	1.08	62.13
P2K2	1.10	50.18	1.36	57.94	1.09	62.39
P3K2	0.73	33.00	0.85	36.04	0.78	44.89
P4K2	1.11	50.62	0.95	40.58	1.13	64.74
P1K3	0.41	18.41	0.63	26.81	0.45	25.86
P2K3	0.76	34.71	1.11	47.33	0.83	47.70
P3K3	0.61	27.71	0.95	40.26	0.74	42.33
P4K3	1.35	61.28	1.55	66.02	1.63	93.47
P1K4	1.45	66.07	2.35	100.18	1.74	100.00
P2K4	2.20	100.00	1.56	66.31	1.53	88.00
P3K4	1.18	53.78	1.38	58.60	1.29	73.86
P4K4	1.09	49.70	1.08	45.87	0.94	53.99

P rates – 0, 30, 45, 60 kg P/ha

P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha

K1, K2, K3, K4

Table 4.21 Potassium uptake of bell pepper in the dry season of 2012

Treatment	Egbeda		Apomu		Jago	
	Uptake (g/kg)	Relative uptake (%)	Uptake (g/kg)	Relative uptake (%)	Uptake (g/kg)	Relative uptake (%)
P1K1	7.27	27.37	7.16	25.77	8.59	27.33
P2K1	14.69	55.29	14.90	53.62	12.45	39.60
P3K1	13.02	49.03	10.59	38.13	10.59	33.70
P4K1	14.71	55.40	8.16	29.37	12.93	41.14
P1K2	16.00	60.24	15.61	56.20	20.24	64.39
P2K2	15.09	56.81	12.64	45.50	17.92	57.02
P3K2	10.04	37.79	8.01	28.83	6.43	20.46
P4K2	10.63	40.02	9.06	32.60	12.07	38.40
P1K3	7.75	29.18	7.56	27.23	8.95	28.46
P2K3	14.97	56.38	21.21	76.34	11.91	37.90
P3K3	12.37	46.57	12.89	46.40	14.06	44.73
P4K3	18.86	71.02	27.34	98.41	19.97	63.53
P1K4	26.56	100.00	26.89	96.80	31.43	100.00
P2K4	24.17	91.01	27.78	100.00	26.95	85.75
P3K4	23.00	86.60	19.87	71.52	17.78	56.57
P4K4	16.89	63.61	17.84	64.22	14.37	45.71

P rates – 0, 30, 45, 60 kg P/ha

P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha

K1, K2, K3, K4

P2K0, P2K2 and P2K0 over the control in Egbeda, Apomu and Jago respectively in 2011 season, while in the wet season of 2012, an increase of 8, 10 and 21 were observed over the control relative to treatments P3K0, P0K2 and P3K3 respectively. In the dry season of 2012 the increases of treatments P2K0, P3K0 and P3K3 over the controls were 11, 7 and 8 respectively in Egbeda, Apomu and Jago soil series.

4.10 Bell pepper yield and P fertiliser response curve

Yield curve of bell pepper in response to P fertiliser application on the 3 soil series in the three seasons are shown in Figures 4.16 - 4.24. Optimum bell pepper yield was obtained at 45 kg P/ha on all the soil series in 2011 and the dry season crop of 2012. But in the wet season of 2012 highest yield was obtained at 60 kg P/ha on Egbeda and Jago soil series and was still increasing. On Apomu soil series in the wet season of 2012 highest yield was obtained at 0 kg P/ha (control) and decreased steadily.

4.11 Phosphorus uptake and fertiliser response curve.

Phosphorus uptake in response to P fertiliser application is shown in Figures 4.25 - 4.27. Highest P uptake was observed at 30 kg P/ha except on Jago soil series which was observed at 60 kg P/ha. The coefficient of determination (R^2) between yield of bell pepper and K application were 0.62 and 0.86 on Egbeda soil series in 2011 and the wet season of 2012, while on Apomu soil series it was 0.42, 0.21 and 0.77 in the seasons consecutively. On Jago soil series R^2 values were 0.52, 0.63 and 0.39 in consecutive seasons. Highest bell pepper yield was obtained at 0 kg K/ha on Egbeda soil series in 2011 and the wet season crop of 2012. But in the dry season crop of 2012 highest yield was obtained at 45 kg K/ha. On Apomu soil series, highest yield was obtained at 30 kg K/ha (control) in 2011 and the wet season crop of 2012. But in the dry season crop of 2012 it was observed at 0 kg K/ha (control). On Jago soil series highest yield were obtained at the same K rate of 45 kg K/ha in the two seasons of 2012 and at 15 kg K/ha in 2011.

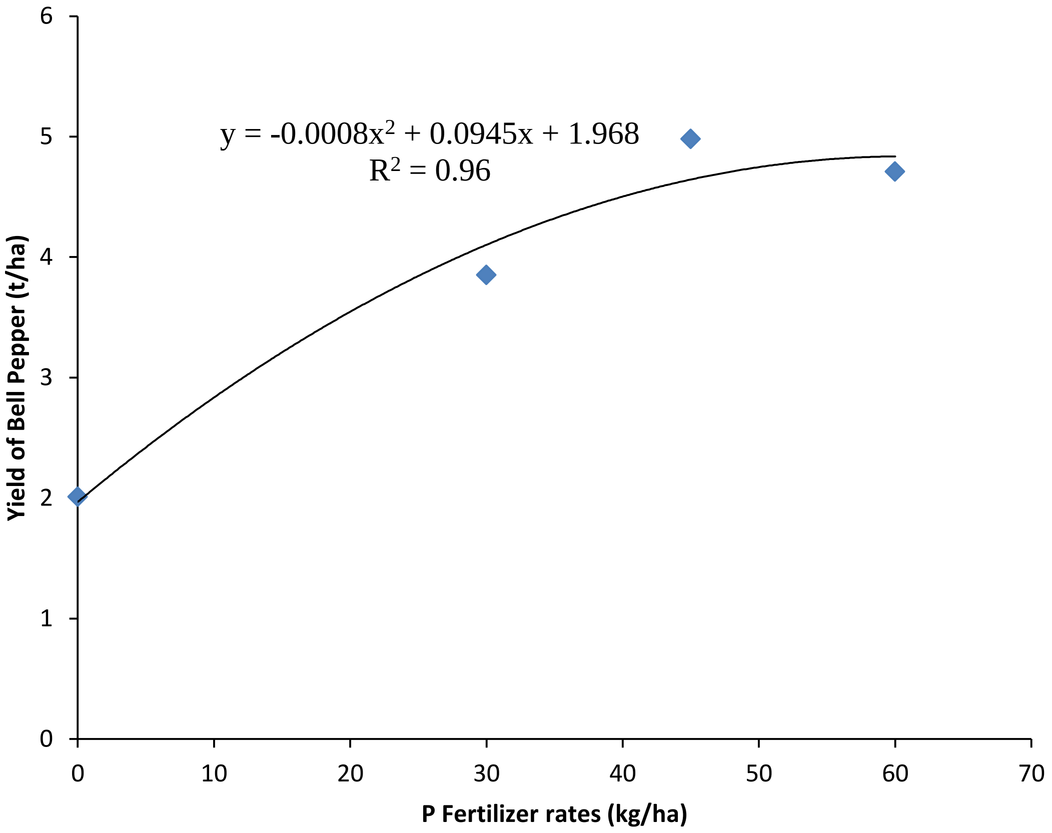


Fig. 4.16 Yield and P fertiliser calibration curve for bell pepper on Egbeda soil series in 2011

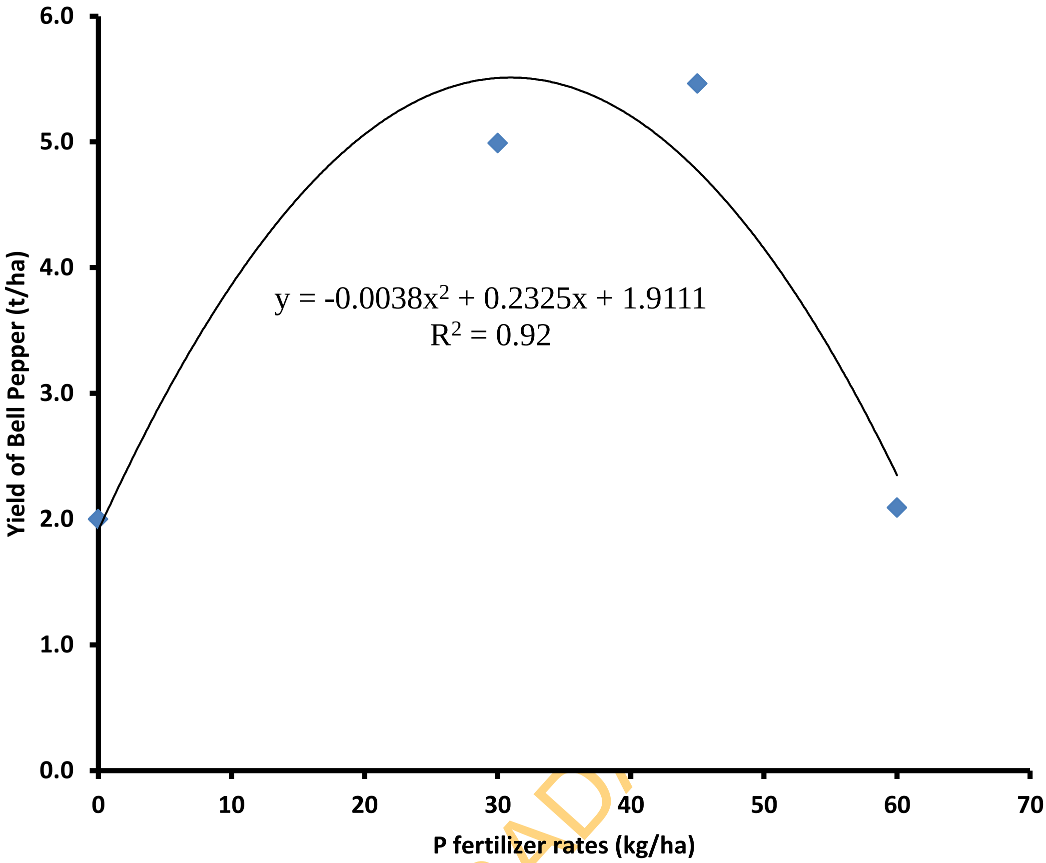


Fig. 4.17 Yield and P fertiliser calibration curve for bell pepper on Apomu soil series in 2011

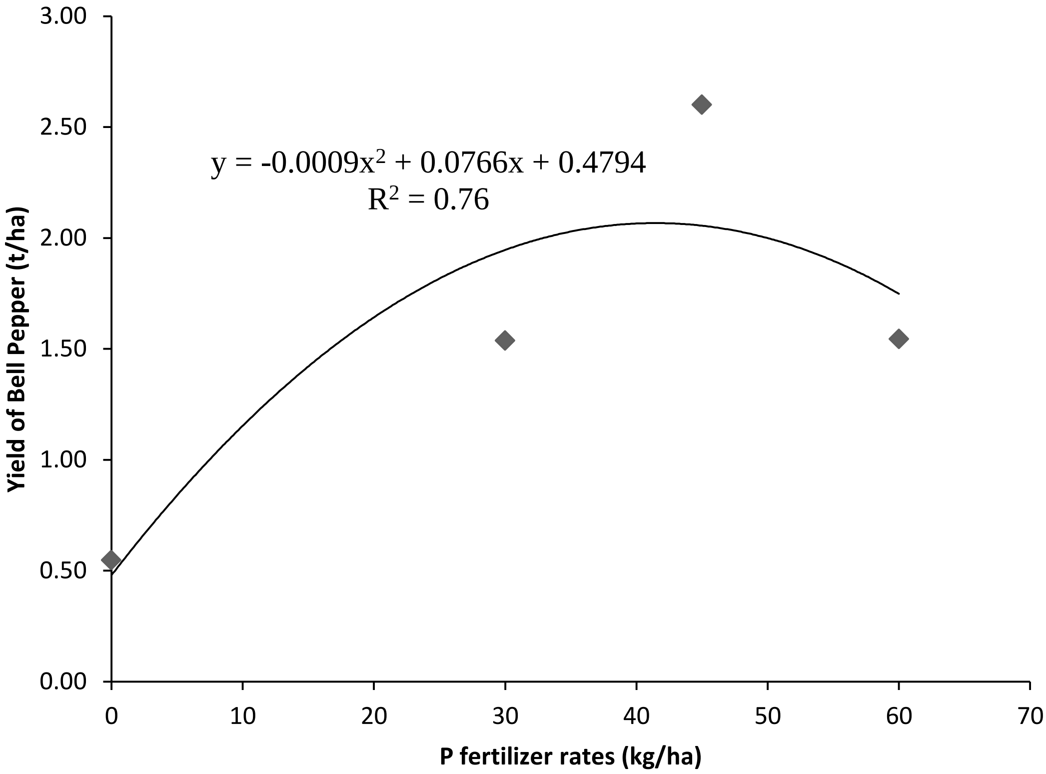


Fig. 4.18 Yield and P fertiliser calibration curve for bell pepper on Jago soil series in 2011

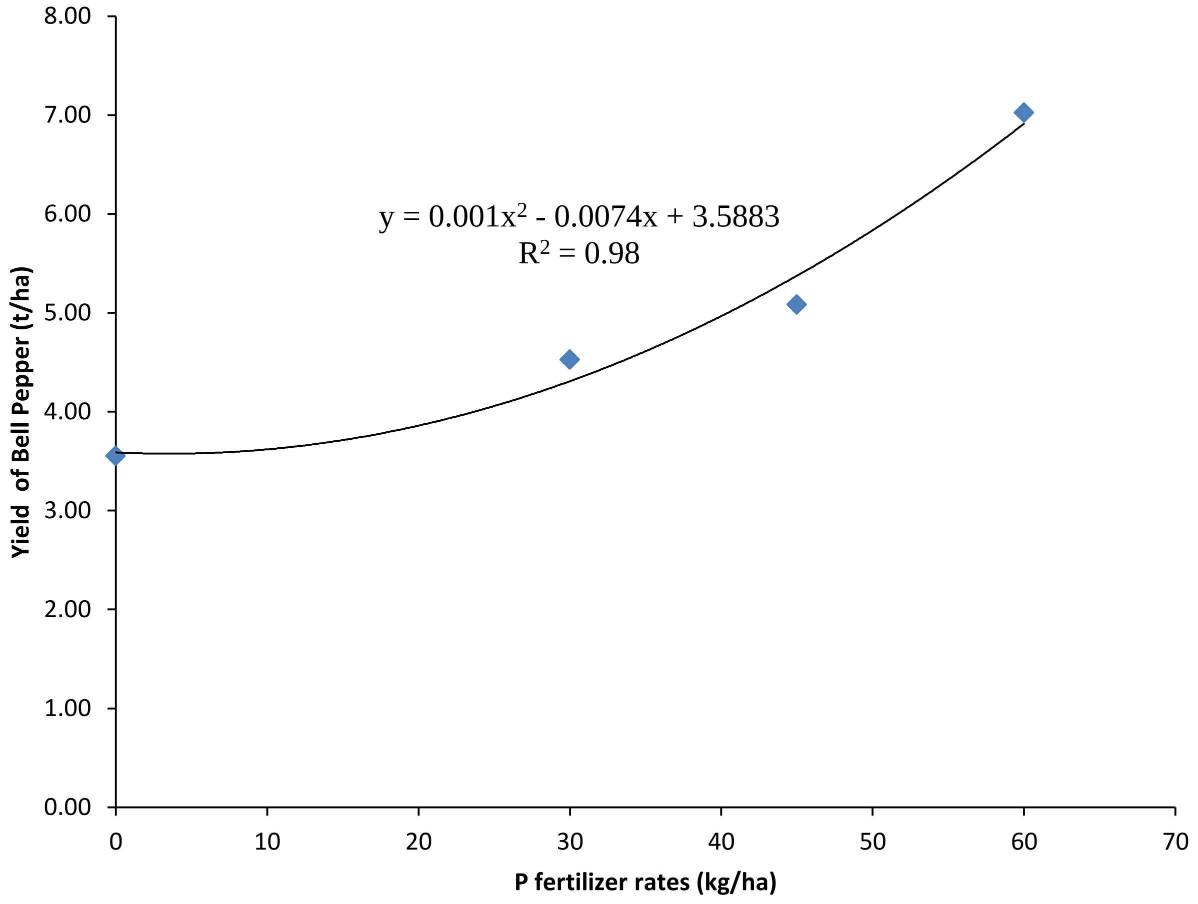


Fig. 4.19 Yield and P fertiliser calibration curve for bell pepper on Egbeda soil series in the wet season of 2012.

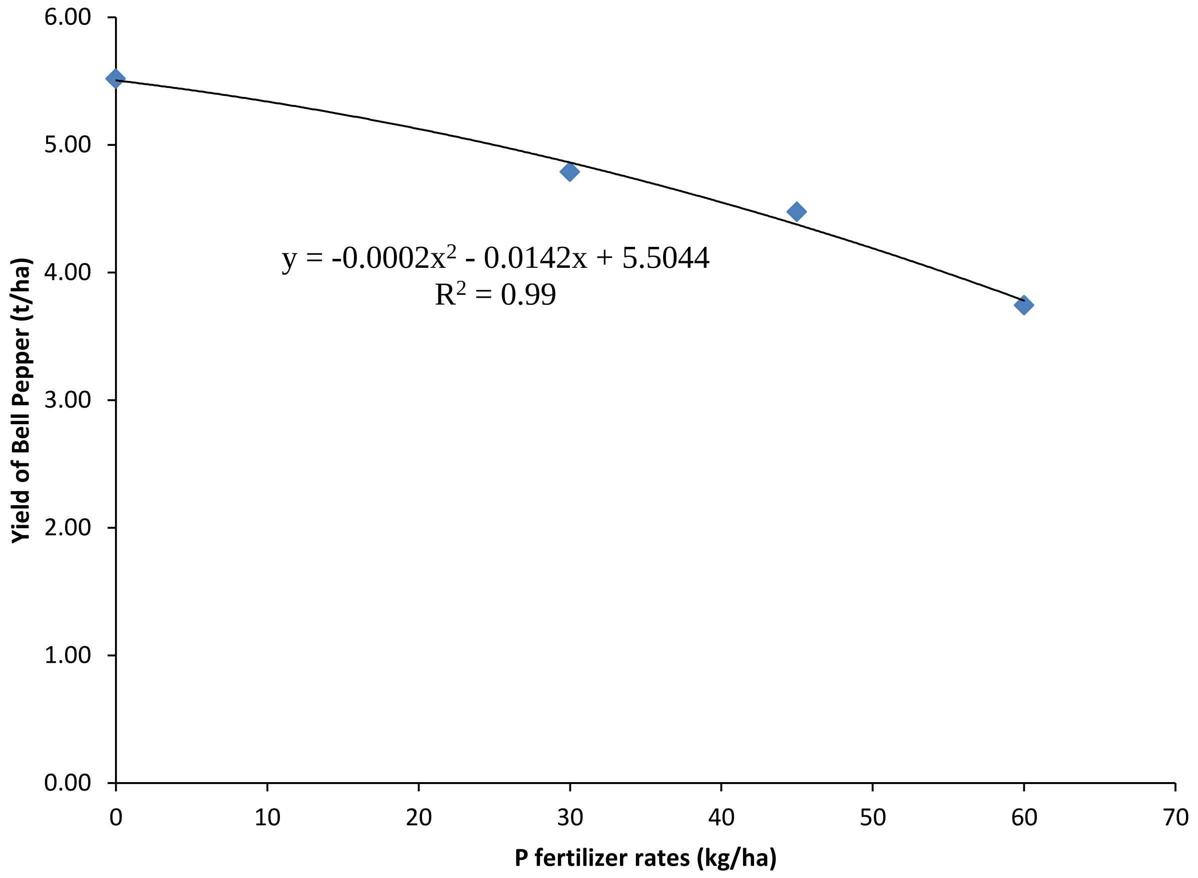


Fig. 4.20 Yield and P fertiliser calibration curve for bell pepper on Apomu soil series in the wet season of 2012.

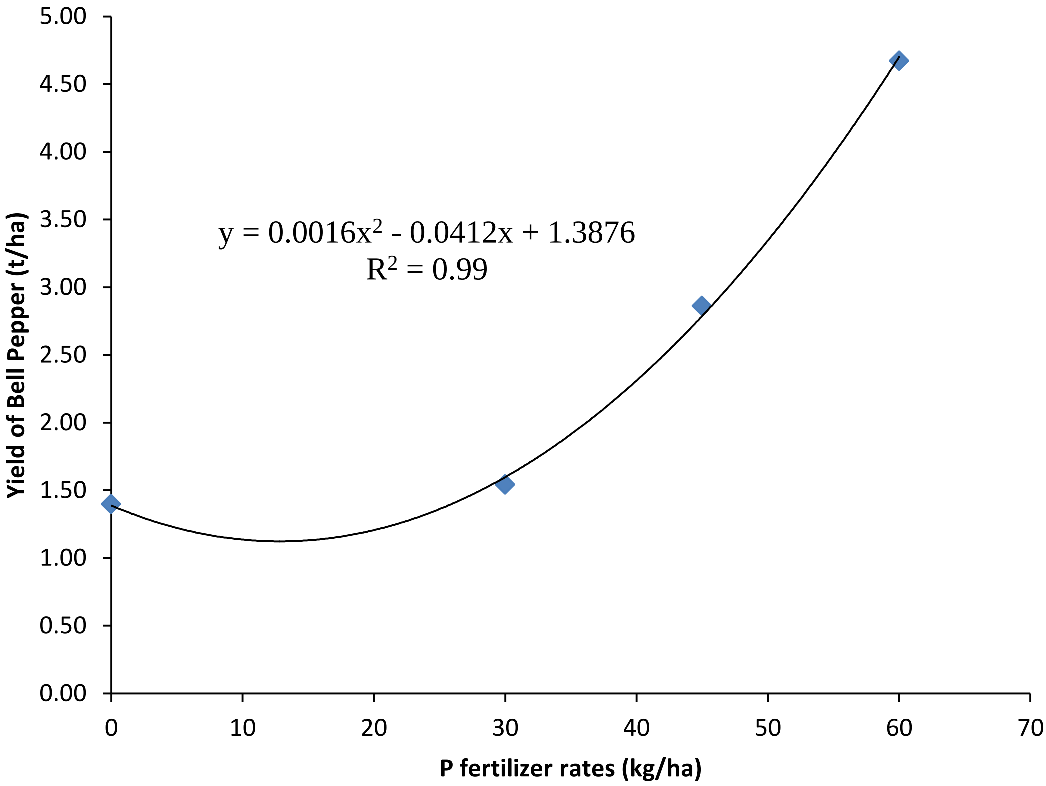


Fig. 4.21 Yield and P fertiliser calibration curve for bell pepper on Jago soil series in the wet season of 2012.

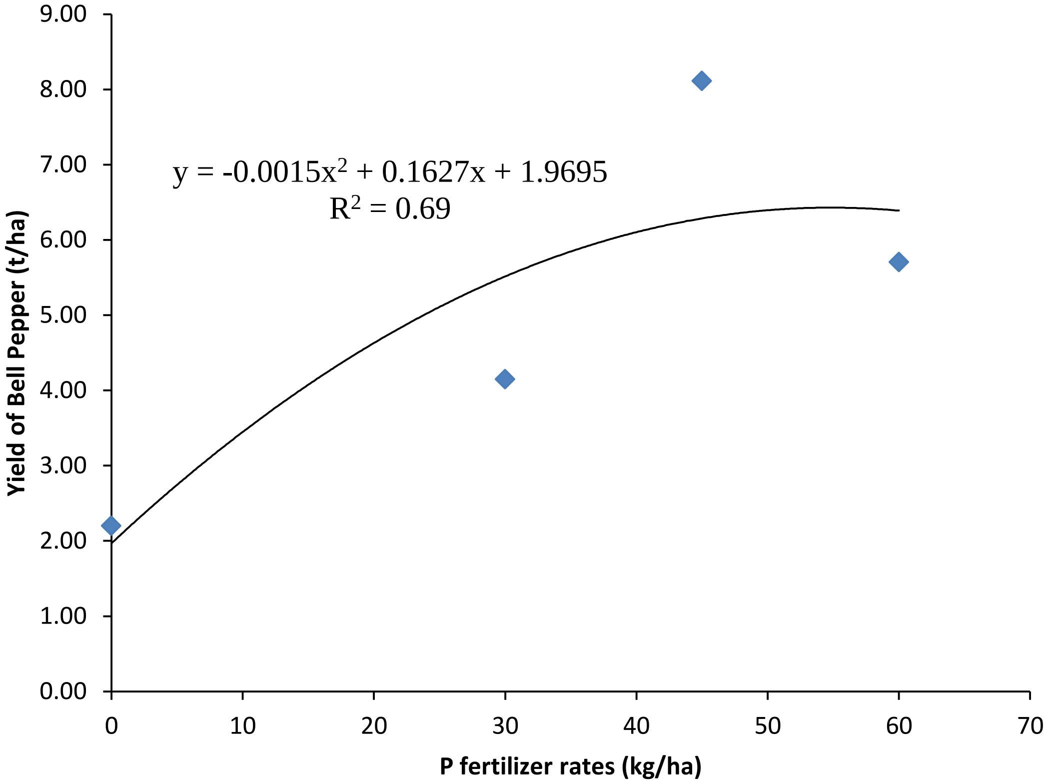


Fig. 4.22 Yield and P fertiliser calibration curve for bell pepper on Egbeda soil series in the dry season of 2012.

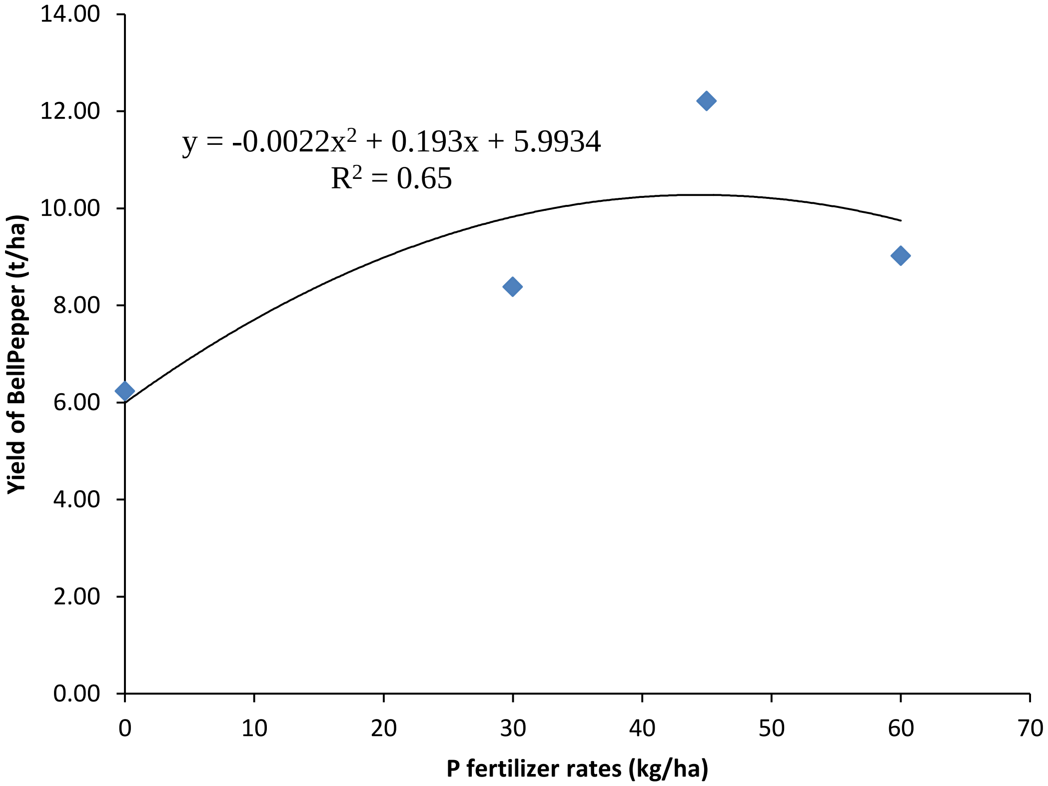


Fig. 4.23 Yield and P fertiliser calibration curve for bell pepper on Apomu soil series in the dry season of 2012.

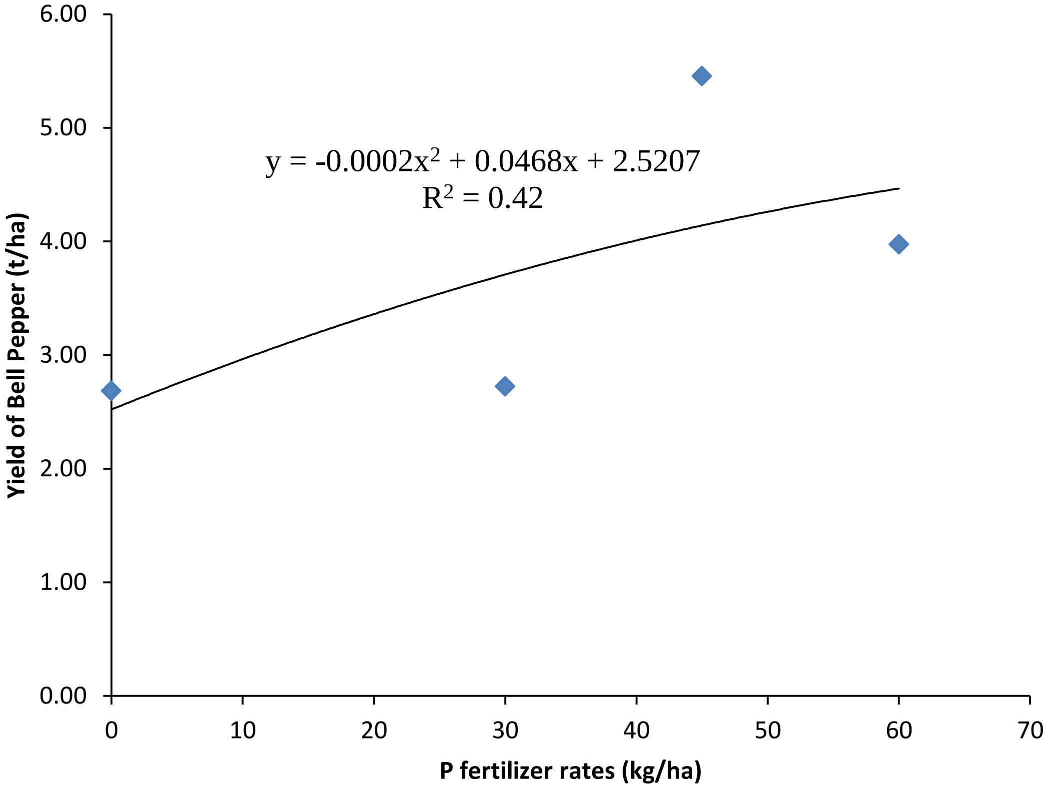


Fig. 4.24 Yield and P fertiliser calibration curve for bell pepper on Jago soil series in the dry season of 2012.

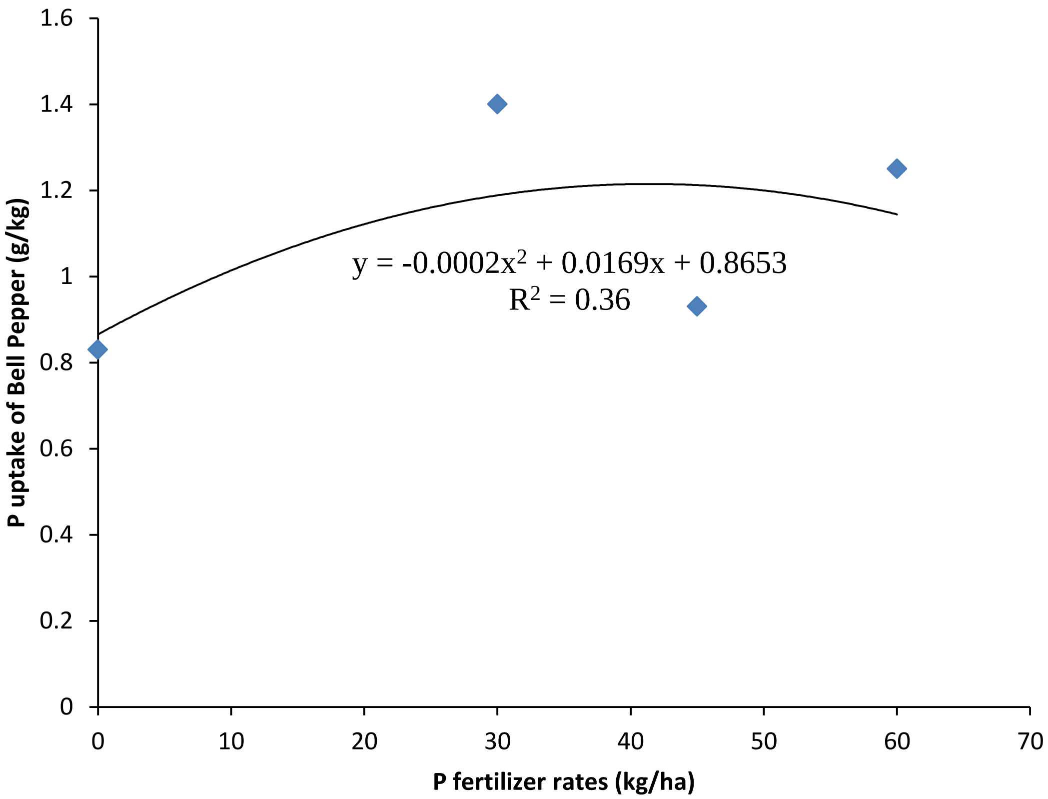


Fig. 4.25 P uptake and P fertiliser calibration curve for bell pepper on Egbeda soil series in the dry season of 2012.

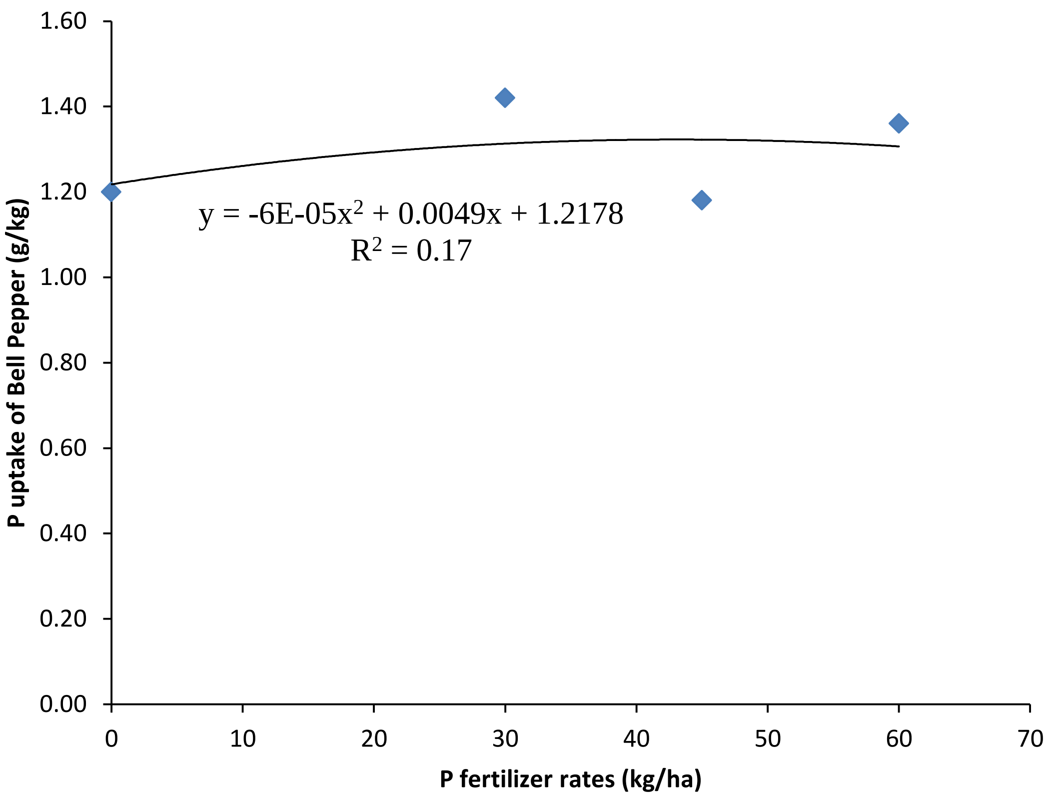


Fig. 4.26 P uptake and P fertiliser calibration curve for bell pepper on Apomu soil series in the dry season of 2012.

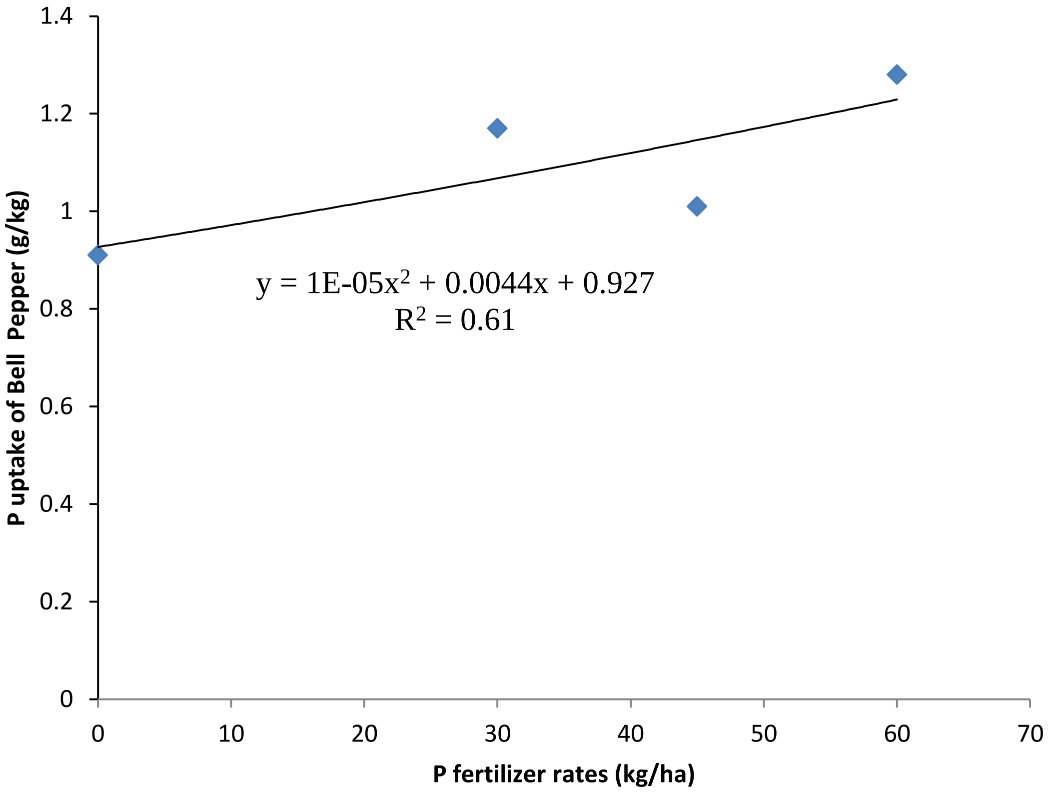


Fig. 4.27 P uptake and P fertiliser calibration curve for bell pepper on Jago soil series in the dry season of 2012.

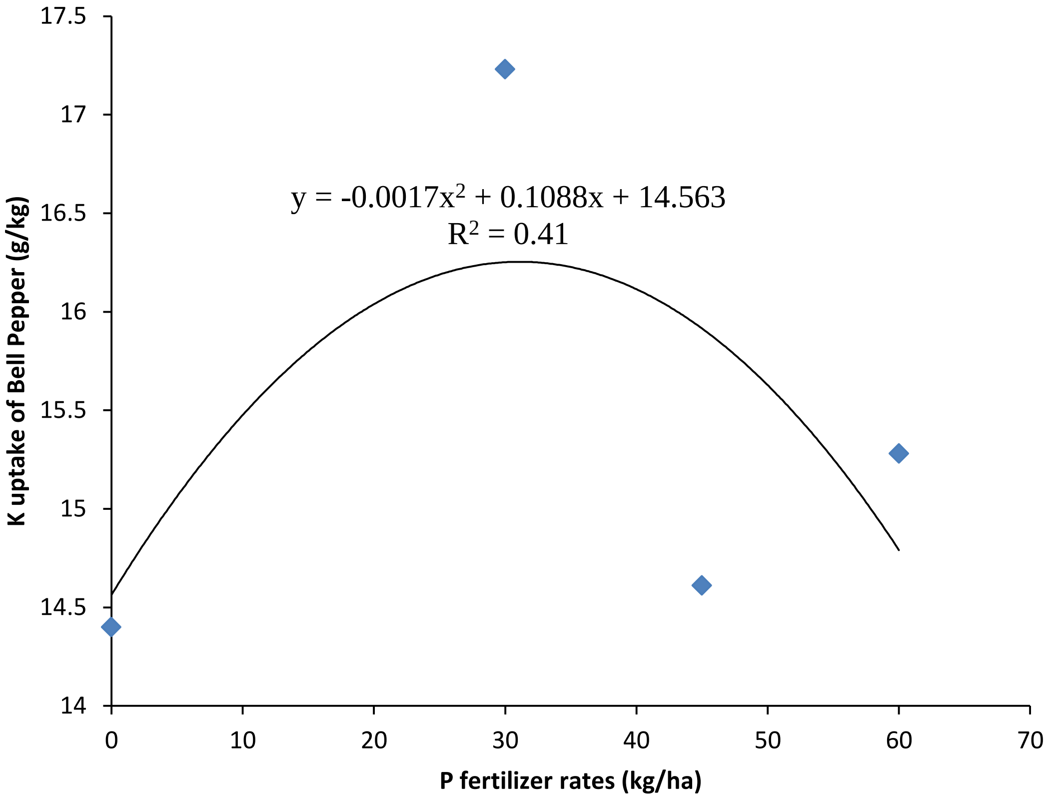


Fig. 4.28 K uptake and P fertiliser calibration curve for bell pepper on Egbeda soil series in the dry season of 2012.

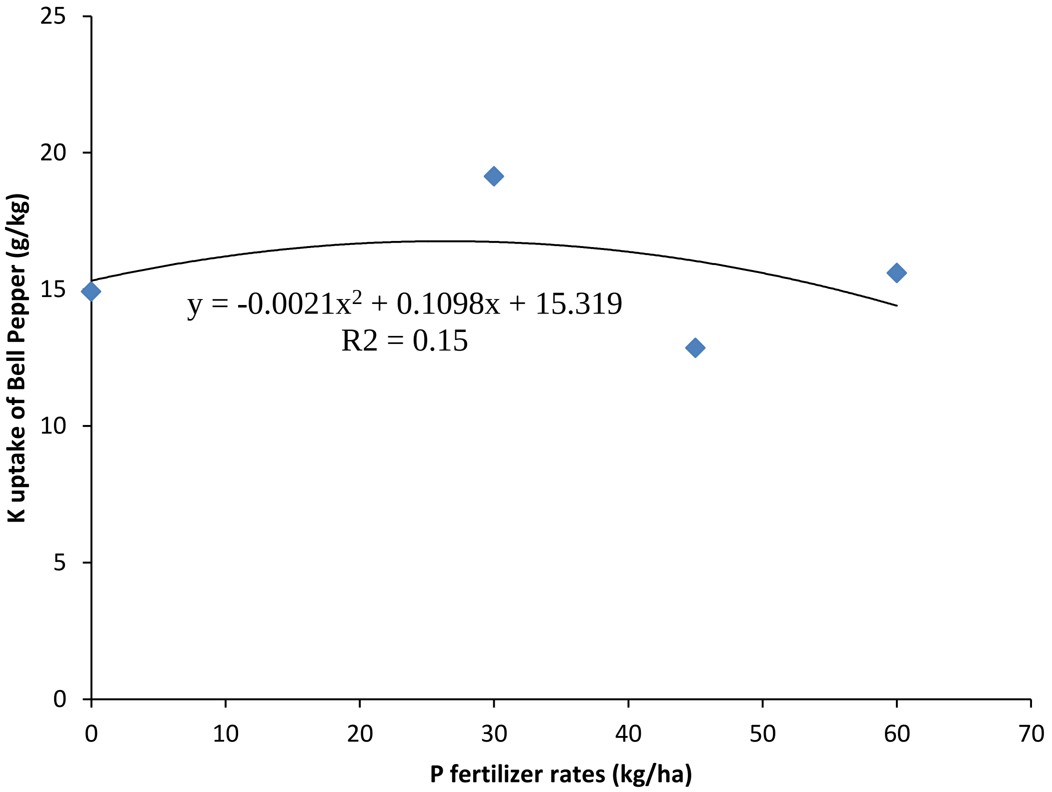


Fig. 4.29 K uptake and P fertiliser calibration curve for bell pepper on Apomu soil series in the dry season of 2012.

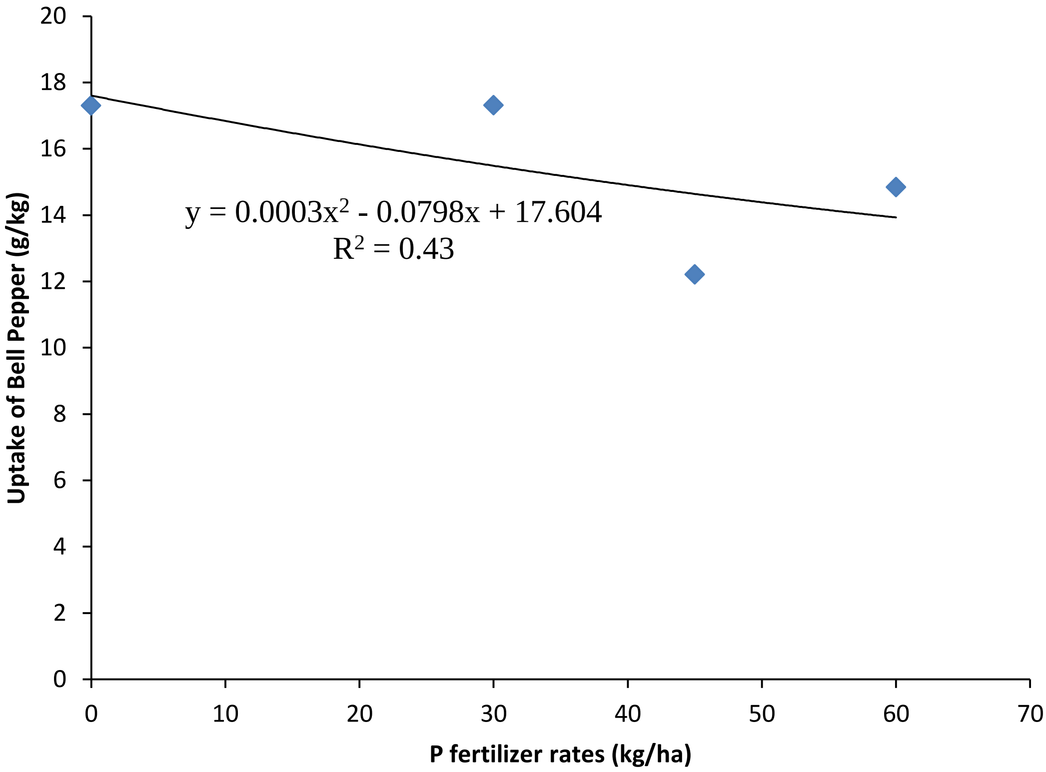


Fig. 4.30 K uptake and P fertiliser calibration curve for bell pepper on Jago soil series in the dry season of 2012.

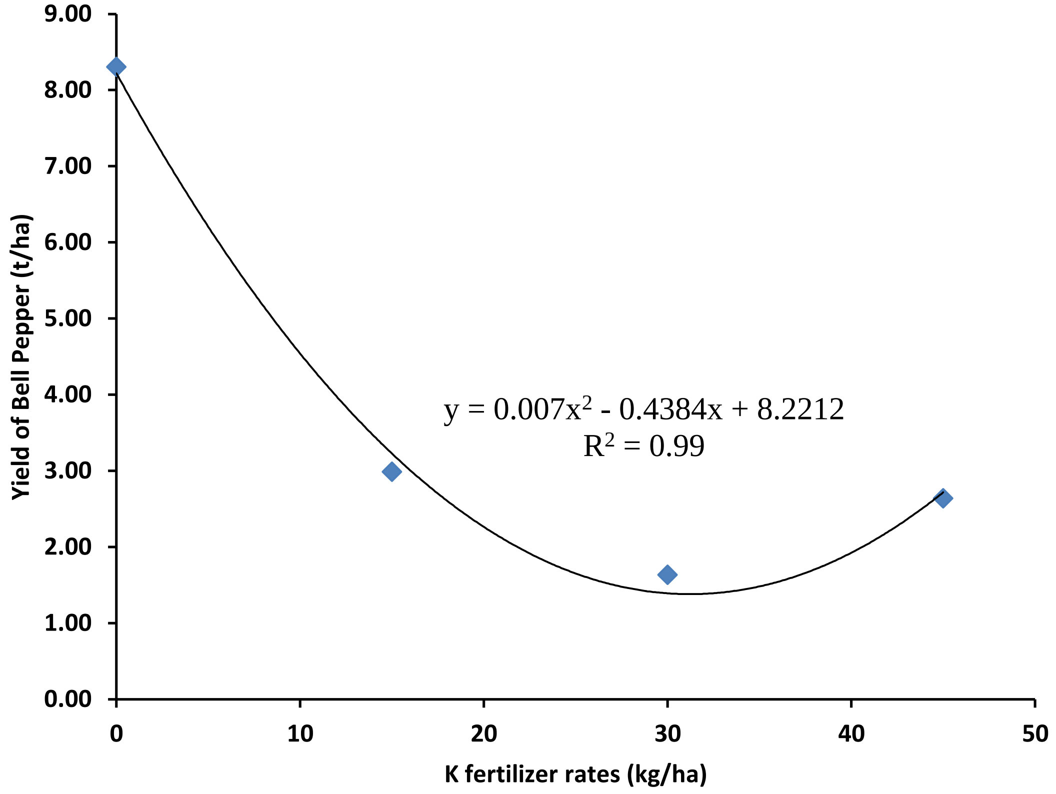


Fig. 4.31 Yield and K fertiliser calibration curve for bell pepper on Egbeda soil series in 2011.

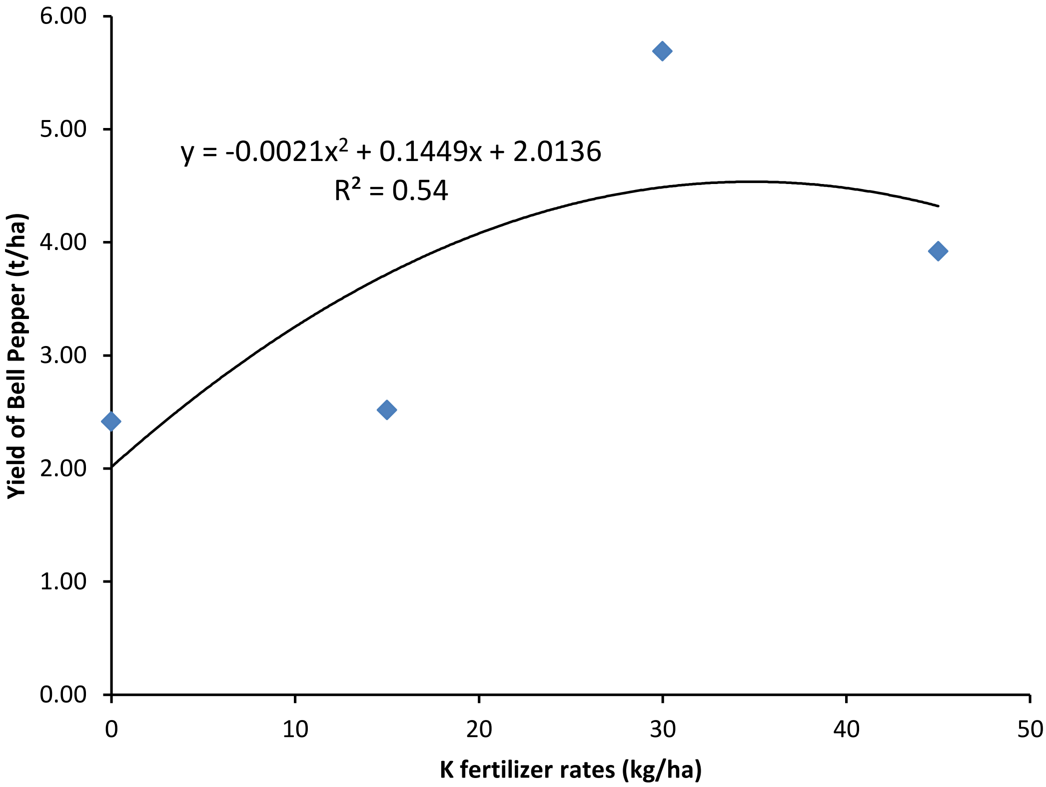


Fig. 4.32 Yield and K fertiliser calibration curve for bell pepper on Apomu soil series in 2011.

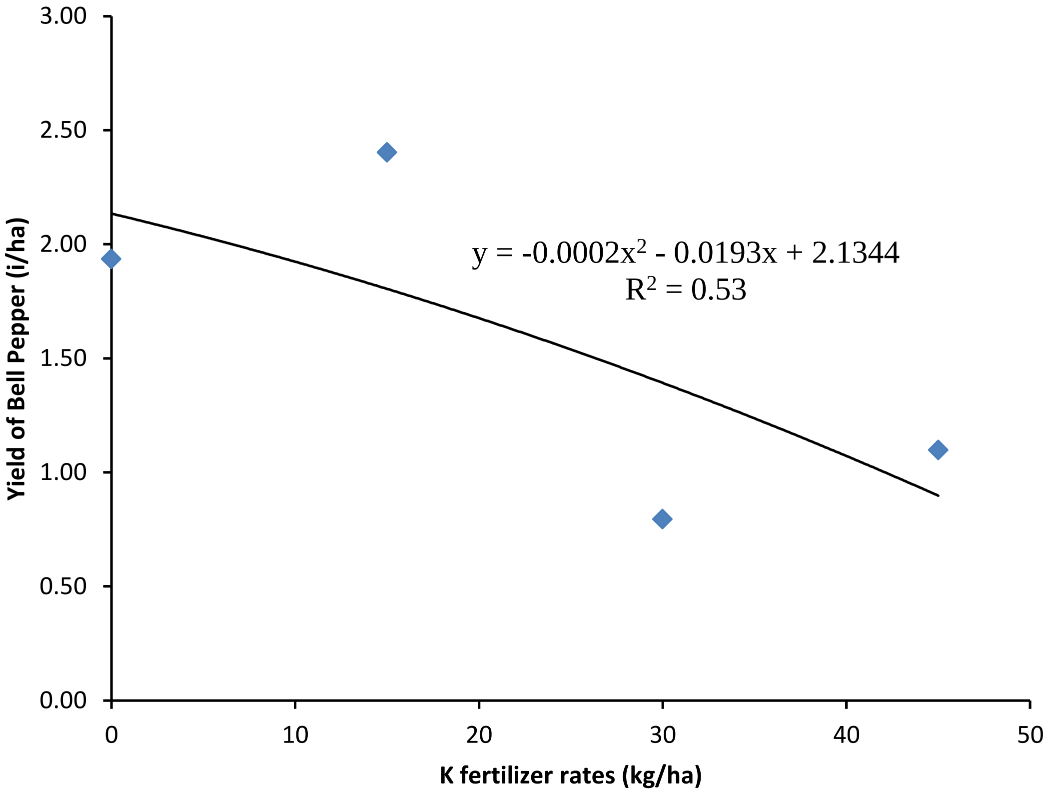


Fig. 4.33 Yield and K fertiliser calibration curve for bell pepper on Jago soil series in 2011.

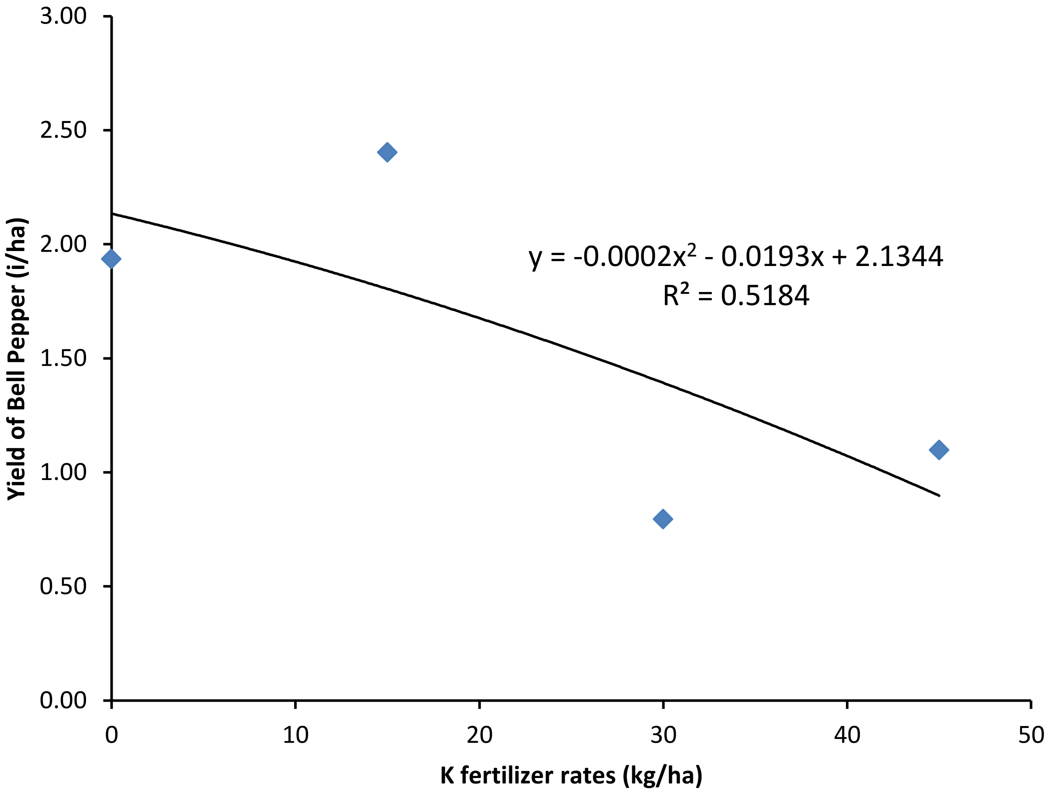


Fig. 4.34 Yield and K fertiliser calibration curve for bell pepper on Egbeda soil series in the wet season of 2012.

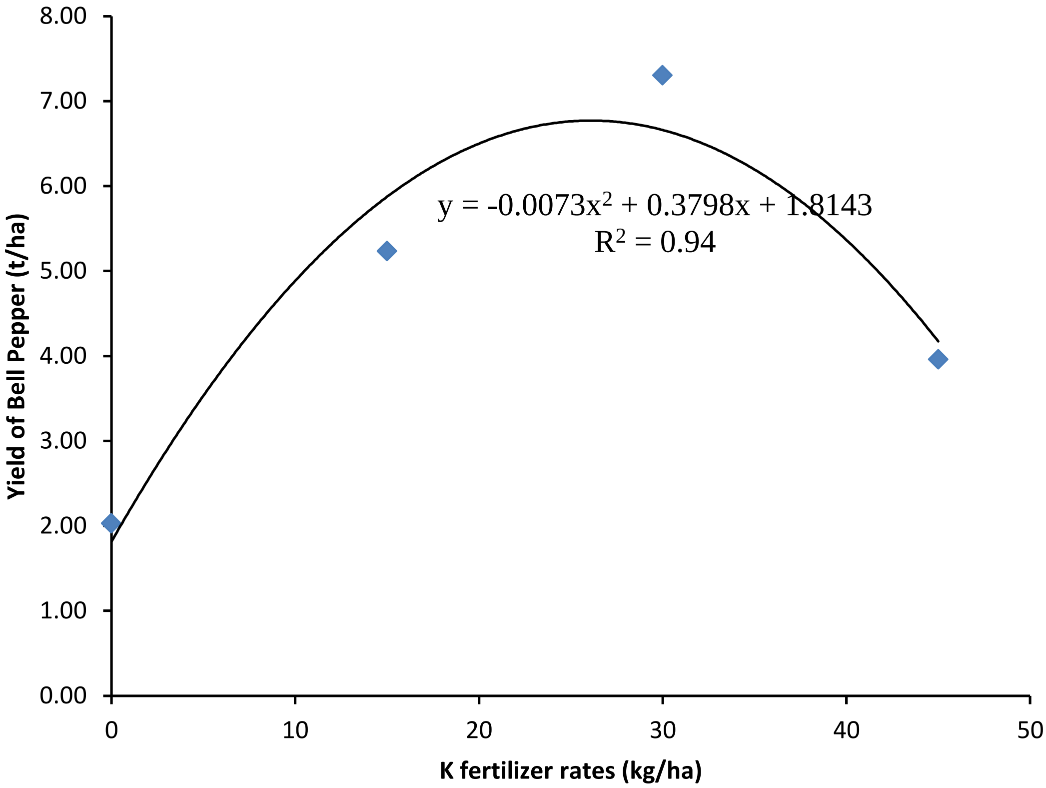


Fig. 4.35 Yield and K fertiliser calibration curve for bell pepper on Apomu soil series in the wet season of 2012.

4.12 Bell pepper yield and K fertiliser response curve

Yield curve of bell pepper in response to K fertiliser application on the 3 soil series in the 3 seasons are shown in Figures 4.36 - 4.47 while P and K uptake in response to K fertiliser application are shown in Figures 4.48 - 4.55.

4.13 Potassium uptake and K fertiliser response curve.

As shown in Table 4.23 , R^2 value of K uptake in response to P application were 0.02, 0.01 and 0.43 on Egbeda, Apomu and Jago soil series respectively. Highest K uptakes were observed at 30 kg P/ha. R^2 values of K uptake (Table 4.24) response to K application on all sites were 0.69, 0.93 and 0.77 respectively with highest observed at 45 kg K/ha as shown in Figures 4.53 - 4.5. Quadratic regression equation between bell pepper yield, uptakes and fertiliser application are also shown in Tables 4.23 - 4.32.

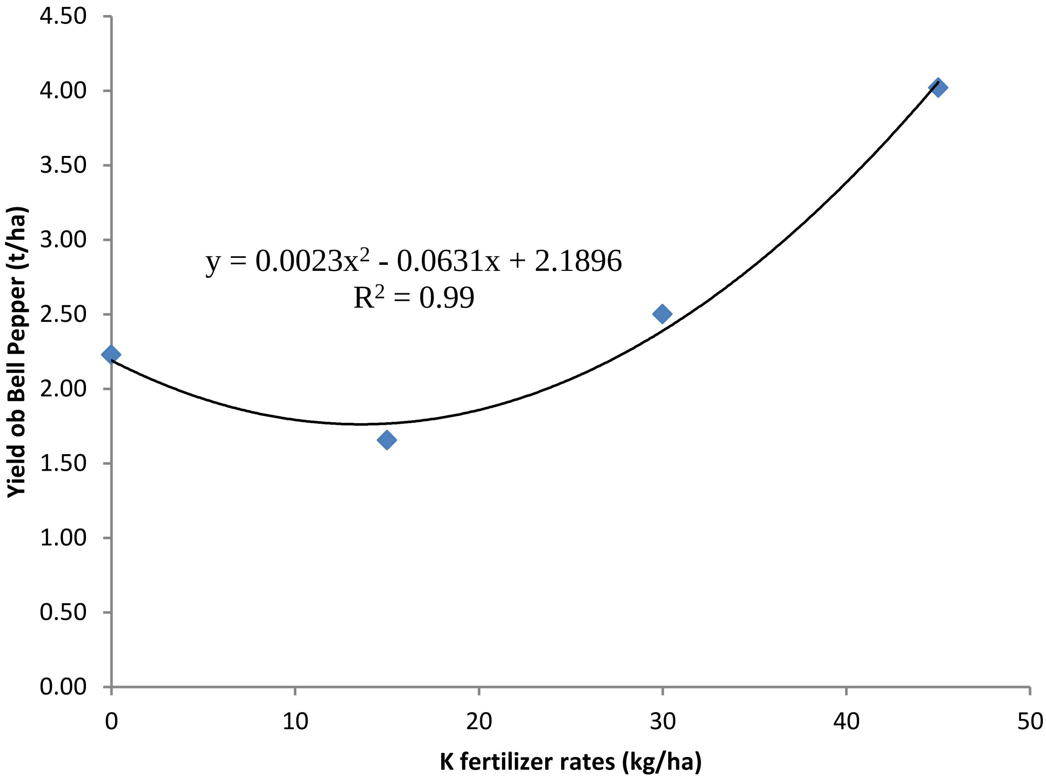


Fig. 4.36 Yield and K fertiliser calibration curve for bell pepper on Jago soil series in the wet season of 2012.

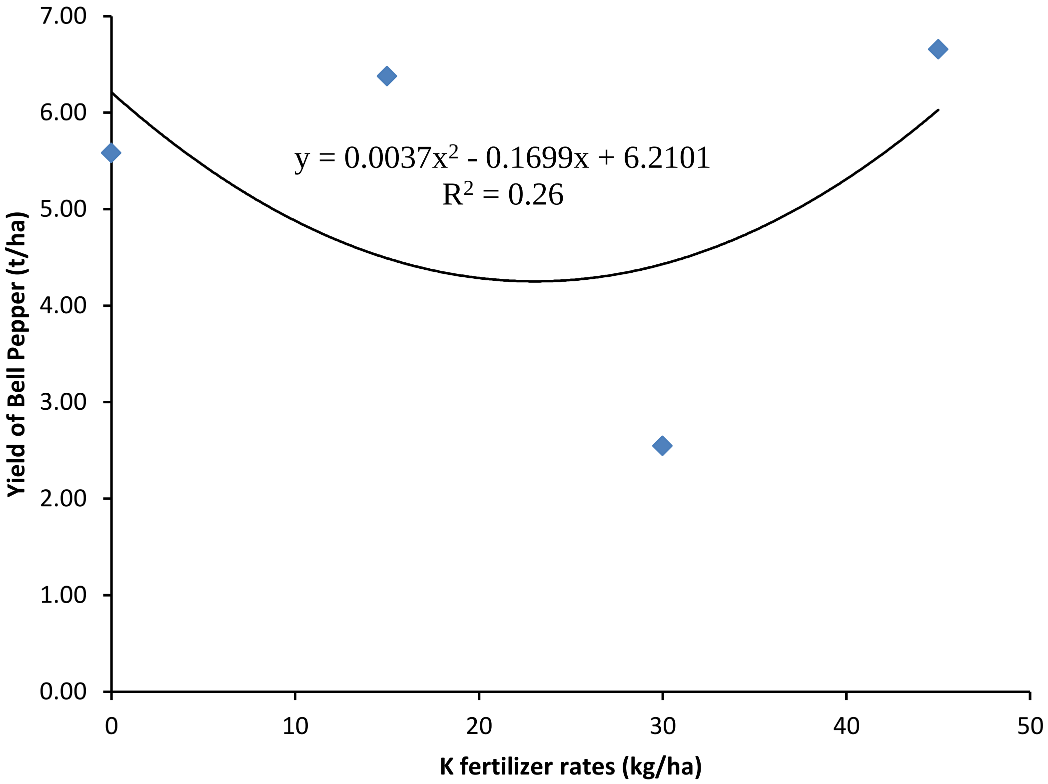


Fig. 4.37 Yield and K fertiliser calibration curve for bell pepper on Egbeda soil series in the dry season of 2012.

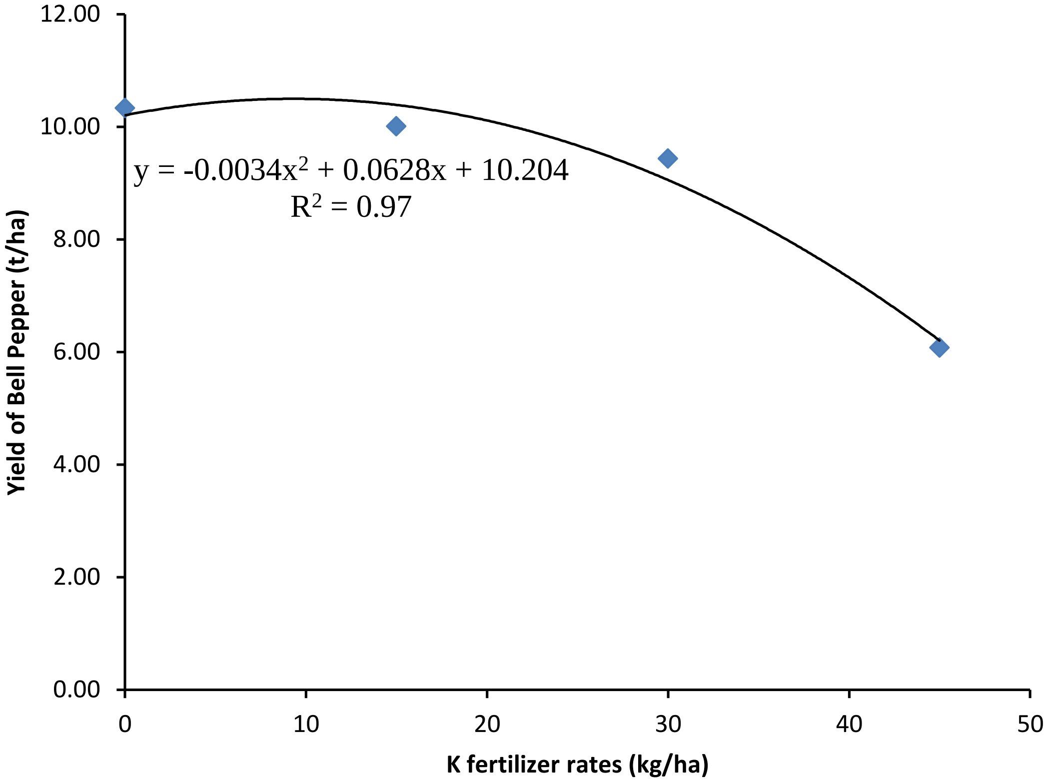


Fig. 4.38 Yield and K fertiliser calibration curve for bell pepper on Apomu soil series in the dry season of 2012

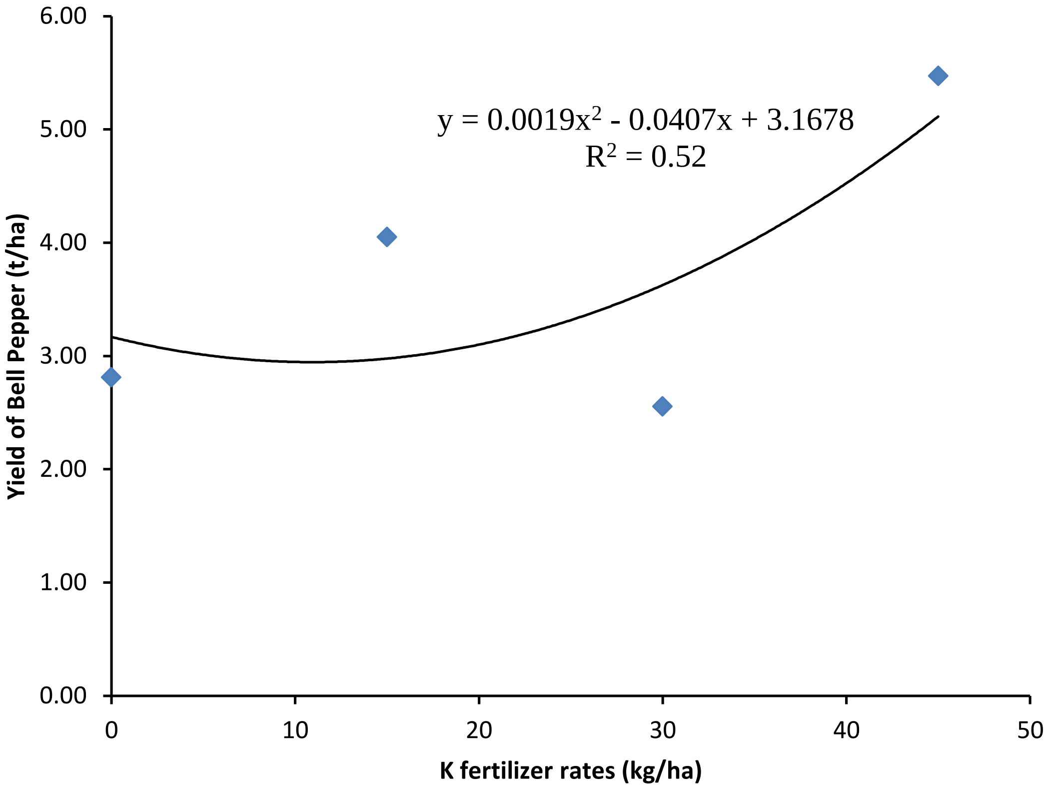


Fig. 4.39 Yield and K fertiliser calibration curve for bell pepper on Jago soil series in the dry season of 2012

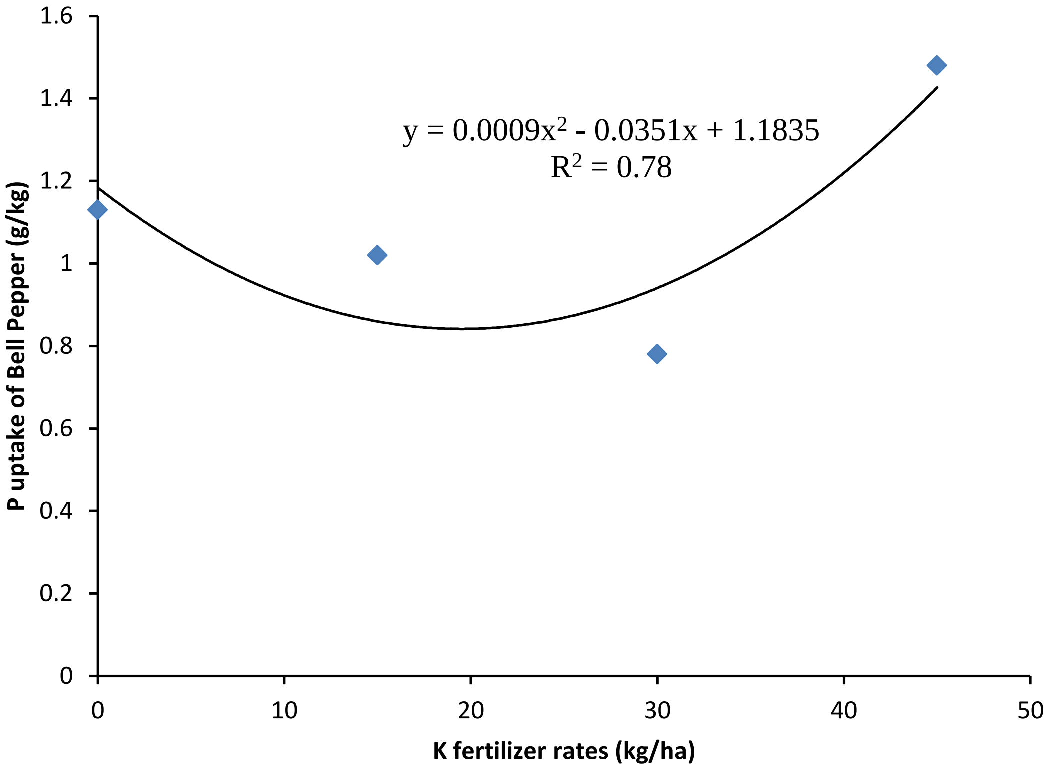


Fig. 4.40 P uptake and K fertiliser calibration curve for bell pepper on Egbeda soil series in the dry season of 2012.

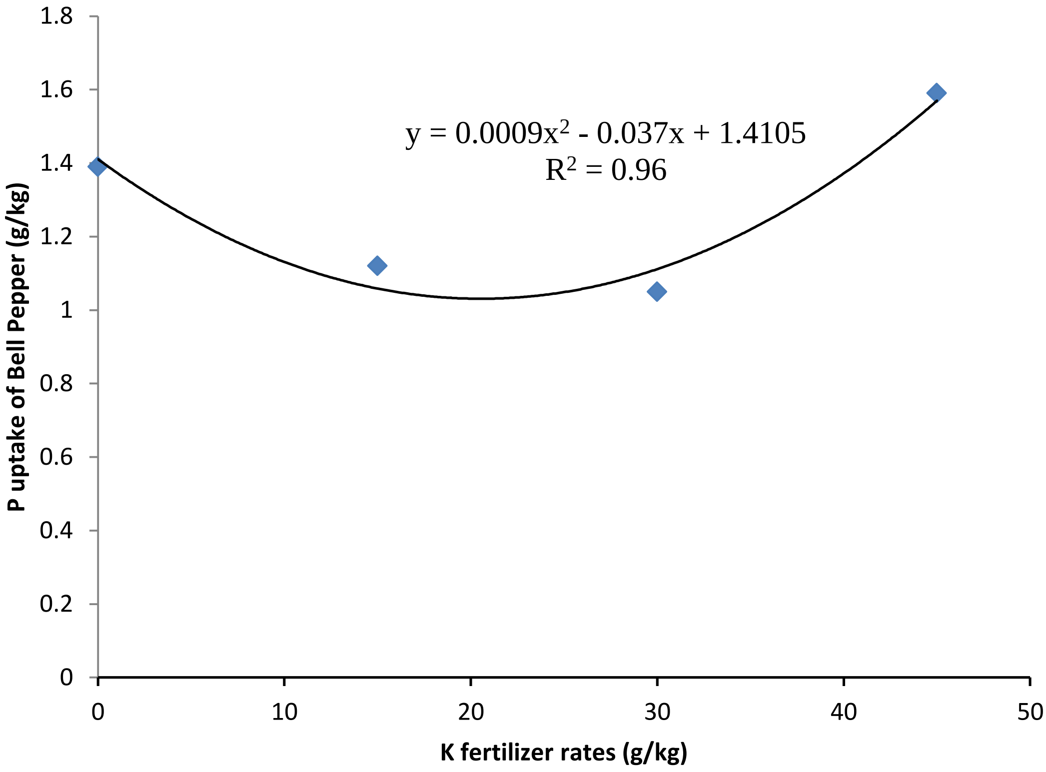


Fig. 4.41 P uptake and K fertiliser calibration curve for bell pepper on Apomu soil series in the dry season of 2012.

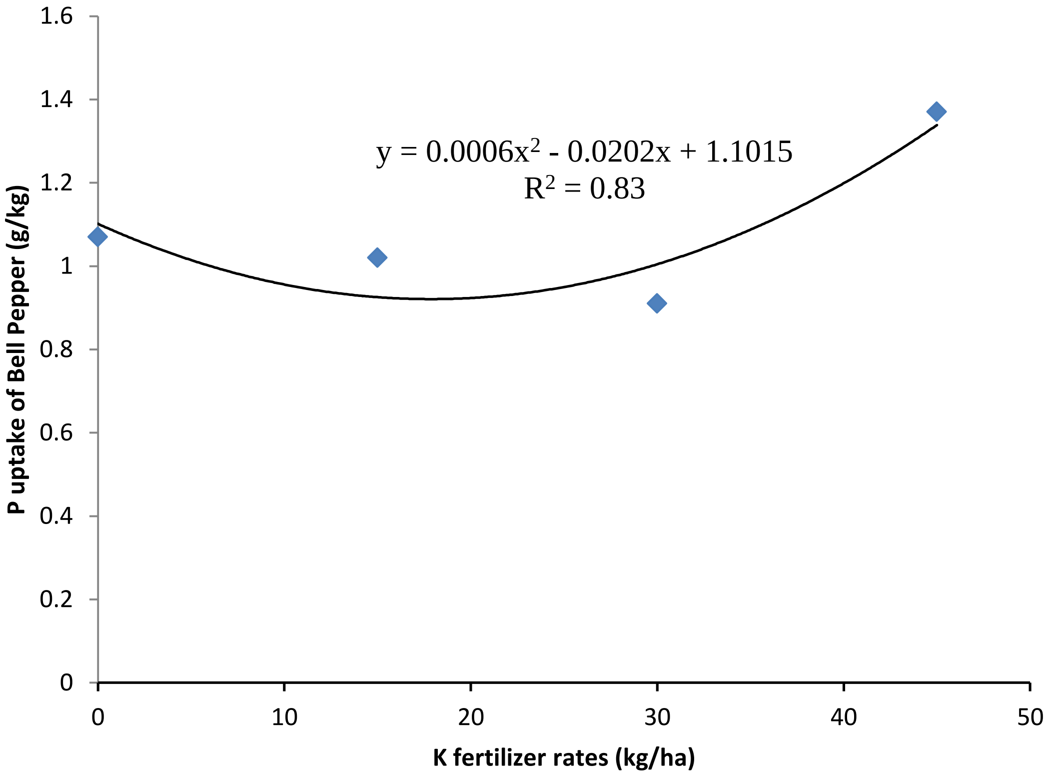


Fig. 4.42 P uptake and K fertiliser calibration curve for bell pepper on Jago soil series in the dry season of 2012.

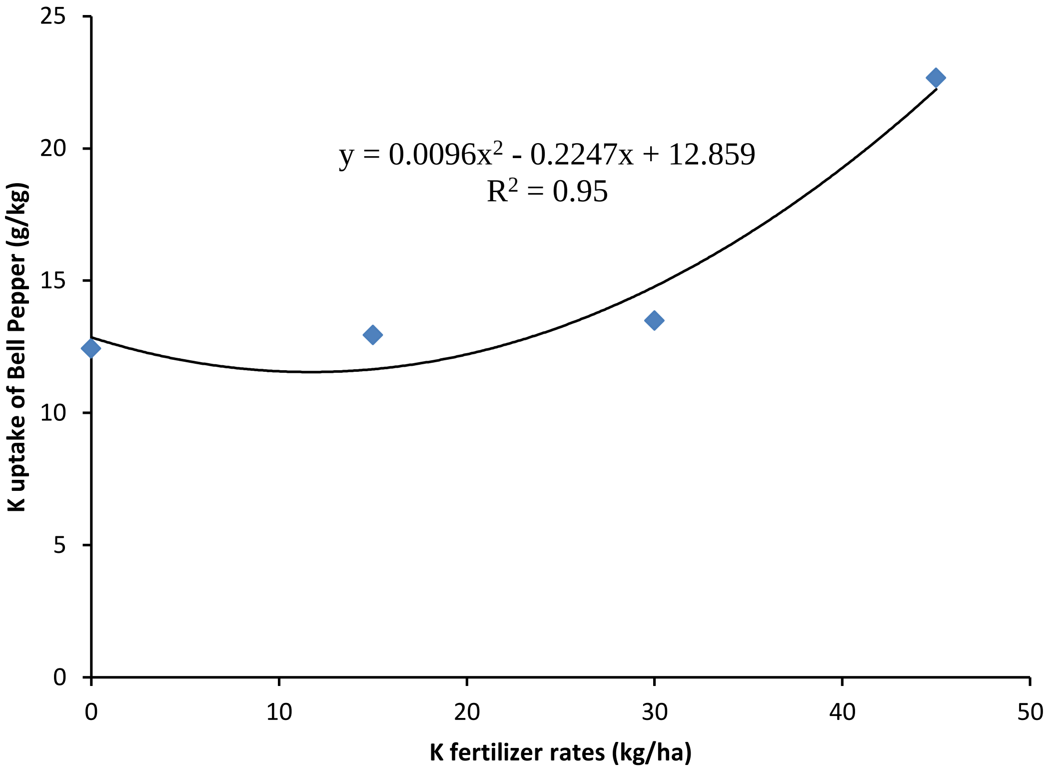


Fig. 4.43 K uptake and K fertiliser calibration curve for bell pepper on Egbeda soil series in the dry season of 2012.

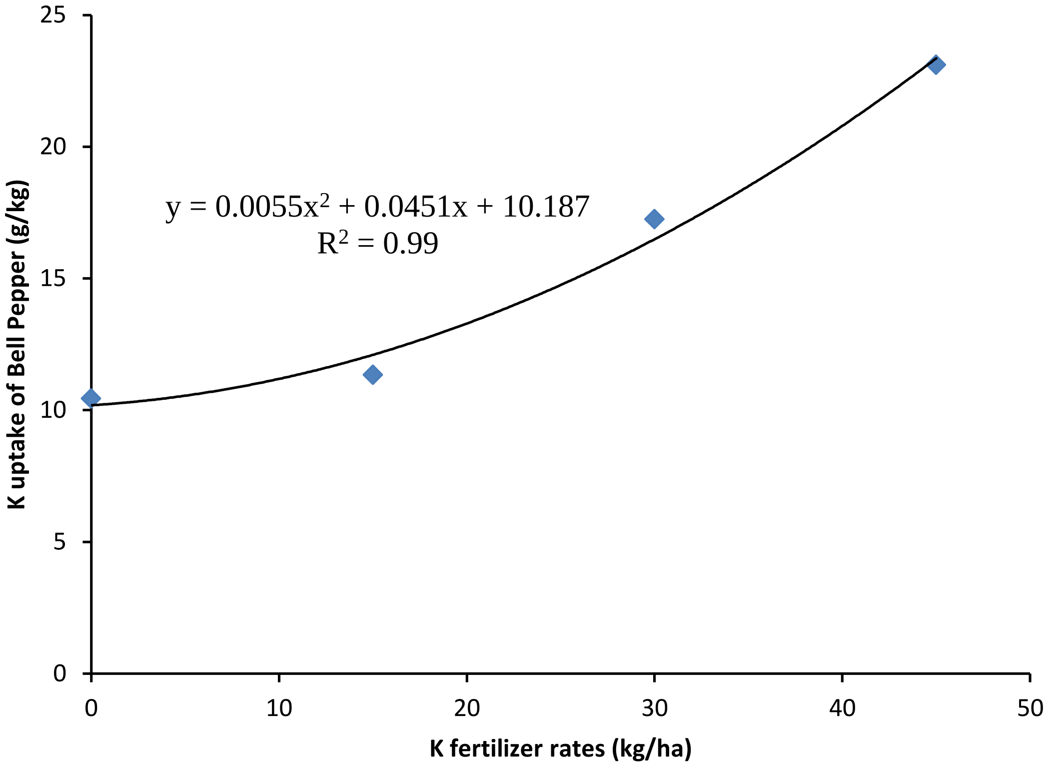


Fig. 4.44 K uptake and K fertiliser calibration curve for bell pepper on Apomu soil series in the dry season of 2012.

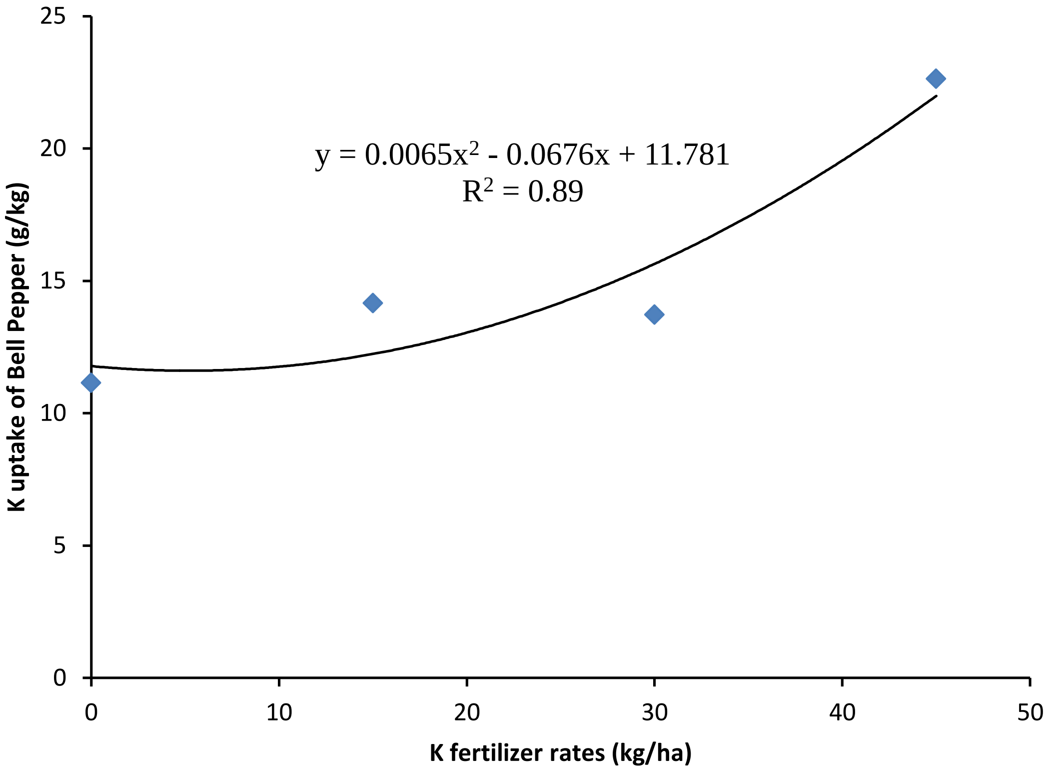


Fig. 4.45 K uptake and K fertiliser calibration curve for bell pepper on Jago soil series in the dry season of 2012.

CHAPTER FIVE

DISCUSSION

Soils used for the studies belong to two soil orders of the Soil Survey Staff, 1990 and eight soil series. The soil orders are Alfisols in Ibadan and Mbato and Ultisols in Bagauda. There are wider variations among Ibadan and Mbato soil series, whereas only one soil series is identified in Bagauda location. The series in Ibadan (Derived Savannah zone) are Egbeda, Apomu and Jago, at Mbato (Humid Forest zone) they are Alagba, Afia Mkpo, Ugbolu and Oji soil series while Gadau soil series is the only one identified at Bagauda (Southern Guinea Savannah).

The pH range (4.0 - 6.3) of the soils explain the soil reactions with P extractants that determines the selection of P extractant on Nigerian soils, while values of 5.2 – 5.8 on sites used for calibration studies are well suited for Bell Pepper growth (Grubben and Denton, 2004). Observations from these studies showed that Mehlich-3 extracted P across soils of varying pH. The textural classes of the soils which are loamy sand, sandy loam and silt loam reflect the parent material from which the soils are formed. Organic Carbon content of the soils (2.33 – 33.33 g/kg) used for correlation studies reflects the cropping history of the sites. Soils with organic carbon content higher than 15.0 g/kg are from sites that have either been under fallow for some years or a plantation which resulted from accumulation of organic material over time, while the sites under continuous cropping had low organic carbon. The total nitrogen (TN) varying from low to high (0.19 – 2.90 g/kg) follows the same trend as in organic carbon. Highest TN was obtained in soils with highest organic carbon. The correlation between organic carbon and total nitrogen is a characteristic of mineral soils whose nitrogen source is mainly organic (Chude et al, 2011). Available P (Bray P1) with an average of 8.34 g/kg was generally below critical level of 15 mg/kg established by Adeoye (1986) for sedimentary soils of South West Nigeria, this probably could be as a result of P depletion due to continuous cultivation. The highest value of 15.89 g/kg is obtained in the soil collected from bounds between experimental plots, a location that is under continuous fallow which allows P build up and conservation. Exchangeable cations were moderate although the effective cation exchange capacity was low. Potassium levels of most of the soils were above the critical level of 0.20 cmol/kg (FMARD, 2004), probably due to K fertiliser application over time. The base saturation was generally high with soils from Mbato having the highest and Bagauda the lowest.

The significantly high coefficient (r) of 0.77 - 0.96 between P extractants and Mehlich-3 extractant are indications that P was extracted from the same pool by all the extractants which suggests that it is a suitable extractant. Phosphorus extracted by Mehlich-3 was not affected by the pH of the soil which was a limitation and disadvantage of recommended extractants. Mallarino and Atia (2005) discovered that soil P measured by Bray extractants were less in $CaCO_3$-affected soil with pH ≥ 8.1 but not when pH was ≤ 7.7. Beegle and Oravec (1990) also, *reported high correlations of Mehlich-3 extractant with Bray1 (r=0.99) and* neutral 1M ammonium acetate K extractant (r=0.96).

The lowest correlation of 0.77 was between Mehlich-3 and Bray P1 while the highest (0.96) was between Mehlich-3 and NH_4F.F + DTPA. This corroborates the assertions of Adeoye (1986) who identified 0.1M NH_4F.HF + 0.005M DTPA (unbuffered) as the best multipurpose extractant suitable for simultaneous extraction of P, K, Mg, Zn and Mn. Although there were significant correlations among all the extractants of P, the difference in the amount of P extracted could be attributed to the pH of the extractants and species of ions present. Higher amount of P extracted by Bray P2 than P1 may be due to the lower pH of Bray P2. The influence of chemical composition of Bray P solutions on P extraction may be due to the fact that acid fluoride and chlorides are effective in extracting Al and Fe bound P which is predominant in the top horizons of sedimentary soils of South West Nigeria as observed by Uzu (1973). On the other hand, the different amounts of P extracted by Bray 1, M3 and MM3 despite similar pH is most likely to be due to the species of ions present in the extractants while the difference in pH and ionic composition may be responsible for amount of P extracted by Olsen. Observations showed that EDTA and DTPA chelates actively participated in P extraction, because highest amounts of extracted P were observed with extractants containing either EDTA or DTPA.

Correlation coefficients (r) relating Mehlich-3 and other K extractants were significantly high except with NH_4F.HF + DTPA (ABD) which were not significant and negative implying that it is not a suitable extractant for K. Although Adeoye (1986) identified 0.1M NH_4F.HF + 0.005M DTPA (unbuffered) as best multipurpose extractant suitable for simultaneous extraction of P, K, Mg, Zn and Mn, observation from this study showed otherwise, probably because Adeoye worked on sedimentary soils of South West Nigeria which is different from Basement complex where this investigation was carried out. The r value of 0.99 between Mehlich - 3 and 1M Ammonium Acetate pH 7.0 - the only recommended extractant for K was quite high and made Mehlich-3 as suitable as 1M Ammonium Acetate pH 7.0 extractant across the soils. Correlation coefficient (r) of 0.78 - 0.95 between P extractants and P uptake of bell pepper were significantly high. Highest "r" of 0.95 observed with Mehlich - 3 is an indication that M3 extract P from soil solution in the same way bell pepper root absorbed P. Prediction of P uptake at a given soil test level of P is thus possible because of the direct relationship between them.

The correlation coefficient between K uptake and K extractants are significantly high except for NH4F.F + DTPA (ABD). The r value of 0.95 observed between Mehlich-3 and K uptake of bell pepper showed that Mehlich-3 absorbed K in the same way as the roots of bell pepper indicating the suitability of Mehlich - 3 as a K extractant across soils of varying chemical properties. Phosphorus and K soil test values extracted by Mehlich-3 could also be converted to corresponding values of P and K extracted by recommended extractants through the conversion equations derived.

The minimum and optimum temperature and the relative humidity prevailing during the wet cropping seasons of 2011 and 2012 were similar, but quite different from the dry season of 2012. Meanwhile, the amount of rainfall recorded varied in the three seasons. The temperature ranges of 20 – 25, 22 – 25 and 20 – 26 °C respectively for the 3 consecutive seasons favoured the growth of bell pepper. Temperatures range of 25 – 34 °C were best for bell pepper growth while temperatures below or above were detrimental to high yield. The prevailing relative humidity (RH) between 68 - 95% over the 3 seasons was relatively high for bell pepper, but unexpectedly, there was no disease outbreak during the seasons. The total amounts of rainfall during the cropping seasons were more than the required 600 mm (Grubben and Denton, 2004) during the growing period, except in the dry season of 2012 when supplemental irrigation was made.

Yield response of bell pepper to P application was dependent on soil P test and P applied. Generally, there were significant increases in yield as applied P rate increased. In 2011 cropping season, there was a steady increase in yield until highest was reached at 45 kg P/ha when soil P test was below 15 mg/kg. Waugh *et al*. (1973) explained that there will be response to fertiliser application if soil test value is below the critical level but not above. Response to P application at soil test level below 15 mg/kg was an indication that the critical level has not been reached. Yield in the 2nd crop of 2012 when soil test value was above 15 mg/kg (the critical range) was lower than the two preceding years. This implies that the critical range has been exceeded, hence reduction in yield. Differences in yield due to fertiliser application on different soils with the same soil test value are possible due to different fixation capacity of the soils (Adeoye, 1986). The native P of Apomu soil series increased from year to year as P fertiliser was added. This was evident in the yield as it decreased in the two cropping seasons of 2012. It was highest in 2011 cropping season when P soil test value was less than 10.0 mg/kg. On Jago soil series highest yield was observed in the 1st cropping of 2012 when initial P was less than 11.0 mg/kg. Fitts and Hanway (1971) obtained critical range for P at 6 – 8 mg/kg in several countries, although Agboola and Corey (1972, 1975) established a critical level of 10 ppm for maize in the soils derived from metamorphic and igneous rocks of Western State of Nigeria. using Bray 1 extractant in a field experiment whereas Okeya in 1979 using Bray 1 and Olsen's modified methods in a greenhouse calibration studies established critical levels at 17 and 12 mg/kg P respectively. Adeoye (1986) in his work on the sedimentary soils of South West Nigeria established a P critical range of 10 – 16 mg/kg for maize. The effects of Phosphorus on the yield of bell pepper in 2011 and the 1st and 2nd cropping of 2012 were significant for treatment combinations. Critical level of 45 kg P ha^{-1} was established by Beegle and Oravec (1990) for corn with Mehlich-3 in Pennsylvania soils. Aliyu *et al*., (1996) and Olanrewaju and Showemimo (2003) obtained highest yield for Pepper at 24 and 24.2 kg P/ha.

High coefficient of determination (R^2) observed in almost all the relationships between yield of bell pepper and applied P in all the soil series in the three seasons were indications that yield is predictable at a given rate of P but not for low R^2. Low R^2 implies that some factors apart from applied P were involved in determining the yield. On Jago soil series in the dry season of 2012, the R^2 between the yield and applied P was low (0.42). This could be as a result of intrinsic properties of the soil, especially the drainage and textural class. Jago soil series are prone to caking during the dry season due to high clay content and reduced soil moisture content. At low soil moisture content, P movement in the soil and absorption by plant root are reduced.

There were significant increases in yield as applied K rate increased. The trends in yield, P and K uptake of bell pepper in the three seasons and soil types could be attributed to soil test value (critical K level), soil moisture content and clay content of the soil. As observed in the 2011 cropping season, there were positive responses to K application when soil K test values were between 0.20 and 0.25 cmol/kg. At values above this, responses were either retarded or negative.

Critical K values as high as 0.45 and low as 0.10 cmol/kg (Lombin and Mustafa, 1981) have been reported. Beegle and Oravec (1990) reported critical levels of 0.20 cmol/kg for Mehlich 3 extracted K. Adeoye (1986), also established 0.20 cmol/kg as critical level of K on sedimentary soils of southwestern Nigeria. Coefficient of determination (R^2) observed between yield of bell pepper and applied K in the three seasons in all the soil series were generally high (0.52 - 0.99) except for Egbeda soil series in the dry season of 2012. The indication is that, yield is highly predictable at a given K rate. The low R^2 observed in Egbeda was probably because of its` sandy texture. This is because K is not easily held within sandy soil. As a consequence of the larger sand particles water moves more easily through these soils and the potential for the loss of K from soil (i.e. leaching) is greater. The low R^2 could also be attributed to low soil moisture content because moisture content of the soil is important for the successful movement of K for use by the crop; the drier the soil the more immobile the K ions will be. High “r” between Mehlich-3 extracted P and K and uptakes of P and K by bell pepper is a proof that it is a suitable multipurpose extractant and could be used across soils of varying soil chemical properties.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

Laboratory, screenhouse and field experiments were conducted to determine the suitability of Mehlich -3 extractant in effectively replacing recommended P and K extractants and enable the prediction of P and K fertiliser requirements of Bell Pepper on some Nigerian soils. For the purpose of determining the suitability of the extractant, 12 surface soil (0 – 15 cm) samples were collected from locations at Ibadan, Mbato and Bagauda, representing three agro-ecological zones of Nigeria, namely; derived savannah, humid forest and northern guinea savannah zones respectively. The soils used covered two soil orders and eight soil series. The two soil orders covered are Alfisol and Ultisol while the soil series were Egbeda, Apomu and Jago from Ibadan, Alagba, Afia Mkpo, Ugbolu and Oji from Mbato, and Gadau from Bagauda. Replicated laboratory analyses were carried out on the soil samples to evaluate correlations between P extracted by Mehlich-3 (M3), Bray-1 (B1), Bray 2 (B2), Olsen (O), Ammonium hydrogen flouride + DTPA P(ABD) and Modified Mehlich-3 (MM3) and K extracted by Mehlich-3 (M3), Ammonium Acetate (AAc), Ammonium hydrogen flouride + DTPA P(ABD) and Modified Mehlich-3 (MM3). Replicated screenhouse studies were also carried out to evaluate relationships between P and K uptake of bell pepper (*Capsicum annuum* L.) and the values of various extractants of P and K.

To calibrate phosphorus and potassium fertiliser requirements of bell pepper based on Mehlich-3 extractant, replicated P and K fertiliser field trials were conducted at Ibadan, in the derived savannah zone of Nigeria on Egbeda, Apomu and Jago soil series over 3 seasons. The first field trial was carried out in the wet season of 2011 while the second and the third were carried out in the wet and dry seasons of 2012 respectively.

The initial P values extracted with M3, B1, B2, O, ABD and MM3 were 3 - 47, 3 - 14, 4 - 32, 0.2 - 20, 8 45 and 8 - 43 mg/kg, respectively, while K values for M3, AAc, ABD and MM3 ranged from 0.22 - 1.10, 0.18 - 0.96, 0.12 - 0.39 and 0.17 - 0.66 cmol/kg, respectively. There were significant correlations among extractants and between extractants and nutrient uptake values. Correlation coefficient (r) between M3 extracted P values and values extracted by other P extractants across all soils ($\alpha_{0.01}$) were positive and high. The values ranged from 0.77 to 0.96. The lowest value was observed in respect of the extraction by BP1 while the highest was observed with ABDP. The r values of the relationship between M3 extracted K values and amounts extracted by other K extractants were also significant ($\alpha_{0.01}$) across all soils except for ABD.

There were significant correlations between P uptake values by bell pepper and M3, B1, B2, O, ABD as well as MM3 extracted P ($p < 0.01$). The values were 0.95, 0.78, 0.88, 0.85, 0.90 and 0.96 respectively. Correlations were also significant between K uptake by bell pepper and the amount of K extracted by the various extractants except for ABD. Correlation coefficient values ranged from 0.93 in MM3 to 0.95 in ABD. Correlation coefficients (r) relating M3 and other conventional P extractants across the soils were significant. Furthermore, correlation relating Mehlich - 3 extracted soil P and P uptake by bell pepper was also significant. Correlation coefficients (r) obtained by relating M3 and other conventional K extractants were also significantly high, except for Ammonium hydrogen flouride + DTPA (ABD). The correlation between Mehlich - 3 extracted soil K and K uptake of bell pepper was also significantly high except for Ammonium hydrogen flouride + DTPA (ABD). Observations and indications from these relationships is that M3 is a suitable multipurpose extractant that could be used as substitute for the recommended P and K extractants.

Phosphorus and K soil values extracted by M3 could be converted to values of existing extractants for fertiliser recommendation purpose through the regression equations obtained. Furthermore, phosphorus or potassium uptake of bell pepper could also be predicted from the regression equation relating extracted soil phosphorus and potassium values and their uptakes.

Field experiments conducted for the purpose of calibrating P and K fertiliser rates for optimum yield of bell pepper showed that there were significant coefficients of determination (R^2) for P and K soil tests by Mehlich-3 in relation to yield of bell pepper on the soil series involved. Response of bell pepper to P and K fertiliser application could be predicted at specific soil test values on the three soil series.

The trend of yield response over the three cropping seasons showed that response of bell pepper to P and K fertiliser application was positive depending on the initial soil test value as extracted by Mehlich-3. In seasons when soil test P and K values were high, there were no response to application of either of the nutrients while in some cases the relationship between yield of bell pepper and increase in applied nutrient was negative. This implies that optimum fertiliser rate has been exceeded.

Phosphorus and K uptake of bell pepper in response to P or K fertiliser application also followed the same trend as the yield. The same trends of observations as for the crop yield were obtained between P and K uptake at different fertiliser rates.

It could be concluded from the results obtained that:

1. Mehlich-3 is a suitable extractant for estimating soil available phosphorus and exchangeable K for the purpose of predicting response to fertiliser application and for advisory P and K fertiliser recommendation for bell pepper.
2. The critical level for P was 15 mg/kg soil while that of K lies between 0.20 and 0.25 cmol/kg
3. Optimum fertiliser rates for bell pepper on the soils was 45 kg P/ha while for K it was 30 kg K/ha.

Recommendations

Mehlich-3 extractant is suitable for extraction of available phosphorus and exchangeable potassium and thus is capable of ascertaining the deficiency or sufficiency of the two nutrients in the soils. It is recommended for the extraction of phosphorus and potassium from the soils as it will make their extraction faster, easier, and cheaper and in ascertaining response of crops to fertiliser application.

For optimum yield of Bell pepper, 45 kg P/ha and 30 kg K/ha is recommended to be applied in a single dose.

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APPENDICES

Appendix 1 Pre planting soil pH for 2012 wet season

Treatment	pH		
	Egbeda	Apomu	Jago
P1K1	5.6	5.7	5.4
P2K1	5.4	5.9	5.7
P3K1	5.8	5.7	5.5
P4K1	5.5	6.0	5.6
P1K2	5.6	5.7	5.5
P2K2	5.7	5.8	5.7
P3K2	5.5	5.9	5.5
P4K2	5.5	5.7	5.6
P1K3	5.5	5.9	5.4
P2K3	5.7	6.0	5.6
P3K3	5.3	5.8	5.4
P4K3	5.7	5.9	5.5
P1K4	5.7	5.8	5.4
P2K4	5.5	6.0	5.2
P3K4	5.7	5.9	5.4
P4K4	5.7	6.0	5.2

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Appendix 2 Pre planting soil available phosphorus (mg/kg) for 2012 wet season

Treatment	Available P (mg/kg)		
	Egbeda	Apomu	Jago
P1K1	0.09	8.12	0.09
P2K1	0.51	12.60	0.10
P3K1	0.34	25.20	0.12
P4K1	1.71	16.20	0.11
P1K2	0.17	13.50	0.13
P2K2	0.10	17.10	0.10
P3K2	0.68	9.90	0.13
P4K2	0.11	25.20	0.10
P1K3	0.12	22.50	0.12
P2K3	0.10	19.80	0.13
P3K3	0.85	23.40	0.13
P4K3	0.85	13.50	0.11
P1K4	0.68	13.50	0.11
P2K4	0.34	35.10	0.11
P3K4	0.17	31.50	0.12
P4K4	1.02	22.50	0.12

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Appendix 3 Pre planting soil exchangeable potassium (cmol/kg) for 2012 wet season

Treatment	Exchangeable K (cmol/kg)		
	Egbeda	Apomu	Jago
P1K1	0.20	0.19	0.22
P2K1	0.34	0.24	0.22
P3K1	0.39	0.25	0.25
P4K1	0.42	0.30	0.25
P1K2	0.35	0.25	0.22
P2K2	0.32	0.24	0.24
P3K2	0.32	0.24	0.22
P4K2	0.29	0.25	0.25
P1K3	0.30	0.22	0.27
P2K3	0.37	0.20	0.25
P3K3	0.32	0.25	0.27
P4K3	0.30	0.20	0.24
P1K4	0.30	0.24	0.27
P2K4	0.29	0.24	0.22
P3K4	0.25	0.20	0.27
P4K4	0.42	0.15	0.27

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Appendix 4 Pre planting soil pH value for 2012 dry season

Treatment	pH		
	Egbeda	Apomu	Jago
P1K1	6.1	6.5	6.0
P2K1	6.0	6.6	6.4
P3K1	6.1	6.4	6.4
P4K1	5.9	6.7	6.3
P1K2	6.1	6.4	6.1
P2K2	6.1	6.5	6.5
P3K2	6.0	6.3	6.2
P4K2	5.9	6.5	6.4
P1K3	6.0	6.4	6.2
P2K3	6.0	6.5	6.4
P3K3	5.9	6.6	6.2
P4K3	6.1	6.6	6.1
P1K4	6.0	6.5	6.2
P2K4	5.9	6.6	6.0
P3K4	6.0	6.6	6.2
P4K4	6.0	6.5	6.0

P rates –	0,	30,	45,	60 kg P/ha
	P1,	P2,	P3,	P4
K rates -	0,	15,	30,	45 kg K/ha
	K1,	K2,	K3,	K4

Appendix 5 Pre planting soil available phosphorus (mg/kg) for 2012 dry season

Treatment	Available P (mg/kg)		
	Egbeda	Apomu	Jago
P1K1	1.76	11.11	0.12
P2K1	13.50	46.80	10.80
P3K1	11.70	52.20	9.00
P4K1	15.30	54.00	12.60
P1K2	9.90	45.00	13.50
P2K2	14.40	51.30	13.50
P3K2	18.90	40.50	15.30
P4K2	15.30	47.70	12.60
P1K3	18.90	51.30	9.00
P2K3	14.40	73.80	15.30
P3K3	19.80	46.80	9.90
P4K3	24.30	54.90	27.00
P1K4	20.70	49.50	12.60
P2K4	18.00	78.30	14.40
P3K4	18.70	58.50	10.80
P4K4	21.60	57.60	12.60

P rates – 0, 30, 45, 60 kg P/ha
P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha
K1, K2, K3, K4

Appendix 6 Pre planting soil exchangeable potassium (cmol/kg) for 2012 dry season

Treatment	Exchangeable K (cmol/kg)		
	Egbeda	Apomu	Jago
P1K1	0.18	0.11	0.08
P2K1	0.40	0.32	0.32
P3K1	0.40	0.38	0.24
P4K1	0.38	0.38	0.26
P1K2	0.43	0.32	0.19
P2K2	0.43	0.24	0.13
P3K2	0.43	0.21	0.13
P4K2	0.40	0.24	0.32
P1K3	0.32	0.24	0.24
P2K3	0.43	0.26	0.13
P3K3	0.40	0.16	0.30
P4K3	0.38	0.26	0.21
P1K4	0.48	0.21	0.19
P2K4	0.48	0.30	0.21
P3K4	0.48	0.21	0.26
P4K4	0.51	0.16	0.26

P rates – 0, 30, 45, 60 kg P/ha
P1, P2, P3, P4

K rates - 0, 15, 30, 45 kg K/ha
K1, K2, K3, K4

Appendix 7 Phosphorus and Potassium content and uptake by bell pepper in screenhouse experiment.

Soil	Content in plant tissue (g/kg)		Uptake in plant tissue (g/kg)	
	P	K	P	K
Ib1	2.89	14.76	3.73	19.04
Ib2	4.02	9.13	6.12	13.97
Ib3	1.23	21.08	1.35	23.19
Ib4	0.92	12.18	1.32	17.42
B1	1.60	45.00	1.15	32.40
B2	1.74	41.63	1.46	34.97
B3	1.36	33.44	1.46	35.78
B4	1.63	33.75	1.22	25.31
M1	5.67	13.69	5.33	12.87
M2	1.69	21.20	1.45	18.23
M3	2.71	24.10	2.14	19.04
M4	1.48	20.39	1.40	19.17

Ib1 – Ib4	Soils from Ibadan, Oyo State
B1-B4	Soils from Bagauda, Kano State
M1-M4	Soils from Mbato, Imo State

Appendix 8 The pH of extractants

Extractant	pH
Bray P1	2.59
Bray P2	1.6
Olsen	9.9
Mehlich-3	2.9
Mehlich -3 + DTPA	2.7
NH4F.F + DTPA	4.6
1M Ammonium Acetate pH 7.0	7.0