EFFECTS OF PALM BUNCH ASH AND MINERAL FERTILIZER APPLICATION ON SOIL CHEMICAL PROPERTIES AND ON THE GROWTH, YIELD AND NITROGEN FIXATION OF THREE PIGEON PEA VARIETIES IN THE SEMI–DECIDUOUS FOREST ZONE OF GHANA

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MPHIL CROP SCIENCE DEGREE.

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DECLARATION

I do hereby declare that, except for other peoples work which have been duly cited and acknowledged, the work herein submitted as a thesis to the Department of Crop Science, School of Agriculture, College of Basic and Applied Sciences, University of Ghana, Legon, for the award of Master of Philosophy in Crop Science degree, is the result of my own investigation and this Thesis has not been presented for another degree elsewhere, either in part, or in whole.

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ABSTRACT

An experiment was conducted at the Forest and Horticultural Crops Research Centre, Kade to investigate the effect of palm bunch ash (PBA) application on soil chemical properties and the growth, nodulation, nitrogen fixation and yield of three early maturing varieties (ICPL 87091, ICPL 88034 and ICPL 88039) of pigeonpea. The experiment was conducted both in the field and in the pot. The three pigeonpea varieties were subjected to three fertilization treatments; 2 t ha^{-1} PBA, 20 kg ha^{-1} PK fertilizer and control. The experiment was laid out in split plot design with the three varieties of pigeonpea as the main plot treatments and the fertilizer as the subplot treatments. The chemical properties of the soil at the experimental site indicated that the soil was strongly acidic (pH of 5.09), high in N (0.24%), low in P (6.8 ppm) and high in exchangeable K (1 meq 100 g^{-1} soil) and moderately high in Mg (1.32 meq 100 g^{-1} soil). Exchangeable Ca was also low (3.56 meq 100 g^{-1} soil). Fertilization had significant effects on the soil chemical properties at harvest in both the field and the pot experiments. In the field experiment, application of PBA significantly increased soil pH (5.82), P (11.18 ppm) and exchangeable cations (3.47, 4.03, 1.17 meq/100 g soil for Mg, Ca and K respectively). The control plots consistently had the lowest levels for all the nutrients. Plant height at 50% flowering was highest among the PBA treated plants (123.6cm) although there were no significant differences among the treatments. With regards to the girth, significant ($p \leq 0.05$) differences were found to exist among the treatments with PBA treated plants giving the biggest girth (1.59 cm), followed by PK treated plants (1.41 cm), while the least girth was obtained in the plants within the control plots (1.18 cm). Similarly, varietal differences also resulted in significant differences in plant girth. Fertilization significantly affected nodule number with the PBA treated plants obtaining the highest nodule number per plant (41) while plants from the control plots recorded the least

number of nodules (22). Nodule dry weight were also significantly affected by the fertiliser treatments with the PBA treated plants obtaining the highest nodule weight of 1.16 g while the control plants recorded the lowest weight of 0.47 g. In the field experiment, percent nitrogen fixed ranged from 20.3% among the control plants to 64.2% among the PBA treated plants with significant differences among the treatments. Nitrogen fixation in the pot experiment followed the same pattern as that of the field experiment and ranged from 39.9% in the control plants to 56.4% in PBA treated plants. In both the field and the pot experiments plant nutrient uptake varied significantly among the different fertiliser treatments with the PBA treated plants consistently having the highest plant nutrient uptake for all the nutrients while plants from the control plots had the least plant nutrient uptake. The results of the experiment indicated that neither the variety nor the fertilizer treatments had any significant effects on the grain yield of the pigeonpea. However, total dry matter yield varied significantly among the different varieties and among the different fertiliser treatments. The variety ICPL 87091 had the highest dry matter yield (7.29 t ha^{-1}) while the variety ICPL 88039 had the lowest dry matter yield (4.95 t ha^{-1}). The PBA treated plots had the highest total dry matter (7.24 t ha^{-1}) while plants from the control plots gave the lowest dry matter yields (4.95 t ha^{-1}). The dry matter harvest index varied significantly among the different varieties. Variety ICPL 87091 which had the lowest grain dry matter yield also had the lowest harvest index (0.16) while variety ICPL 88039 which had the least stover and litter dry matter yield had the highest harvest index (0.32).

Based on the results it can be concluded that the application of PBA is an effective way of amending acidic soils at a relatively low cost as well as improving the growth and the grain yield of legumes. Thus in rural areas where P and K fertilisers as well as liming materials are not readily available but PBA are in abundance, farmers should be encouraged to use PBA on their farms in order to achieve higher grain yields at a lower cost, while correcting soil acidity and improving the soil fertility.

DEDICATION

This piece of work is dedicated to my parents, Mr. Lawrence Kwame Asante and Madam Dinah Aninagyei as well as my siblings.

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TABLE OF CONTENTS

CONTENT **PAGE**

LIST OF TABLES

ABBREVIATIONS

km^2	Square Kilometre
%	Percentage
N	Nitrogen
kg/ha	Kilogramme per hectare
kg	Kilogramme
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
P_2O_5	Phosphorus pent oxide
K_2O	Potassium oxide
m	meters
Cm	Centimetres
^0C	degree Celsius
Fe	Iron
Al	Aluminium
H_2PO_4	Phosphoric acid
mm	Millimetres
m^2	meter square
g	grams
H_2O_2	Hydrogen peroxide

CHAPTER ONE

1.0 INTRODUCTION

1.1 Introduction

Pigeonpea (*Cajanus cajan*) is known to be one of the legumes effective in the restoration of soil fertility (Barnes, 1995; Rao *et al.*, 2002; Adjei–Nsiah, 2006; Adjei–Nsiah, 2012). This is because pigeonpea has a natural ability to fix large proportion of its own nitrogen. The extensive root system of pigeonpea makes soil more friable, improves its tilth and facilitates water infiltration. Pigeonpea is also known for its ability to access insoluble phosphates in low P soils, increasing the availability of soluble P for subsequent crops (Ae *et al.*, 1990). Pigeonpea root exudates have been found to contain phenolic compounds (e.g. piscidic acid), which chelate Fe to free P in Fe bound P in soils for crop uptake (ICRISAT, 1999). It has also been reported that pigeonpea root exudates dissolve phosphate–containing rocks (e.g. phosphate rocks) to make P available for crop use (Ae *et al.*, 1990). Pigeonpea offers the benefits of improving long–term soil quality and fertility when used as green manure (Onim *et al.*, 1990), cover crop (Bodner *et al.*, 2007), or alley cropped (Mapa and Gunasena, 1995). The legume also has the ability to reduce the level of root–knot nematodes in the succeeding crop when used as green manure (Daniel and Ong, 1990). Pigeonpea has been used successfully under coffee plantations as a cover crop to improve soil properties, reduce weed competition as well as act as a food source for predators (Venzon *et al.*, 2006). Maize yields have been increased by 32.1% in West Africa by using pigeonpea as a cover crop (Sogbedji *et al.*, 2000). Pigeonpea is used in alley cropping, and being perennial, it can be rationed successfully for subsequent crops in no till production systems (Lal *et al.*, 1978). Rotation farming and intercropping are common practices by small-scale farmers in Africa (Sakala *et al.*, 2000) and pigeonpea has been reported to be best suited for both.

Other than transferring fixed N to the inter–planted crop, pigeonpea has the ability to bring minerals from deeper soil horizons to the surface by means of its deep rooting system, also improving soil air circulation (Kumar Rao *et al.*, 1983) to the benefit of the accompanying crop. Pigeonpea initial slow growth reduces competition for light, water and soil nutrients when intercropped (Dalal, 1974) thereby minimizing any negative impact on the main crop. Under rotation farming, the residual effect of N fixed by pigeonpea on a following cereal crop can be as much as 40 Kg/ha (Nene, 1987). There is also the potential of using pigeonpea in the control of *Striga* (*Striga* spp.) weed, which is a major problem in Africa. Rotation with pigeonpea in *Striga* infested soils of western Kenya showed pigeonpea as one of the most productive crops with a remarkable decrease of *Striga* populations in maize planted after pigeonpea (Oswald and Ransom, 2001).

One great challenge facing the pigeonpea industry in Ghana is the unavailability of improved seeds (Adjei–Nsiah, 2012). Most of the varieties that are available in the country are the late maturing types with maturity period of about 40 weeks (Nene and Sheila, 1990). Another characteristic of these late maturing varieties is their sensitivity to photoperiod. Flowering in these varieties is dependent on exposure of the plants to specific day lengths, unlike the improved varieties that can flower independent of day length (Omanga *et al.,* 1995). Pigeonpea, like most legumes is a moderate feeder which requires moderately high quantities of nutrients for its optimum growth and yield (Remanandan and Asiegbu, 1993; Egbe and Kalu, 2004). Due to its natural ability to fix nitrogen into the soil through the Biological Nitrogen Fixation, pigeonpea requires lower levels of nitrogen in the soil, or from applied fertilizers, than other crops. This makes the use of fertilizers high in nitrogen irrelevant for the cultivation of pigeonpea (Egbe and Kalu, 2004). Some major nutrients required by pigeonpea include phosphorus (P) and potassium (K). Pigeonpea shows little response to nitrogen fertilization, but rather responds positively to a moderate amount of phosphorus and potassium fertilization (Sa and Israel, 1991). Pigeonpea also requires an appropriate amount of calcium and magnesium (Robson *et al.*, 1981). The influence of P on symbiotic nitrogen fixation in leguminous plants has received considerable attention, but its role in the process remains still unclear. Phosphorus is the most limiting nutrient and an application of 17 to 26 kg P ha^{-1} gave higher yield in soybean than no application (Andrew and Robins, 1969; Israel, 1987; Israel, 1993).

Deficiencies of Potassium (K) also reduce the weight of nodules and the specific nitrogenase activity of pigeonpea (Lynd *et al.*, 1984). However, improving the productivity of pigeonpea through P and K mineral fertilizer application is difficult as P and K fertilizers are not readily available in rural markets and smallholder farmers hardly apply mineral fertilizers to legumes. An alternative to mineral fertiliser is the palm bunch ash. Palm bunch ash has been found to have high pH and contains varying amounts of nutrients such as calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P) (Adjei–Nsiah, 2012). This makes PBA a suitable material for raising the soil pH and raising the levels of other nutrients for uptake by crop plants. Studies carried out in parts of Africa show that plant derived ash including those of wood and cocoa pod increased P, K, Mg, Ca status and pH of the soil and yield of vegetables, maize, rice and millet (Oguzor and Ezekiel, 2006; Khanna and Raison, 2006; Ojeniyi *et al*, 2002; Ojeniyi and Adejobi, 2002; Odedina *et al*, 2003; Owolabi *et al*, 2003). In Ghana, Adjei–Nsiah (2012) also found that application of PBA increases the grain yield of maize as was also reported by Awodun *et al.* (2007) in Nigeria. In cassava, Ojeniyi *et al*. (2009) and Ezekiel *et al.* (2009) reported that PBA when applied as fertilizer increased the root weight, length and diameter in cassava tubers. Palm bunch ash has also been reported to result in increased performance of many legumes (Adu–Dapaah *et al.*, 1994; Ikpe *et al.*, 1997; Ojeniyi *et al.*, 2002; Ojeniyi and Adejobi, 2002; Van Reuler and Jassen, 1996; Owolabi *et al.*, 2003, Odedina *et al.*, 2003). Oguzor (2007) reported that application of palm bunch ash affected the emergence and yield of groundnut significantly and therefore recommended that for economic purpose, palm bunch ash should be applied to groundnut for optimal yield. Singh *et al. (*2003) also found out that the addition of palm bunch ash to a cowpea field neutralized soil acidity and increased ion exchange capacity as well as water holding capacity of the soil. This, they concluded resulted in increased growth, biomass and grain yield in cowpea.

1.2 Objective

The main objective of this study was to determine the extent to which the addition of palm bunch ash and inorganic fertilizer (P and K) can affect the growth, yield and nitrogen fixation in pigeon pea.

1.3 Specific objectives

1. To assess the effect of palm bunch ash and a combination of P_2O_5 and K_2O on the growth and grain yield of pigeon pea.
2. To determine the influence of palm bunch ash and inorganic fertilizer on the amount of nitrogen fixed by pigeonpea, using maize as a reference crop.
3. To determine the effect of palm bunch ash application on soil chemical properties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The pigeon pea– Family and Botany

The pigeon pea (*Cajanus cajan*), also known as *Gandule bean*, *tropical green pea*, *kadios*, *Congo pea*, *gungo pea*, fio–fio, mgbụmgbụ, or *no-eye pea*, is a member of the family *Leguminoseae* (Van der Maeson, 1995). It is an erect shrub which shows considerable variations in height, ranging from 1–4 meters. In most of the genotypes, branching begins from the sixth to the tenth node, that is, from 15–20 cm above the ground. Pigeonpea is a short–lived leguminous perennial that is managed in agricultural systems as annuals or biennials. It may reach 4 m in height, but usually about 1.5 m. Woody at the base of the plant, the side branches are generally erect (Morton, 1976). The vertical taproot is deep and extensive, reaching depths of 1–2 m, with multiple branches (Anderson *et al.*, 2001; Sheldrake and Naranyanan, 1979). Maturity ranges from 90 to 280 days. Pigeonpea genotypes are generally grouped into four categories: extra short duration (< 105 days), short duration (≈ 105–145 days), medium (≈ 146–199 days), and late maturing (> 200 days) cultivars (van der Maesen, 1989). Other maturity classifications have been proposed, with up to 10 categories (Silim and Omanga, 2001). Shorter–duration lines frequently are determinate, although indeterminate growth habit occurs across maturity groups.

Pigeonpea is a quantitatively short–day plant. Genotypes tend to be extremely sensitive to photoperiod and temperature; this can greatly alter phenology, height, and productivity. A transect study in Kenya demonstrated that slightly cooler average temperatures can dramatically delay maturity in short and extra short duration cultivars; days to maturity were 94 days at 23^{0}C vs. 175 days at 18 ^{0}C (Silim and Omanga, 2001). Delayed maturity frequently reduces yield because of late season drought stress, and interferes with planting a subsequent crop. Pigeonpea (*Cajanus cajan* (L.) Millspaugh) is the only cultivated food crop of the Cajaninae sub–tribe of the economically important leguminous tribe, Phaseoleae, which contains many bean genera consumed by man (e.g. *Phaseolus, Vigna, Cajanus, Lablab* and *Macrotyloma*). Within the tribe Phaseoleae, the sub–tribe Cajaninae is well distinguished by the presence of vesicular glands on the leaves, calyx, and pods (van der Maeson, 1995). Eleven other genera remain in the Cajaninae, the larger ones being *Rhynchosia*, *Eriosema*, *Dunbaria* and *Flemingia*.

The cultivated pigeonpea stands alone as a crop species in the sub–tribe; most species of this sub-tribe belong outside the pigeonpea gene pool, or at most, in its tertiary gene pool, although several *Cajanus* species can be placed in the secondary gene pool (van der Maesen, 1991). The primary gene pool includes cultivar collections of *Cajanus cajan*. The secondary gene pool includes *C. acutofolius, C. albicans, C. cajanifolius, C. lanceolatus, C. latisepalus, C. lineatus, C. reticulatus, C. scarabaeoides* var. *scarabaeoides, C. sericeus,* and *C. trinervius*. The tertiary gene pool contains *C. goensis, C. heynei, C. kerstingii, C. mollis, C. platycarpus, C. rugosus* and *C. volubilis* (van der Maesen, 1991). There are little, if any, chances of species crossing between different gene pools under natural conditions because of incompatibility. It would be very difficult, therefore, to use resistance genes for resistance to diseases, pests, and abiotic stresses from the wild species into the cultivated pigeonpea. However, some scientists have succeeded in crossing pigeonpea with wild related species (Singh and Sekhon, 1979; Aruna *et al.,* 2005; Mallikarjuna and Saxena, 2005). With the recent revision of the taxonomy of *Cajanus* (van der Maesen, 1991), the *Atylosia* species do not appear to differ sufficiently from *Cajanus* to warrant generic status. Morphological, cytological, chemical, and hybridization data support this merger, even if the needed taxonomic changes are for convenience. The genus *Atylosia* forms the secondary gene pool of 34 known species. *Atylosia* and *Cajanus* are mainly distinguished by a persistent aril, or strophiole, on the seeds of *Atylosia*. The character is simply inherited and has occurred in some cultivars in *Cajanus*. It is reported that 22 out of 34 *Atylosia* species occur in India, Sri Lanka, and Burma, one in Mauritius, seven in Australia, one in Malasyia, two in China, and one in Thailand (Sharma and Green, 1980). *Cajanus*, as recognized now, has 32 species and the genus *Cajanus* is distributed in the old world with 18 species in Asia, 15 in Australia and one in Africa (van der Maesen, 1991). The only distinct difference between the two genera is that *Cajanus* is found only under cultivation, while *Atylosia* spp are all uncultivated, wild, weedy forms (Sharma and Green, 1980). However, it is not known how far *Atylosia* is from domestication.

In 1956, Deodikar and Thakar observed close affinity between *Cajanus* and some erect species of *Atylosia* and suggested the possibility of transferring Fusarium wilt resistance from *Atylosia* to *Cajanus*. Three species, *A. lineata, A. sericea,* and *A. scarabaeoides*, were successfully crossed with *C. cajan*. Cytological studies showed that all were close to *Cajanus*, but *A. lineata* is the closest (Sharma and Green, 1980). However, more recent crosses revealed *A. cajanifolia* to be the closest relative of *C. cajan*. Except for pod and seed characters, it is difficult to distinguish *Atylosia* from *Cajanus* (Sharma and Green, 1980). There are thus increased possibilities of transferring some desirable genes from the wild relatives into cultivated pigeonpea for disease and pest resistance and yield. Reddy (2004) suggested several appropriate methods for exploitation of the genes. He proposed traditional breeding methods (TBM) and marker-assisted selection (MAS) for crossing *C. cajan* with weedy counterparts or progenitors of cultivated pigeonpea in the primary gene pool (*C. cajanifolius*). Reddy (2004) also proposed TBM, MAS, and introgression through backcross (BC) programmes between pigeonpea and cross–compatible species producing more or less fertile hybrids in the primary and secondary gene pool. For crossing with the tertiary gene pool, embryo rescue, chromosome doubling and BC + MAS would be appropriate for crossing between pigeonpea and cross–compatible species, producing viable but sterile hybrids. Reddy (2004) also proposed that protoplast fusion, aided by molecular markers, would be suitable for crossing pigeonpea with cross–compatible species, producing non–viable hybrids in the same tertiary gene pool and other gene pools.

2.2 Origin and distribution of pigeon pea

Most of the evidence points to India as the place where pigeonpea originated because of the presence of several wild relatives, the large diversity of the crop gene pool, ample linguistic evidence, a few archaeological remains, and the wide usage in daily cuisine (van der Maesen, 1990). The diversity of the crop in India is much larger than in Africa, and this made Vavilov, in 1951, list pigeonpea to be of Indian origin (van der Maesen, 1990). However, it spread quite early to the rest of the world. India and Myanmar account for 16 related wild species, one of which, *C. cajanifolius*, could be considered as a progenitor (van der Maesen, 1990). Many authors including Purseglove (1968) and Rachie and Roberts (1974) considered Eastern Africa as the centre of origin, as pigeonpea seems to occur wild in Africa (van der Maesen, 1990). The scarce, but often cited, archaeological evidence of one seed in an ancient Egyptian tomb, and the wild occurrences in Africa, further favoured speculation that pigeonpea had an

African origin (van der Maesen, 1990). However, Africa harbours only one close wild relative of pigeonpea, *C. kerstingii* (van der Maesen, 1990).

Pigeonpea is widely grown on the Indian subcontinent. It is also grown in Southeast Asia, Africa, and the Americas. There is a substantial area under pigeonpea production in Kenya, Malawi, Mozambique, Tanzania, and Uganda in Africa, and in the Dominican Republic and Puerto Rico in Central America. In most other countries, pigeonpea is grown in small areas and as a backyard crop (Nene and Sheila, 1990). India has dominated production of pigeonpea (91.3% of world production) during the last decade (Muller *et al.*, 1990). The other countries with a notable pigeonpea production are Malawi (3.5%), Eastern Africa (2.6%), Nepal and Myanmar in Asia (1.5%) and the Americas (1.1%) (Muller *et al.*, 1990).

2.3 Importance of pigeon pea

Pigeonpea offers many benefits to subsistence farmers as a food and cash crop and also ensures stable crop yields in times of drought (Nene and Sheila, 1990). As a food source, pigeonpea offers a cheap source of valuable protein to people. Its protein content averages 21%, although some high-protein lines are being bred with up to 30% protein (Sharma and Green, 1980; Gupta *et al.*, 2001; Saxena *et al.*, 2002). Pigeonpea has more minerals, ten times more fat, five times more vitamin A, and three times more vitamin C than ordinary peas (Madeley, 1995). Pigeonpea yields more energy, protein, and beta–carotene ha^{-1} than other important pulse crops (Muller *et al.*, 1990). The World Health Organization (WHO) recommends 0.75 g of protein daily for each kg of body weight to meet the needs of most of the general world population (Shils *et al.*, 1994). In the southern region of Malawi, pigeonpea forms an integral part of the diet of small–scale farmers, and, more especially, it forms part of the ration provided to workers on large-scale farms. Pigeonpea is consumed as dhal (split cotyledons), whole cooked seed, and cooked green pods. The seed husks and pod walls of pigeonpea are commonly fed to cattle, and green leaves are used as cattle fodder. After the pods are harvested, plants are often left in the field for cattle to graze the new green leaves such plants produce (Nene and Sheila, 1990; Shiying *et al.*, 2001). Pigeonpea is not only used as fodder for domestic animals (Shiying *et al.*, 2001; Arya *et al.*, 2002), but also has the potential to fill the late summer/fall (off–season) gap in forage availability (Arnold, 2002). In one experiment, scientists showed that pigeonpea cultivar ICPL 93047 produced 54 t ha^{-1} of green fodder and 29 t ha^{-1} of dry fodder in five cuttings (Shiying *et al.*, 2001). In Malawi and the other Eastern African countries, pigeonpea is processed into dhal and exported to India, Europe and South Africa.

Pigeonpea, as a legume, improves soil fertility through biological nitrogen fixation. It is reported to contribute approximately 40 kg N ha^{-1} (Kumar Rao *et al.*, 1990). Maize yields have been increased by 32.1% in West Africa by using pigeonpea as a cover crop (Sogbedji *et al.*, 2000). Pigeonpea is used in alley cropping, and being perennial, it can be rationed successfully for subsequent crops in no till production systems (Lal *et al.*, 1978). Rotation farming and intercropping are common practices by small–scale farmers in Africa (Sakala *et al.*, 2000) and pigeonpea has been reported to be best suited for both.

Leaf fall at maturity not only adds to the organic matter in the soil, but also provides additional nitrogen. This also benefits subsequent cereal crops when grown in a mixture with maize and sorghum (Sakala, 1992; Yun *et al.*, 2001; Arya *et al.*, 2002). The deep root system of pigeonpea is reported to break plough pans, thus improving the soil structure (Nene and Sheila, 1990). The deep rooting system also enables the plant to be drought tolerant (Nene and Sheila, 1990; Johansen, 2003) and among the legumes, pigeonpea has a relatively high level of dehydration tolerance (Johansen, 2003). The extensive ground cover provided by pigeonpea prevents soil erosion by wind and water, encourages infiltration, minimizes sedimentation, and smothers weeds (Nene and Sheila, 1990).

Pigeonpea is a perennial, but is most often cultivated as an annual crop. Because of the long maturity period of pigeonpea, the landraces and the traditional cultivars are almost always grown as intercrops or in mixed cropping systems with shorter–duration crops. In Africa, pigeonpea is commonly intercropped with maize, sorghum, cowpeas and cassava (Nene and Sheila, 1990). The mixed cropping systems have advantages to the farmer, especially in optimizing land utilization. Pigeonpea is used as a green manure crop in some countries. The tall perennial plants can serve as windbreak hedges, and occasionally pigeonpea plants are used as shade for tree crops or vanilla (Nene and Sheila, 1990). Pigeonpea is also grown as a perennial to mark field boundaries. Pigeonpea is one of the crops that contribute significantly to fuel wood for many households. The dry stems of pigeonpea are an important household fuel wood (Chatarvedi *et al.*, 2001; Shiying *et al.,* 2001). Ten tons per hectare of dry sticks can routinely be obtained from pigeonpea to serve as fuel wood (Nene and Sheila, 1990). In an agro forestry trial at Bunda College in Malawi, Edje (1984) reported that at the end of the second year, the pigeonpea crop grown at 5000, 10000 and 20000 plants ha^{-1} produced 10.1, 11.7 and 12.5 t ha^{-1} of fuel wood, respectively. Faris and Singh (1990) reported fuel wood of 57.6 t ha^{-1} in Colombia and 51 t ha^{-1} in Western Australia in two cuttings within one year. After eight months in India, an actual wood yield of 32 t ha^{-1} was obtained in one cutting. In India, the pigeonpea sticks are also used to make field fences, huts, and baskets (Nene and Sheila, 1990). Pigeonpea has many traditional medicinal uses. Dry roots, leaves, flowers, and seeds are used in different countries to treat a wide range of ailments of the skin, liver, lungs, and kidney (Nene and Sheila, 1990). The roots are used to treat febrile diseases and relieve fever, constrict tissue for controlling bleeding, and destroy internal worms. The leaves can be used to treat jaundice, trauma, cough, burn infection and bedsores (Shiying *et al.,* 2001).

2.4 Mineral requirements of pigeonpea

The major nutrients that are mostly found in the soil are Nitrogen, Phosphorus, Potassium, Magnesium and Calcium. These major nutrients play key roles in the growth, development and yield of plants. Nitrogen is an important component of many important structural, genetic and metabolic compounds in plant cells. It is a major component of chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e. photosynthesis). It is also a major component of amino acids, the building blocks of proteins. Some proteins act as structural units in plant cells while others act as enzymes, making possible many of the biochemical reactions on which life is based. Nitrogen is a component of energy-transfer compounds, such as ATP (adenosine triphosphate) which allows cells to conserve and use the energy released in metabolism. Finally, nitrogen is a significant component of nucleic acids such as DNA, the genetic material that allows cells (and eventually whole plants) to grow and reproduce. Nitrogen plays the same roles (with the exception of photosynthesis). Phosphorus is one of the most important soil nutrients next to nitrogen required by plants in large amounts.

Phosphorus is an important element in providing cellular energy for biochemical synthesis in plants (Hoffland *et al.,* 1989).With decline in soil fertility and increasing low soil pH in fragile tropical soils, phosphorus is gradually becoming unavailable to plants (Uyovbisere *et* *al.*, 2000), usually due to fixation by the oxides of Fe and Al and their hydroxides (Moyin–Jesu, 2008). Legumes are phosphorus loving plants; they require phosphorus for growth and seed development, and most especially in nitrogen fixation which is an energy–driving process. Legumes can fix between 11–120 kg N/ha (Sanginga, *et al.*, 2000). However, this is not achievable in the tropics because of low soil fertility and poor farming practices. In crop rotation, legumes are known to contribute significantly to the yields of subsequent crops like cereals and tubers (Nottidge *et al.*, 2008) and this has been attributed to the amount of nitrogen and other nutrients returned into the soil by the legumes. Careful application of phosphorus fertilizer to legumes must be geared towards enhancing not only their growth and yield, but also nitrogen fixation. In Ghana, farmers hardly apply mineral P–fertilisers to legumes. They therefore rely entirely on the natural available soil phosphorus and other nutrients for N–fixation and growth, and this has resulted in lower yield and low N–fixation by these legumes. Phosphorus moves very little in most soils (less than an inch in most soils), stays close to its place of origin, and crops seldom absorb more than 20% of fertilizer phosphorus during the first cropping season after application. As a result, little soil phosphorus is lost by leaching. This residual phosphorus remains in the rooting zone and will be slowly available to succeeding crops. Precipitation of phosphorus as slightly soluble calcium phosphates occurs in calcareous soils with pH values around 8.0. Under acid conditions, phosphorus is precipitated as Fe or Al phosphates of low solubility. Maximum availability of phosphorus generally occurs in a pH range of 6.0 to 7.0. This is one of the beneficial effects of liming acid soils. Maintaining a soil pH in this range also favours the presence of H_2PO_4 ions which are more readily absorbed by the plant than HPO_4 ions which occur at pH values above 7.0.

Potassium (K) is an important macronutrient and the most abundant cation in higher plants. K has been the target of some researchers mainly because it is essential for enzyme activation, protein synthesis and photosynthesis (Marschner, 1995), and it mediates osmo–regulation during cell expansion, stomatal movements and tropisms. If potassium supply is inadequate, the stomata become slow to respond to osmoregulation. Furthermore, K is necessary for phloem solute transport and for the maintenance of cation: anion balance in the cytosol as well as in the vacuole. K supply from soil can be rate limiting for agricultural production. Under conditions of osmotic and ionic stress, to know the K dynamic of plant is very important (Flowers, 2003) because the K^+ ion, such as prolina, and some other N compounds (Munns, 2002), plays a pivotal role in the cell osmotic adjustment and ion homoeostasis. Moreover the plants present distinguishable responses to that nutrient. The scientific literature has shown that many forest species do not respond to the application of K^+ suggesting they are adapted to reduced availability of this nutrient, possibly due to an efficient uptake and or use (Silva *et al.*, 1996).

Magnesium plays a vital role in photosynthesis, as it is the central atom in the chlorophyll molecule. It is involved in many enzyme reactions. It reacts with phosphorus in uptake and transport. Magnesium is also quite mobile in the plant, and yellow deficiency symptoms first appear on the older leaves, as it moves to the younger leaves of plants. Since the 19th century, it has been appreciated that Ca^{2+} plays a crucial role in determining the structural rigidity of the cell wall (reviewed in Wyn Jones and Lunt, 1967; Burstrom, 1968). During cell wall formation, the acidic pectin residues (e.g., galacturonic acid) are secreted as methyl esters, and only later deesterified by pectin methylesterase, liberating carboxyl groups, which bind Ca^{2+}. It follows that low Ca^{2+} should make the cell wall more pliable and easily ruptured, whereas high concentrations should rigidify the wall and make it less plastic. It had become apparent in the mid to late fifties that modifying the Ca^{2+} produced a pronounced effect on cell growth. Thus, elevating the Ca^{2+} led to an inhibition in shoot or coleoptile growth, whereas reducing its concentration promoted cell and tissue elongation (Bennet–Clark, 1956; Tagawa and Bonner, 1957).

2.5 Effects of Phosphorus and Potassium on the growth of legumes

Nitrogen, phosphorus, potassium and water are considered as the major limiting factors in crop growth, development and finally economic yield (Parry *et al*., 2005).

Phosphorus application not only increases the plant biomass (Patel and Kotecha, 2006; Tariq *et al*., 2007) but also improves its protein contents (Joshi and Mali, 2004). The deficiency of phosphorus in legumes depressed the activity of nitrogen fixing bacteria (Giller and Cadisch, 1995; Rahman *et al*., 2008) for which the availability of nitrogen in root zone was also reduced. The combined application of PK increased the weight of individual nodule in clover up to 4 times over control (Lynda *et al*., 1984).

The potassium is the third most important essential nutrient after nitrogen and phosphorus. The need for potassium to be included in fertilization programme was felt after the results of doctrine study of Von Leibig in 1840. Its adequate supply during growth period improved the water relations of plant and photosynthesis (Garg *et al.*, 2005) and weight and number of nodules per plant (Premartne and Oertli, 1994; Paulino *et al.*, 1995).

In an experiment to determine the effect of different levels of P and K on the growth, forage yield and quality of Cluster bean, Ayub *et al.* (2012) found out that the application of P and K fertilizer had a positive effect on plant morphological traits like, height, leaf area and number of branches per plant, stem diameter, fresh and dry biomass. The application of PK at the rate of 80–85 kg/ha exhibited the highest values for number of branches (23.33) and leaf area per plant (1920.30 cm^2), fresh (32.71 t ha^{-1}) and dry matter yield (7.73 t ha^{-1}). The maximum plant height (139.30 cm) was achieved with application of PK at the rate of 70–75 kg ha^{-1}. It was also found out that the application of P alone could not produce significantly higher plant height, leaf area per plant and stem diameter over the control treatment. The results are comparable to that of Reager *et al*. (2003) for both the plant height and number of branches per plant, though an increase in number of branches of mung bean with phosphorus application has been reported by Ali *et al.* (2010).

Reports on soybean observed and recorded that the plant height and leaf area increased significantly with P application. Plant height increased with increased P application up to 17 kg P ha^{-1}. The authors attributed this to the fact that P being an essential constituent of plant tissue significantly influenced the plant height of crop. Kumar and Chandra (2008) also observed significant improvement in plant height of soybean through P–fertilization. The plant height of relay strip intercropping soybean decreased markedly with increased K application up to 112.5 kg K ha^{-1}. Their findings were in unconformity with the results obtained by Adel *et al.* (1994) who reported increase in plant height of soybean at high K application. The possible reason was that K application improved the growth and development of soybean, as well as increased the uptake efficiency of soil nutrients.

2.6 Effects of Phosphorus and Potassium on yield of Legumes

In an experiment on pigeonpea, Deshbhratar *et al.*, (2010) reported that Phosphorus application significantly influenced grain yield, straw–yield, attributed characters like number of pods per plant, number of grains per pod as well as the weight and crude protein percentage. The mean increase in grain yield (straw yield, number of pods plant^{-1}, number of grains pod^{-1}, and grain yield per plant and test weight) was significantly increased up to application of 20 kg P ha^{-1} and also were significantly superior over other levels. The results of their study were in conformity with those earlier recorded by Shrivastava and Verma (1996) and Nadal *et al.* (1987) who also reported an increase in grain yield of pea as a result of P application.

Several studies (Bly *et al.*, 1997) have also shown that application of P to soybean increased 100 seeds weight, number of pods per plant and grain yield. Chiezey *et al.* (2009) found out that the application of P stimulated soybean leaf expansion, hence more light interception for photosynthetic activities, leading to high dry matter accumulation, high seed yield, pod yield and 100 seeds weight. Increased yield with application of P has also been reported by various workers in pea (Chandra *et al.*, 1989), pigeonpea and French beans (Parma *et al.*, 1999).

In lentil, Niri *et al.* (2010) reported a 12% increase in reproductive growth and grain yield over the control as a result of the addition of 40 kg ha^{-1} P fertilizer. Their results were in agreement with that of Khaladbarin and Slamzadeh (2006), who also reported an increase in reproductive growth as well as in the yield of lentil as a result of P fertilization.

Jahan *et al.* (2009) reported an increase in grain yield as a result of application of potassium fertilizer. In their experiment, it was found that, apart from the increase in grain yield, K fertilization also resulted in increased number of branches, number of pods per plant and 1000 seed weight. Azad *et al*. (1995) and Singh (1998) have also reported that seed yield of lentil increased with increasing levels of potassium application. Similar results were reported by Tariq *et al.* (2001) who worked on Mung bean.

Working on cowpea, Ullah *et al.* (2007) found that application of K fertilizer increased pod length and 1000 seed weight of cowpea. They concluded that plants that were treated with K fertilizer gave significantly higher seed weight than those that did not receive K treatment. This confirmed the results of Mohankumar and Pillai (1979) who reported an increase in grain yield as a result of K fertilization. Ali *et al.* (2007), reporting on chickpea found out that the application of K fertilizer significantly increased the seed yield, compared to the control. A similar result was obtained for 1000-seed weight in the same experiment. They further reported on yield components such as the number of branches per plant, and found that the various levels of potash gave higher number of branches compared to the control.

In pea (*Pisum sativum*), Amjad *et al.* (2004) reported a significant increase in seed yield per plant as a response to different phosphorus and potassium fertilizer levels, compared to the control. They reported that as the rate of P application increased, seed yield also increased significantly. Venkateswarlu and Ahlawat (1991) reported that 1000 seed weights increased with the increasing doses of phosphorus being statistically insignificant. Due to the fact that phosphorus fertilization was effective in the generative period of the plant, and that such fertilization led to a much better granulation, enhancement and improvement occurred in 1000 seed weights with the increasing doses of phosphorus.

2.7 Effects of Palm Bunch Ash (PBA) on Growth of Legumes

According to Robson and Lonragan (1970), high soil acidity depresses growth of annual legumes by affecting plant nutrition, promoting Al toxicity and suppressing rhizobial survival and multiplication, but this situation can be corrected by the use of liming agents such as Palm Bunch Ash.

Safo *et al.* (1997) found that cowpea plants that received PBA retained their leaves longer compared to their control plants that did not receive the PBA which showed P deficiency by shedding their basal leaves early; an attribute of P deficiency. They also recorded higher cowpea dry matter yield in the PBA amended plots compared with the cowpea plants in the control plots that did not receive PBA. They attributed the P deficiency in the control plots to high acidity and low fertility of the soil. They also found out that application of Palm bunch ash significantly ($p < 0.05$) increased shoot and root dry matter yields and also increased plant height, number of leaves and branches, and stem thickness.

In an experiment to find out the effects of PBA on the germination and seedling growth of soybean, Onwugbuta–Enyi and Offor (2010) reported that lower concentrations of PBA had positive effects on seed germination, seedling growth, as well as fresh and dry weights of soybean. The positive effect was found to increase with increase in the concentration of PBA up to 40%, above which, the effect became inhibitory. The authors attributed the positive effects of lower concentration of PBA on the parameters studied to improved soil fertility as palm bunch ash is known to contain a number of mineral nutrients that promote plant growth. The inhibitory effect was attributed to high osmotic pressure which made imbibition difficult resulting in retarded growth and low germination percentage. Oguzor (2007), investigating the effect of PBA on the growth and yield of groundnut also observed poor field germination with the application of PBA. He however reported a significant ($p < 0.05$) increase in plant height of the groundnut in response to the application of PBA. The good growth observed among plants treated with PBA in this study, according to the author might have resulted from the improvement in the pH and general fertility of the soil as a result of the application of the PBA. A tissue P concentration of 0.27% at a PBA application of 0.83 g kg^{-1} soil (1,860 kg PBA ha^{-1}) is comparable to the sufficiency level of P in soybean and groundnut at early pegging.

2.8 Effects of PBA on Yield of Legumes

Oguzor (2007) reported that yield of groundnut was positively enhanced when PBA was applied at 500 g $plant^{-1}$. The resulting yield increase was attributed to adequate nutrient availability in the soil which promoted plant nutrient uptake and subsequently, yield increase. Other types of plant derived ash have also been found to increase yield of legumes such as cowpea, (Owolabi *et al.*, 2003; Adu–Dapaah *et al.*, 1994; Odedina *et al*., 2003; Ojeniyi *et al*., 2003; Ojeniyi and Adejobi, 2002; Obi and Ekperigin, 2001) black gram (Raijiv and Prakash, 2012) and peas (Cox *et al.*, 2003). Cox *et al.* (2001) in their experiment on pea reported an increase in grain yield as a result of the application of coal ash as a soil amendment. They attributed their results to the fact that coal ash slightly suppressed phosphatase activity, while it increased soil pH and also improved infiltration.

In an experiment on Black Gram (*Vigna mungo*), Raijiv and Prakash (2012) reported an increase in yield parameters such as dry matter production, number of pods per plant, number of seeds per pod, 1000 seed weight and yield per plant as a result of the application of wood ash. They further reported that all the micronutrients in the wood ash increased number of seeds per pods. Mahakulkar *et al.* (1994) and Gowda *et al.* (1995) also reported increased pod weight and pod yield in groundnut as a result of Palm Bunch Ash application. Kalyani *et al.* (1993) also observed increased pod weight per plant with ash application.

2.9 Effects of PBA and mineral fertiliser on nitrogen fixation in legumes

Cadish *et al.* (1989), evaluating the effects of K fertilizer on N_2 fixation of a number of forage legumes reported that, the plants that were treated with K fertiliser fixed a higher amount of Nitrogen than the control plants. In their research, they realised that all the legumes that were treated with K fertilizer derived at least 70% of their N from symbiosis whereas without K application, both lower values and larger differences in P fixed between species were observed. They further made an assumption that the increase in P fixed with K supply could improve N_2 fixation. They then concluded that the application of P and K fertilizer increases the amount of Nitrogen fixed by legumes. Tsvetkova and Georgiev (2003), also conducting an experiment to determine the effect of P on nodulation and N fixation in soybean found out that non-optimal supply of P decreased the nodule mass and number. They further detected that alteration of P supply in nutrient solution caused significant changes in phosphorus metabolism in both the host and the nodules of soybean. The changes in P supply decreased nodule fresh and dry weight by almost 50%, in both P deficient and P oversupplied plants. The excess of P decreased nodule number up to 35% in comparison with control. Nodulation of P–deficient soybean was less affected, but most of the nodules showed smaller size in comparison with the control. It was then concluded that, though P is required by legumes for effective nodulation and N_2 fixation, the quantities that are supplied to the plants should be optimal. In another experiment to ascertain the effects of P on N fixation in Vicia faba, Mengel *et al.* (1974) found out that plants which were well supplied with inorganic nutrients were able to fix more N_2 by their root nodules than plants that were deficient in one or another element. They attributed their findings to increased photosynthesis. The fact that photosynthesis favours N_2 fixation by root nodules has been reported by Lindstrom *et al.*

(1952). This was attributed to improved supply of carbohydrates to the roots so that number and size of the nodules will be increased. Such an effect is also exerted by K^+. It has also been experimented that the contribution of legumes in soil improvement found out that the application of P and K to broad beans resulted in an increased nodule dry weight as well as an increase in the amount of Nitrogen fixed.

According to Robson and Lonragan (1970), high soil acidity depresses growth of annual legumes by affecting plant nutrition, promoting Al toxicity, suppressing rhizobial survival and multiplication as well as suppressing the nodulation process and the symbiotic N_2–fixation. In order to promote nodulation and N_2 fixation in acidic soils, a liming agent such as Palm Bunch Ash (PBA) has been proven to be effective. Brauer *et al. (*2002), conducting a research on the effects of liming on root development and nodulation of clovers found out that Nitrogen content of plants grown in limed soil was significantly higher than that found with plants in unamended soil. Their results was in conformity with that of Syed–Omar *et al.* (1990) who, working on peanut reported an increased nodulation as a result of amending the soil with liming agents such as Palm Bunch Ash. It has also been reported by Unkovich *et al*. (1996) that liming increases nodulation and N_2 fixation in legumes.

2.10 Effects of organically derived ash on soil chemical properties

Several studies (Obi and Ekperigin, 2000; Ojeniyi *et al.,* 2002; Owolabi *et al.,* 2003; Odedina *et al.,* 2003; Awodun *et al.,* 2007) have shown that plant-derived ash has positive effects on soil chemical properties. Awodun *et al.* (2007), in their experiment on maize found out that, compared with the control, the addition of PBA at different rates (2 t ha^{-1}, 4 t ha^{-1}, 6 t ha^{-1} and 8 t ha^{-1}) increased soil OM, N, P, K, Ca and Mg contents significantly ($p > 0.005$). Other authors (Obi and Ekperigin, 2000; Ojeniyi *et al.,* 2002; Owolabi *et al.*, 2003; Odedina *et al.*, 2003; Ojeniyi and Adejobi 2002; Smith *et al*., 2001; Adu–Dapaah *et al.*, 1994; Van Reuler and Janssen, 1996) have reported that ash derived from plant sources were effective as liming material and source of nutrients for several crops including rice, pepper, tomato, maize and yam. Safo *et al.* (1997)**,** experimenting on cowpea found out that PBA application significantly increased soil pH, available P and exchangeable K^+ and Mg^{2+}, but decreased soil total N. Soil pH increased from 4.7 to 7.2 over a range of PBA application; 0.00, 0.42, 0.83, 1.67, 2.50, 3.33 and 4.17 g kg^{-1} of soil. They attributed the decrease in soil total N with PBA application to greater supply of the other nutrients that caused increased growth. This observation supports the assertion that some legumes can deplete soil N if symbiotically supplied N is inadequate. Onwuka *et al.* (2009), in their research on maize reported that the application of organic liming materials such as wood ash increased the soil pH, reduced soil exchangeable acidity, exchangeable aluminium and exchangeable hydrogen. According to Fageria *et al. (*2007) liming materials contain basic cations and basic anions (CO_3^{2-}) that are able to pull H^+ from exchange sites to form $H_2O + CO_2$. Cations occupy the space left behind by H+ on the exchange. This result was in agreement with Voundi Nkana *et al*. (1998) and Ojeniyi *et al.* (1999) who reported that Palm Bunch Ash increased the soil pH.

Plant nutrient availability is greatly influenced by soil pH. With the exception of P, which is most available within a pH range of 6 to 7, macronutrients (N, K, Ca, Mg and S) are more readily available within a pH range of 6.5 to 8, while the majority of micronutrients (B, Cu, Fe, Mn, Ni, and Zn) are more available within a pH range of 5 to 7. In modifying soil pH of acidic soils, palm bunch ash has a neutral or slightly alkaline pH and marked buffering capacity. The application of PBA appears to be extremely useful on acid soils. It acts as a pH corrector, thus avoiding the risk of aluminium or manganese toxicity which is likely to take place at pH values below 5 (Gallardo–Lara and Nogales, 1987). Several workers have reported increases in soil pH by addition of PBA. For example, Gallardo–Lara and Nogales (1987) reported increases in soil pH values from 2.8 to 5.8 through addition of PBA. Increase in soil pH from 4.9 to 5.8, 5.3 to 6.8, 5.4 to 5.8, 5.8 to 6.4, 6.0 to 6.6 and 6.1 to 7.6 have been reported (Zhang *et al.*, 2006). Obi and Ekperigin (2001) studied effect of liming materials such as plant derived ash and flue dust on maize yield. The materials were found to increase soil pH and maize yield. Other studies carried out in different parts of Africa found that plant derived ash including those of wood and cocoa pod increased P, K, Ca, Mg status of soil and pH and yield of vegetables, rice, millet and maize. These increases in soil pH were usually proportional to the PBA application rate rather than quality. The increase in the soil pH may be due to the mineralisation of carbon and the subsequent production of OH^- ions by ligand exchange as well as the introduction of basic cations, such as K^+, Ca^{2+}, and Mg^{2+} (Mkhabela and Warman, 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The experiment was carried out at the University of Ghana Forest and Horticultural Crops Research Centre (FOHCREC), Kade which lies within latitude 6^0 09 and 6^0 06 N and longitude 0^0 55 and $0^0$49 W in the Kwaebibrim District of the Eastern Region of Ghana. The centre is located in the semi–deciduous forest agro–ecological zone of Ghana and has an altitude of 135.9 m above sea level.

3.2 Soil

The soils of the research area are developed from rocks of the Birrimian system (middle Pre–Cambrian) (Adu, 1992) which constitute mainly of argillaceous sediments metamorphosed into phylite (Ahn, 1961). These soils are well drained and belong to the forest Ochrosol Great Soil Group of the Ghanaian soil classification system (Bramner, 1962; Owusu–Bennoah *et al.*, 2000) and are generally classified as Acrisols in the FAO–Unesco Revised Legend and as Utisols in Soil Taxonomy (Soil Survey Staff, 1998).

3.3 Climate and weather

The study site is characterized by a bimodal rainfall pattern with peaks in June and October with a brief dry spell in August and a dry season from December to March. The total annual rainfall during the experimental period was 1677.9 mm.

3.4 Experimental details

Two different types of experiments were conducted; field and pot experiments. The field experiment was conducted from June, 2011 to February, 2012. The pot experiment was also conducted from October 2011 to January 2012.

3.4.1 Field experiment

3.4.1.1 Land preparation and experimental layout

The experimental plot which was previously cultivated to maize had been fallowed for one year. The field was dominated by *Chromolaena odorata*. The field was cleared using cutlass, and stumping done with the aid of mattock. The entire field was sprayed with glyphosate herbicide at the rate of 900 g a.i. ha^{-1} four weeks after clearing the field.

The experiment was conducted in a split plot design with four replications. The main plot treatments consisted of three varieties of pigeonpea (ICPL 87091, ICPL 88034 and ICPL 88039) and the subplot treatments were 20 kg ha^{-1} NPK (0–30–20) and 2 t ha^{-1} palm bunch ash (PBA) and a control (No fertilizer application). Each main plot measured 12×8 m^2 with an inter–plot distance of 3 m. Each sub–plot treatment consisted of 3 rows each measuring 8 m.

3.4.1.2 Germination Test

Prior to planting of the seeds on the field, a viability test was conducted on each of the varieties used. Three different sets of petri dishes were washed, wiped and sterilized with 70% alcohol. The dishes were lined with clean and uncontaminated filter papers. The filter papers were moistened with distilled water. Forty seeds each of the three pigeon pea varieties were put into the three differently labelled petri dishes. The seeds were arranged in each dish such that no one seed had any contact with another. The cover of each of the dishes were also lined with a moistened layer of filter paper and used to cover the seeds in each dish. The set–up was left undisturbed for four days. Below are the results of the germination test:

ICPL 87091 (variety v1): 87.5%

ICPL 88034 (variety v2): 90%

ICPL 88039 (variety v3): 77.5%

The mean percentage of germination was computed as follows:

$$\text{Mean percentage} = \frac{\text{Number of seeds that emerged}}{\text{Total number of seeds in petri dish}} \times 100 \qquad [3.1]$$

The above results indicate that the seeds of each variety were viable for the experiment.

3.4.1.3 Taking of initial samples (soil and PBA)

Before clearing the land, soil samples were taken to a depth of 0–15 cm for both physical and chemical analysis. A sample of the oil palm bunch ash, herein referred to as PBA was also taken and analyzed for its pH, organic carbon content, total nitrogen, available phosphorus, and exchangeable cations (K, Mg and Ca).

3.4.1.4 Soil analysis

Core soil samples were collected randomly from the 0–15 cm depth on the site using a soil auger. Soil was then mixed thoroughly and the bulk sample was taken to the laboratory, air–dried and sieved to pass through a 2 mm screen for chemical analysis. The soil pH (1:1 soil to water ratio) was determined using a glass calomel electrode system (Crockford and Nowell, 1956). The soil N was determined by the micro–Kjedahl method (AOAC, 1970) while available soil P was extracted by the Bray P1 extractant, measured by the Murphy blue colouration and determined on a spectronic 20 at 882 Um (Murphy and Riley, 1962). Soil K, Ca and Mg were extracted with a 1M NH4OAC, pH 7 solution, then K analysed with a flame photometer while Mg and Ca were determined with an atomic absorption spectrophotometer (Jackson, 1958).

3.4.1.5 Planting

Three pigeon pea varieties namely (ICPL 87091, ICPL 88034 and ICPL 88039) an improved maize (var. Obaatanpa) were planted between 14 and 15^{th} June, 2011. The four treatments were randomized within four replicate blocks. The plot size was 12 m x 8 m with 3 m paths between the plots. The pigeonpea were spaced at 1 m and two seeds per hill, sown at 0.5 m within rows and thinned to one seedling per stand when they were 14 days old. The maize (var. obaatanpa) was planted at 1 m × 0.2 cm with two seeds per hill and later thinned to 1 seed per stand.

3.4.1.6 Sub–plot treatment application

Three sub–plot treatments were applied to the pigeon pea plants at 14 days after planting. These included:

i. control (no fertilizer applied),

ii. 2 t ha^{-1} palm bunch ash (PBA) and

iii. 20 kg ha^{-1} NPK (0–30–20)

Each sub–plot treatment consisted of 48 plants made up of 3 rows of 16 plants with each sub–plot treatment separated by a guard row. The fertilizer treatments were applied in a form of ring application. The application rate per plant was calculated using the area of a hectare and the planting distance as shown in the formula below:

$$\text{Plant population per hectare} = \frac{\text{Area of land per hectare } (10{,}000\ m^2)}{\text{Planting Distance}} \qquad [3.2]$$

$$\text{Amount of fertilizer per plant} = \frac{\text{Application rate of fertilizer}}{\text{Plant population per hectare}} \qquad [3.3]$$

3.4.2 Cultural practices

3.4.2.1 Weed control

Weeding was done as and when the need arose. The first weeding was done at 3 weeks after planting, and was done carefully with the use of hoes to avoid cutting down the plants. The subsequent ones were done 8, 13 and 21 weeks after planting (WAP).

3.4.2.2 Pest control

Pyrinex 48EC at 1 mL/L was applied to control insect pests such as grasshoppers, stem borers, leaf miners and bean pod borers while Cymethoate at 7.5 mL/L of water was sprayed to control termites. Spraying was started when the plants were three weeks old and repeated every three weeks when it was suspected that the effect of the previous spraying had reduced.

3.4.3 Destructive harvesting (growth and dry matter determination)

3.4.3.1 Destructive harvest of pigeon pea

Destructive harvesting was done at 50% flowering. Out of the 48 plants contained in each treatment, ten plants covering an area of 5 m^2 were sampled at 50% flowering (which was approximately 10 WAP) for plant growth measurements, nodulation and dry matter analysis. Whole plants were uprooted with the aid of an earth chisel. Removal was done carefully in order not to damage the roots of the plants and also to be able to retrieve all nodules. Before the plants were uprooted, the plant height as well as the girth was taken using a meter rule and vernier callipers respectively. The plant samples were taken to the laboratory and the following data were taken: number of fruiting branches, number of flowers and number of fruits.

The plant shoots were chopped into pieces and put into well labelled envelopes and dried in an oven at a temperature of 70^{o}C for 48 hours to constant weight. The dried samples were milled and a sub–sample taken for nutrient analysis.

3.4.3.2 Destructive harvest of maize

Harvesting of the maize was done at the same time as the pigeonpea. An area of 5 m^2 was demarcated on each maize plot, as was done for the pigeon pea. Due to the planting distance (1 m × 0.2 m) that was used, the number of maize plants that fell within this area totalled 25. The above ground parts of each maize plant was chopped and packed in labelled envelopes. The samples were dried in an oven at a temperature of 70^{o}C for 48 hours for dry matter determination. The dried samples were milled and a sub–sample taken to the laboratory for nutrient analysis.

3.4.4 Removal of nodules and weighing

To prevent loss of nodules in the soil, the sampled plants were carefully dug out together with a ball of earth around it at a radius within which plant roots were not profound. The plants, together with the soil were placed in plastic buckets or bowls. Careful search for the nodules was done to get all the nodules from each plant. The number of nodules on each plant was recorded. The nodules of each plant were put into labelled envelopes and dried in an oven. Drying was done at a temperature of $70^{o}C$ for 48 hours and the dry weight was taken by weighing on an electronic scale.

3.4.5 Data Collected

3.4.5.1 Plant height (cm)

The heights of the ten tagged plants were taken in each treatment at 50% flowering. Measurement was made from the base of the plants (above ground) to the highest growing point using a meter rule, and recorded in centimetres (cm).

3.4.5.2 Plant girth (cm)

The girths of the tagged plants were measured using a vernier calliper. The girth was measured at 5 cm from the soil surface around the base of the tagged plants at 50% flowering.

3.4.5.3 Number of leaves, fruiting branches and flowers per plant

This was determined after the plants were uprooted and taken to the laboratory. The number of leaves of the tagged plants were counted and recorded.

The number of fruiting branches refers to the number of branches that had borne floral buds and or flowers. They were counted and recorded.

The number of flowers on each plant were also counted and recorded.

3.4.5.4 Grain yield per plot (g)

Grain yield was done on per plot basis. Ten plants were used as record plants in each treatment for grain yield determination. Harvesting was done when the matured pods took on a brownish–black colour and dried up. All the matured pods on the tagged plants in each treatment were plucked and bagged in a labelled polythene bag. The pods were taken to the laboratory and transferred into labelled envelopes. They were then dried in an oven for 48 hours at 70˚c to constant weight. The oven dried pods were crushed and the grains extracted. The grains were weighed in grams on an electronic scale and recorded. A total of three harvests were done during the first harvest season which occurred between November and December, 2011, and therefore the sum of the grains in all three harvests was recorded as the yield per plot for the first season. After the first season harvest, flowering and pod production occurred again so another set of harvest was done between January and February, 2012 and recorded as yield per plot for the second season. The second season harvest was also made up of three harvests. The values for the yield per plot were used to compute the yield in tons per hectare.

3.4.5.5 Hundred seed weight

One hundred seeds were selected at random from each treatment in each variety. The seeds were weighed and recorded in grams as 100 seed weight.

3.4.6 Determination of nitrogen fixation

The difference method was based on the difference in total N between the N_2–fixing legume and the reference crop. Thus the amount of N_2 fixed was estimated by the N difference method as:

$$\text{N from nitrogen fixation} = N_{legume} - N_{maize} \qquad [3.4]$$

And the % N derived from N_2–fixation is calculated as:

$$\%\ \text{N from nitrogen fixation} = \frac{(N_{legume} - N_{maize})}{N_{legume}} \times 100 \qquad [3.5]$$

3.5 Pot Experiment

3.5.1 Pot Filling

Soil was collected from 0–15 cm depth from the field, air–dried for 14 days and sieved through a 2 mm sieve. The sieved soil was used to fill polythene bags. A total of forty poly bags each measuring 36 cm × 28 cm were filled with 5 kg soil.

3.5.2 Experimental Layout

The experiment was set up in a Completely Randomized Design with four replications. The bags were arranged on wooden boards to avoid direct contact of the roots with the soil at the experimental site. The same planting distance as was used on the field was used here (1 m × 0.5 m). Each replication also had a maize plant as a non–fixing reference.

3.5.3 Planting and treatment application

The seeds of the same three pigeon pea varieties (ICPL 97091, ICPL 88034 and ICPL 88039) as used for the field experiment and a local maize (var. Obaatampa) were planted on the 7th of October 2011 at a rate of three seeds per pot and thinned to one plant per stand 14 days after planting. Each treatment consisted of four plants. Fourteen days after planting the following sub-treatments were applied to each of the three pigeonpea varieties:

i. control (no fertilizer applied),
ii. 2 t ha^{-1} palm bunch ash and
iii. 20 kg ha^{-1} NPK (0–30–20)

The treatments (fertilizer) were applied to the plants in a ring form. Each sub–plot treatment consisted of four plants.

3.5.4 Cultural practices

The pots as well as the experimental site were kept free from weeds by regular hand picking and hoeing respectively. In cases where the need arose, supplementary irrigation was done. To control insect pests, Cymethoate and Pyrinex 48EC were sprayed on the plants at a rate of 3 mL/L at 21 days after planting.

3.5.4 Harvesting

Harvesting was done at late pod filling stage from all treatments for Nitrogen fixation measurements.

3.5.5 Experimental Data Collected

Data was taken from four plants in each treatment for each variety of pigeon pea, as well as the maize. Both vegetative and yield parameters were taken and recorded. Below are the data that were taken;

a. Plant height at 50% flowering
b. Plant girth at 50% flowering
c. Number of flowers at 50% flowering
d. Shoot and root dry weight at harvest

e. Number of leaves per plant at harvest

f. Number of fruiting branches per plant at harvest

g. Number of nodules and nodule dry weight

3.6 Plant analysis

Prior to the laboratory analyses, soil and EFB ash samples were air dried and sieved with a 2 mm sieve. Plant samples were oven dried at 70^{o}C for 48 hours, the shoot dry weigh was taken and the plant samples were milled and analysed for pH, N, P, K, Mg, Ca, and organic matter.

3.6.1 Determination of plant nitrogen and amount of Nitrogen fixed

Total nitrogen in the plant samples were determined by the acid digestion Kjeldahl method. One–tenth gram (0.1 g) of milled plant sample was weighed into a 250 mL Kjedahl flask and a tablet of digestion accelerator (selenium catalyst), was added followed by 5 mL concentrated sulphuric acid. The mixture was digested until the digest became clear. The flask was then cooled and its content transferred into a 100 mL volumetric flask with distilled water and quantitatively made up to volume. A 5 mL aliquot of the digest was taken into a Markhan distillation apparatus. Five millilitres (5 mL) of 40% NaOH solution was added to the aliquot and the mixture distilled. The distillate was collected in 5 mL of 2% boric acid solution. Three drops of a mixed indicator containing methyl red and methylene blue were added to the distillate in a 50 mL Erlenmeyer flask and then titrated against 0.01M HCl acid solution (Bremner, 1965). The percent nitrogen was calculated from the titre value.

The amount of nitrogen fixed was calculated using the total N–difference method. In this method, the nitrogen content in the maize samples was subtracted from the total amount in the pigeonpea samples (shoot and grains) and expressed as a percentage using the formula:

$$\%\text{N from } N_2 - \text{fixation} = \frac{(N_{legume} - N_{maize})}{N_{legume}} \times 100 \qquad [3.6]$$

3.6.2 Determination of Plant Total Phosphorus

Five millilitres (5 mL) aliquot of the digest (described in section 3.6.1 above) was taken into a 50 mL volumetric flask in duplicates. The pH was adjusted using P–nitrophenol indicator and neutralized with a few drops of 4M NH_4OH until the solution turned yellow. Eight millilitres (8 mL) of reagent B; prepared by dissolving 1.056 g of ascorbic acid in 200 mL of reagent A [12 g of ammonium molybdate + 0.2998 g of antimony potassium tartrate dissolved in 250 mL of distilled water. The dissolved reagents were added to 1000 mL 0f 2.5M H_2SO_4 (148 mL of conc. H_2SO_4), mixed thoroughly and made to the 2000 mL mark (Watanabe & Olsen, 1965). The solutions were mixed thoroughly by shaking and allowing to stand for 15 minutes for the colour to stabilize. The colour changed to blue of different shades depending on the concentration of phosphorus available in the soil. A blank was prepared with distilled water and 8 mL of reagent B. The spectrophotometer was calibrated using 25 mg L^{-1} standard P solution prepared in the same manner as above. The total P was determined on a spectronic 20 at 882 Um (Murphy and Riley, 1962).

3.6.3 Determination of Potassium, Magnesium and Calcium

Exchangeable K in the digest (described in section 3.6.1 above) was determined by aspirating directly into Jenway flame photometer (PFP7). Calcium and Mg in the extract was determined using the Atomic Absorption Spectrometer (AAS). All parameters determined were expressed in percentages.

3.7 Statistical analysis

Data collected were subjected to analysis of variance (ANOVA), using Genstat statistical package (version 9), and where significant differences were observed, the least significance difference (LSD) test at 5% probability level was used to compare the treatment means

CHAPTER FOUR

4.0 RESULTS

4.1 Experiment I: FIELD EXPERIMENT

4.1.1 Selected chemical and physical properties of the soil at the experimental site.

The initial soil chemical properties of the experiment are presented in Table 4.1. The pH value of the soil indicated that the soil at the experimental site was strongly acidic, high in N and exchangeable K and moderately high in Mg. Exchangeable Ca was low at the experimental site. The pH of 5.09 of the soil at the start of the experiment suggests the soil moderately acidic. The soil texture was silty loam.

Table 4.1: Some chemical and physical properties of the soil at the experimental site.

Property	**Level**
pH_w (1:1 H_2O)	5.09
Organic matter (%)	4.20
Total N (%)	0.24
Available P (mg kg^{-1})	6.81
Particle size (%)	
Sand	36
Silt	53
Clay	11
Exchangeable Cations (meq/100 g soil)	
K^+	1.00
Ca^{2+}	3.56
Mg^{2+}	1.32

4.1.2 Chemical properties of Palm bunch ash (PBA) used in the experiment

The chemical properties of PBA used in the experiment are presented in Table 4.2. Palm bunch ash was alkaline (pH of 10.89) and contained relatively high values of K, Ca, P and Mg but a low value of N. The high pH of the PBA and high values of the exchangeable cations justifies the use of PBA as liming material for acidic soils and also as source of nutrients for plants.

Table 4.2: Chemical properties of the Palm bunch ash (PBA) used in the experiment.

Property	Level
pH_w (1:1.25 H_2O)	10.89
Organic Carbon (%)	0.55
Total N (%)	0.08
Available P (ppm)	269.57
Exchangeable Cations (meq/100 g soil)	
K^+	582.77
Ca^{2+}	34.93
Mg^{2+}	29.08

4.2 Effects of variety and fertilizer on Growth Parameters of three pigeonpea varieties

4.2.1 Effects of fertilizer on plant height of three pigeonpea varieties at flowering

There were no significant differences in plant height among the three varieties used (Appendix 1). Similarly, plant height was not significantly ($p \geq 0.05$) influenced by the application of fertilizer. Even though the results showed no significant differences in plant height, PBA treated plants had a plant height 123.6 cm, while the control had a height of

121.1 cm. Likewise the interaction between the variety and the treatments was not significant (Appendix 1).

4.2.2 Effects of fertilization on plant girth of three pigeonpea varieties at flowering

Plant girth at flowering was significantly influenced by variety and fertilizer application (Appendix 2). Plant girth for the three pigeonpea varieties ranged from 1.3 cm for ICPL 88039 to 1.6 cm for ICPL 87091. However, there was no significant difference between ICPL 88034 and ICPL 88039 (Table 4.3).

Fertilizer application affected the plant girth significantly ($p \leq 0.05$) (Appendix 2). Plant girth ranged between 1.18cm and 1.59cm (Table 4.3). Interaction between the variety and fertilizer application with respect to plant girth was not significant.

Table 4.3a: Plant girth (cm) of three pigeonpea varieties at flowering stage.

Variety	**Plant girth (cm) at flowering**
ICPL 87091	**1.6**
ICPL 88034	**1.3**
ICPL 88039	**1.3**

LSD (0.05); Variety: 0.162

Table 4.3b: Effects of fertilizer on plant girth (cm) of three pigeonpea varieties at flowering.

Fertilizer	Plant girth (cm) at flowering
Control	1.2
PBA	1.6
PK	1.4

LSD (0.05); Fertilizer: 0.209

4.2.3 Effects of fertilizer on shoot and root dry weight of three pigeonpea varieties at flowering.

The results of the effect of variety and fertilization on shoot dry weight indicated that there were no significant differences in the shoot dry weights of the three pigeonpea varieties that were used in this experiment (Appendix 3). Also, amendment of the soil with fertilizer did not result in any significant differences in shoot dry weight (Appendix 3). The interaction between the variety and the fertilizer was not significant (Appendix 3).

Root dry weight as affected by pigeonpea variety and fertilizer application were not significantly different (Appendix 4). There were no significant ($p \leq 0.05$) differences between the three pigeon pea varieties with respect to root dry weight. The weight ranged between 3.14g to 6.06g. Root dry weight of the pigeon pea plants was not significantly ($p \leq 0.05$) affected by fertilization. The weight recorded ranged from 4.28g to 5.69g. The variety by fertilizer interaction was also not significant with respect to root dry weight (Appendix 4).

4.2.4 Effects of fertilizer on total dry weight of three pigeonpea varieties at flowering.

The results of the effect of variety and fertilization on the total dry weight per plant (g) showed that, there was no significant difference among the three varieties (Appendix 5). The highest total dry weight was however obtained by variety ICPL 87091 (51 g), while the lowest total dry weight was given by the variety ICPL 88039 (30 g). Total dry weight of the pigeonpea varieties was also not significantly ($p \leq 0.05$) influenced by fertilization. The PBA treated plots however recorded the highest total dry weight per plant (49 g) and the least (38 g) was recorded by the control plants. The interaction between the fertilizer application and pigeonpea varieties was also not significant (Appendix 5).

4.2.5 Effects of fertilizer on total above ground dry weight of three pigeonpea varieties at flowering

The application of fertilizer did not result in any significant differences in the total above ground dry weight of the pigeonpea (Appendix 6). Similarly, the interaction between the fertilizer application and the varieties was not significant (Appendix 6). However there were significant differences in the total above ground dry weight of the three varieties of pigeonpea that were evaluated.. Variety ICPL 87091 gave the highest (0.96 t ha^{-1}) total above ground dry weight and ICPL 88039 recorded the least (0.62 t ha^{-1}) total above ground dry weight (Table 4.4).

Table 4.4: Total above ground dry weight of three pigeonpea varieties at flowering stage.

Variety	Total above ground dry weight (t ha^{-1})
ICPL 87091	0.97
ICPL 88034	0.90
ICPL 88039	0.62

LSD (0.05); Variety: 0.28300

4.2.6 Effects of fertilizer on number of leaves and number of flowers of three pigeonpea varieties at flowering.

The number of leaves produced by pigeonpea was not significantly affected by varietal differences, fertilization and the interaction between variety and fertilizer (Appendix 7). The number of leaves as affected by varieties ranged from 344 leaves per plant to 403 leaves per plant. Number of leaves per plant, as affected by fertilization ranged from 333 leaves per plant to 386 leaves per plant. The interaction between fertilizer application and pigeon pea variety in terms of leaf production was not significant ($p \leq 0.05$).

The number of flowers per plant as affected by variety and fertilization was not significantly different (Appendix 8). Number of flowers among the fertilizer treatments ranged from 55 flowers per plant to 72 flowers per plant.

4.2.7 Effects of fertilizer on number of fruiting branches of three pigeonpea varieties at flowering.

Based on the analysis of the results obtained, varietal differences, fertilization and the interaction between variety and fertilizer did not significantly affect the number of fruiting branches per plant at flowering stage (Appendix 9). The number of fruiting branches per plant ranged from 7 branches per plant to 16 branches per plant.

4.2.8 Effects of fertilizer on nodule number of three pigeonpea varieties at flowering stage

Table 4.5a indicates that the least number of nodules per plant was produced by variety ICPL 87091 (26) nodules, which was significantly less than that of ICPL 88039 which produced the highest (37) nodules.

The number of nodules per plant was also significantly ($p \leq 0.05$) affected by the various fertilization treatments (Table 4.5b). Among the three treatments, PBA application resulted in the highest number of nodules per plant (41 nodules), which was significantly ($p \leq 0.05$) different from PK amended plots (37 nodules) and those in the control treatment (22 nodules).

Table 4.5a: Number of nodules of three pigeonpea varieties at flowering stage.

Variety	Nodule number per plant at flowering
ICPL 87091	26
ICPL 88034	36
ICPL 88039	37

LSD (0.05); Variety: 2.1

Table 4.5b: Effects of fertilizer on number of nodules of pigeonpea at flowering stage.

Fertilizer	Nodule number per plant at flowering
Control	22
PBA	41
PK	37

LSD (0.05); Variety: 3.1

4.2.9 Effects of variety and fertilizer on nodule dry weight per plant at flowering stage

Table 4.6a and Table 4.6b show the results of the effect of variety and fertilization on nodule dry weight per plant at flowering. There were significant differences ($p \leq 0.05$) in the nodule dry weight per plant among the three varieties of pigeonpea (Appendix 11). Variety ICPL 88039 gave the significantly highest ($p \leq 0.05$) nodule dry weight per plant (0.97 g), and the least by ICPL 87091 (0.68 g).

Fertilization also resulted in significant ($p \leq 0.05$) differences in nodule dry weight per plant of the three pigeonpea varieties at flowering stage (Appendix 11). The highest nodule dry weight per plant was recorded by the PBA treatment (1.16 g), followed by PK–treated plants (0.94 g), and the least was recorded by the control plants (0.47 g). The interactive effect of variety and the fertilization was not significant (Appendix 11).

Table 4.6a: Nodule dry weight of three pigeonpea varieties at flowering stage.

Variety	**Nodule dry weight (g) per plant**
ICPL 87091	0.68
ICPL 88034	0.93
ICPL 88039	0.97

LSD (0.05); Variety: 0.0816

Table 4.6b: Effects of fertilizer on nodule dry weight of three pigeonpea varieties at flowering stage.

Fertilizer	**Nodule dry weight (g) per plant**
Control	0.47
PBA	1.16
PK	0.94

LSD (0.05); Fertilizer: 0.1008

4.2.10 Effects of variety and fertilization on number of days to 50% flowering (DAP)

The number of days to 50% flowering was not significantly affected by varietal differences, fertilization and the interaction between variety and fertilizer (Appendix 12). The number of days to 50% flowering ranged from 81days to 83 days.

4.2.11 Effects of variety and fertilizer on number of days from planting to first harvest

The varieties did not significantly affect the number of days from planting to first harvest (Appendix 14). The fertilizer and variety interaction was also not significant ($p \leq 0.05$).

However, fertilization had a significant ($p < 0.05$) effect on the number for days from flowering to first harvest. The results shown in Table 4.7 indicates that PBA–treated plants recorded the least number of days from planting to first harvest (121 days), whiles PK–treated and control plants recorded 123 and 125 days respectively.

Table 4.7: Effects of fertilizer on number of days from planting to first harvest of three pigeonpea varieties.

Fertilizer	Number of days from planting to first harvest
Control	125
PBA	121
PK	123

LSD (0.05); Variety: 2.1

4.2.12 Effects of variety and fertilizer on number of days from flowering to harvest

Fertilization of the pigeonpea had a significant effect on the number of days from flowering to harvest (Appendix 13). However, varietal differences and the interaction of variety and fertilizer both did not result in any significant effect on the numbers of days from flowering to harvest (Appendix 13).

The results presented in Table 4.8 shows that, pods from PBA–treated plants matured earlier (39 days), compared to that of PK fertilizer treated plants (41 days) and the control treatment (42 days).

Table 4.8: Effects of fertilizer treatment on number of days from flowering to harvest of three pigeonpea varieties.

Fertilizer	Number of days from flowering to harvest
Control	42
PBA	39
PK	41

LSD (0.05); Variety: 1.5

4.3 Plant nutrient analyses

4.3.1 Effects of variety and fertilization on plant nitrogen content at flowering

Table 4.9 shows the results of the effect of variety and fertilization on plant tissue N at flowering stage. The interactive effect of variety and fertilizer application was significant ($p < 0.05$) (Appendix 15). ICPL 88039 gave the least amount of plant nitrogen (1.18%) under the control experiment, while ICPL 87091 and ICPL 88034 gave 1.30% and 1.33% respectively. In the plots that were treated with PK, ICPL 87081 gave the least amount of plant nitrogen (1.65%), while ICPL 88034 and ICPL 88039 gave 1.74% and 1.99% respectively. The highest amount of plant nitrogenwas given by plant that were treated with PBA. ICPL 88039, ICPL 87091 and ICPL 88034 gave 2.72%, 2.75% and 3.05% respectively. Similarly, fertilizer application also had a significant effect on the plant tissue N content at flowering. However, varietal differences did not result in significant differences in plant tissue N content at flowering stage (Appendix 15). The results in Table 4.9 indicate that plants from plots amended with PBA gave the highest N content (2.84 %) whiles the plants from PK–treated and control plots resulted in N concentrations of 1.79% and 1.27% respectively.

Table 4.9: Effects of variety and fertilizer on plant nitrogen (%) content at flowering.

Variety	**Fertilizer**			
	Control	PBA	PK	Mean
87091	1.30	2.75	1.65	1.90
88034	1.33	3.05	1.74	2.04
88039	1.18	2.72	1.99	1.96
Mean	**1.27**	**2.84**	**1.79**	

Lsd (0.05); Fertilizer: 0.135 Variety × Fertilizer: 0.261

4.3.2 Effects of variety and fertilizer on plant phosphorus content at flowering

Table 4.10 shows the results of the effect of variety and fertilization on plant phosphorus content at flowering. The interactive effect of varietal differences and fertilization significantly affected the plant tissue P content (Appendix 16).

Also varietal differences and fertilization significantly affected the plant P levels (Appendix 16). Among the varieties, ICPL 87091 gave the highest plant P composition (0.37%), followed by ICPL 88039 (0.36%) and ICPL 88034 (0.33%). PBA application significantly ($p \leq 0.05$) increased the plant P composition and gave the highest plant P (0.47%) compared to PK (0.38%) and the Control (0.21%) plants respectively (Table 4.10).

Table 4.10: Effects of fertilization on tissue phosphorus content (%) of three pigeonpea varieties at flowering.

Variety	Fertilizer			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	0.26	0.48	0.37	**0.37**
ICPL 88034	0.12	0.47	0.38	**0.33**
ICPL 88039	0.25	0.55	0.39	**0.36**
Mean	**0.21**	**0.47**	**0.38**	

Lsd (0.05); Variety: 0.0280 Fertilizer: 0.0195 Variety × Fertilizer: 0.0362

4.3.3 Effects of variety and fertilizer on plant potassium content at flowering

Varietal differences and fertilization independently had a significant effect on the plant K content at flowering stage (Appendix 17). Table 4.11 shows that among the three varieties, ICPL 87091 produced significantly ($p \leq 0.05$) the highest K content (1.45%) with ICPL 88039 giving the least (1.32%). Table 4.11 also indicates that plants from plots amended with PBA gave significantly ($p \leq 0.05$) higher plant K content (1.53%) compared with plants that received PK (1.34%) and plants in the control (1.30%) plots. The interaction of variety and fertilizer treatment did not had any significant effect on the plant K content at flowering stage (Appendix 17).

Table 4.11a: Effects of variety on plant potassium content at flowering.

Variety	Plant potassium content (%)
ICPL 87091	1.45
ICPL 88034	1.41
ICPL 88039	1.32

Lsd (0.05); Variety: 0.027

Table 4.11b: Effects of fertilizer on plant potassium content at flowering.

Treatment	Plant potassium content (%)
Control	1.30
PBA	1.53
PK	1.34

Lsd (0.05); Fertilizer: 0.038

4.3.4 Effects of variety and fertilizer on plant magnesium content at flowering

The results of the effect of variety and fertilization on plant Mg content at flowering are presented in Table 4.12. The interaction of variety and fertilizer had a significant effect on the plant Mg content (Appendix 18). Fertilization independently also had a significant ($p \leq 0.05$) effect on the Mg content of the pigeonpea plants. As indicated in Table 4.12, all the three varieties recorded the highest plant Mg content in plots amended with PBA, followed by plants from PK–amended plots and the control plant being the least. Plants from PBA–

amended plots gave the significantly highest Mg level (0.34 %) compared to PK (0.28%) and the control (0.27%).

Table 4.12: Effects of variety and fertilizer on plant magnesium content at flowering.

Variety	Fertilizer			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	0.27	0.33	0.28	0.29
ICPL 88034	0.28	0.33	0.28	0.30
ICPL 88039	0.27	0.35	0.28	0.30
Mean	**0.27**	**0.34**	**0.28**	

Lsd (0.05); Variety: 0.017 Fertilizer: 0.007 Variety × Fertilizer: 0.019

4.3.5 Effects of variety and fertilizer on plant calcium content at flowering

The results of the effect of variety and fertilization on plant Ca content are presented in Table 4.13). There were significant ($p \leq 0.05$) differences in the Ca levels among the varieties and the treatments applied. ICPL 87091 gave the highest Ca content (0.62%), followed by ICPL 88034 (0.57%) and ICPL 88039 (0.57%). Similarly plants from PBA–treated plots had the highest Ca content (0.68%) compared to PK (0.58%) and the Control (0.51%) The interaction between the fertilizer application and the varieties had a significant ($p \leq 0.05$) effect on the Ca content of the pigeonpea plants (Appendix 19).

Table 4.13: Effects of variety and fertilizer on plant calcium content (%) at flowering.

Variety	Fertilizer			
	Control	PBA	PK	Mean
ICPL 87091	0.53	0.75	0.58	**0.62**
ICPL 88034	0.46	0.64	0.62	**0.57**
ICPL 88039	0.53	0.64	0.54	**0.57**
Mean	**0.51**	**0.68**	**0.58**	

LSD (0.05); Variety: 0.005 Fertilizer: 0.016 Variety × Fertilizer: 0.023

4.3.6 Nitrogen fixation in pigeonpea as affected by varietal differences and fertilizer

The percentage of nitrogen fixed in pigeonpea as affected by variety and fertilization is shown in Table 4.14. The interaction of variety and fertilizer had a significant effect on the percentage of nitrogen fixed in pigeonpea, with all the three varieties fixing higher amount of nitrogen in plots treated with PBA (62.89%,63.07% and 66.59% for ICPL 88039, ICPL 97091 and ICPL 88034 respectively). Plots treated with PK gave 38.30% for ICPL 87091, 41.74% for ICPL 88034 and 48.76% for 88039. The control plots fixed the least amount of nitrogen with ICPL 88039 fixing 14.59%, ICPL 87091 fixing 22.35% and ICPL 88034 fixing 23.84%. . Similarly, the fertilizer amendments also had a significant effect on the percentage of nitrogen fixed. However, varietal differences alone did not have any significant effect on the percentage of nitrogen fixed in pigeonpea (Appendix 20).

Table 4.14: Percent N fixation by three pigeonpea varieties as affected by varietal differences and fertilizer.

Variety	Fertilizer			
	Control	PBA	PK	Mean
ICPL 87091	22.35	63.07	38.30	41.24
ICPL 88034	23.83	66.59	41.74	44.05
ICPL 88039	14.59	62.89	48.76	42.08
Mean	**20.26**	**64.18**	**42.94**	

Lsd (0.05); Variety: 5.220 Fertilizer: 3.061 Variety × Fertilizer: 6.247.

4.4 Yield and yield parameters from the Field experiment.

4.4.1 Effects of variety and fertilization on weight of 100 grains

Table 4.15 shows the results of the effect of variety and fertilizer application on weight (g) of 100 grains of pigeonpea grown under field conditions. Analysis of the data showed that fertilization alone and the interaction between variety and fertilizer did not have any significant effect on the weight of 100 grains of pigeonpea (Appendix 21). However, varietal differences had a significant effect on the weight of 100 grains of pigeonpea (Appendix 21). Among the varieties, grains from ICPL 87091 (12.08 g) weighed more than grains from ICPL 88034 (10.17 g) and ICPL 88039 (10.08 g) (Table 4.15).

Table 4.15: Effects of varietal differences on weight of 100 grains of pigeonpea.

Variety	Weight of 100 grains (g)
ICPL 87091	12.08
ICPL 88034	10.17
ICPL 88039	10.08

Lsd (0.05); Variety: 0.419

4.4.2 Effects of variety and fertilizer on total grain yield per hectare

Table 4.16 show the results of the effect of variety and fertilization on total grain yield per hectare of three pigeonpea varieties. There were significant differences ($p \leq 0.05$) in grain yield among the three varieties during the second season harvest (Appendix 23). Variety ICPL 88034 gave the highest grain yield (0.99 t ha^{-1}), followed by ICPL 88039 (0.72 t ha^{-1}) and ICPL 87091 (0.26 t ha^{-1}) respectively (Table 4.16). Similarly, there were significant differences ($p \leq 0.05$) in grain yield among the various treatments during the second season harvest (Appendix 23). The results presented in Table 4.16b indicates that the highest grain yield was produced by PBA–treated plants (0.76 t ha^{-1}) followed by PK–treated plants (0.72 t ha^{-1}) and the least was produced by plants from the control plots (0.49 t ha^{-1}).

Table 4.16a: Total grain yield of three pigeonpea varieties

Variety	Total grain yield (t ha^{-1})
ICPL 87091	0.26
ICPL 88034	0.99
ICPL 88039	0.72

Lsd (0.05); Variety: 0.488

Table 4.16b: Effects of fertilizer on total grain yield of pigeonpea

Fertilizer	Total grain yield (t ha^{-1})
Control	0.49
PBA	0.76
PK	0.72

Lsd (0.05); Treatment: 0.157

4.4.3 Effects of variety and fertilizer on total grain yield per hectare

Analysis of the results of the total grain yield per hectare for both seasons showed that there were no significant differences among the varieties (Appendix 24). Thus varietal differences, fertilization and the interaction of variety and fertilizer did not have any significant effect on the total grain yield per hectare. There were no significant differences ($p \geq 0.05$) in grain yield among the three varieties. The grain yield ranged from 1.13 t ha^{-1} to 1.82 t ha^{-1}

Fertilizer application did not result in any significant difference ($p \geq 0.05$) in the grain yield of the pigeonpea plants in both seasons. The grain yield, as affected by fertilizer treatment ranged from 1.32 t ha^{-1} to 1.76 t ha^{-1}.

4.4.4 Effects of variety and fertilizer on total grain dry matter, stover dry matter, litter dry matter, total dry matter and harvest index

Tables 4.17a to Table 4.17d shows the results of the effects of variety and fertilization on stover dry matter, litter dry matter and total dry matter and harvest index. There were no significant ($p \leq 0.05$) differences in the total grain dry matter (DM) among the different pigeonpea varieties (Appendix 25). Total grain dry matter ranged from 1.13 t ha^{-1} to 1.82 t ha^{-1}. Total grain DM was also not significantly influenced by fertilization and ranged between 1.32 t ha^{-1} and 1.76 t ha^{-1} .

Stover dry matter was significantly ($p \leq 0.05$) affected by the varietal differences of pigeonpea that were used (Appendix 26). Stover dry matter ranged from 0.623 t ha^{-1} with variety ICPL 88039 to 0.967 t ha^{-1} with ICPL 80791 (Table 4.17b).

The results also indicated that there were significant ($p \leq 0.05$) differences among the varieties in terms of litter dry matter. The litter DM for the different pigeonpea varieties were significantly different from each other, and gave 0.62 t ha^{-1}, 0.91 t ha^{-1} and 1.80 t ha^{-1} for the varieties ICPL 88039, ICPL 88034 and ICPL 87091 respectively (Table 4.17a).

Significant differences existed among the fertilizer in terms of total dry matter, but there no significant differences with regards to the varieties. There were no significant differences among the interaction of the variety and treatment (Appendix 27). Total dry matter yields were 3.023 t ha^{-1}, 3.448 t ha^{-1} and 3.903 t ha^{-1} in the control, PK, and PBA treatments respectively (Table 4.17c).

There were significant ($p \leq 0.05$) differences among the varieties of pigeonpea with respect to harvest index (Appendix 28). Harvest index for the different varieties were 0.54 with the variety ICPL 87091, 0.66 for ICPL 88034, and 0.71 for the variety ICPL 88039 (Table

4.17d). Harvest index did not significantly differ among the different fertilizer treatments. Similarly, the interaction of variety and fertilizer treatment was not significant for harvest index (Appendix 28).

Table 4.17a: Effects of varietal differences on Litter Dry Matter.

Variety	**Litter Dry Matter (t ha^{-1})**
ICPL 87091	1.80
ICPL 88034	0.91
ICPL 88039	0.62

Lsd (0.05); Variety: 0.418

Table 4.17b: Effects of varietal differences on Stover Dry Matter.

Variety	**Stover Dry Matter (t ha^{-1})**
ICPL 87091	0.97
ICPL 88034	0.90
ICPL 88039	0.62

Lsd (0.05); Variety: 0.283

Table 4.17c: Effects of fertilizer treatments on Total Dry Matter.

Variety	**Total Dry Matter (t ha^{-1})**
PBA	3.90
PK	3.45
Control	3.02

Lsd (0.05); Fertilizer: 0.603

Table 4.17d: Effects of varietal differences on Harvest Index of pigeonpea.

Variety	**Harvest Index (%)**
ICPL 87091	0.54
ICPL 88034	0.66
ICPL 88039	0.71

Lsd (0.05); Variety: 0.103

4.5.1 Effect of variety and fertilizer on soil pH

Varietal differences and the interaction between variety and fertilizer did not significantly affect the pH of the soil after 280 days (Appendix 29). However application of fertilizer alone significantly ($p \leq 0.05$) affected soil pH. The results of the effect of fertilization on soil pH are presented in Table 4.18. Among the various fertilizer treatments, PBA application resulted in highest pH value (5.82), compared with PK (5.19) and the control (5.14).

Table 4.18: Effect of fertilizer on soil pH after 280 days of fertilizer application.

Fertilizer	Soil pH
Control	5.14
PBA	5.82
PK	5.19

Lsd (0.05); Variety: 0.048

4.5.2 Effect of variety and fertilizer on soil total nitrogen content

Table 4.19 shows the results of the effect of variety and fertilization on soil total nitrogen after 280 days of application. There were significant differences ($p \leq 0.05$) among the fertilizer treatments with regards to soil N concentration at the time of sampling (280 days after fertilizer application). Among the three fertilizer treatments, PBA application resulted in the highest (0.399 %) soil N concentration, followed by the PK treatment (0.332 %) and the least soil total N concentration by the control treatment (0.273 %). Varietal differences did not have any significant effect ($p \geq 0.05$) effect on soil N concentration (Appendix 30).

The interactive effect of variety and fertilizer had a significant effect on the soil N content (Appendix 30). For all varieties, plots treated with PBA recorded the highest soil N (Table

4.19). However, fields treated with PBA and planted with ICPL 87091 recorded the highest (0.429%) soil N.

Table 4.19: Effect of variety and fertilizer on soil nitrogen (%) content.

Variety	Treatments		
	Control	**PBA**	**PK**
ICPL 87091	0.28	0.43	0.32
ICPL 88034	0.29	0.38	0.34
ICPL 88039	0.25	0.39	0.33
Mean	**0.27**	**0.40**	**0.33**

Lsd (0.05); Fertilizer: 0.015 Variety × Fertilizer: 0.029

4.5.3 Effect of variety and fertilizer on soil available phosphorus concentration

The results of the independent effect of variety and fertilization on soil available phosphorus are presented in Table 4.20. Soil available phosphorus was not significantly ($p > 0.05$) affected by the interaction of variety and fertilizer treatments (Appendix 31). Among the pigeonpea varieties, it was observed that significant ($p \leq 0.05$) differences existed in the soil P concentration. The soil under variety ICPL 88039 had significantly ($p \leq 0.05$) the highest soil P content (10.67 ppm) (Table 4.20). The second significantly ($p \leq 0.05$) highest soil P content was given by ICPL 88034 (10.26ppm), and the least was given by ICPL 87091 (8.11 ppm) . Soil P content was significantly ($p \leq 0.05$) affected by the fertilizer. PK fertilizer gave the significantly ($p \leq 0.05$) highest P content (11.39 ppm), while PBA treated plots gave 11.18ppm , and the significantly ($p \leq 0.05$) least P content given by soils in the control plots.

Table 4.20a: Effect of variety on soil available phosphorus concentration.

Variety	Phosphorus concentration (ppm)
ICPL 87091	8.11
ICPL 88034	10.26
ICPL 88039	10.67

Lsd (0.05); Variety: 1.068

Table 4.20b: Effect of fertilizer on soil available phosphorus concentration

Fertilizer	Phosphorus concentration (ppm)
Control	6.47
PBA	11.18
PK	11.39

Lsd (0.05); Fertilizer: 1.321

4.5.4 Effect of variety and fertilizer on soil potassium concentration

The results of the effect of variety and fertilization on soil exchangeable potassium are presented in Table 4.21. There were significant ($p \leq 0.05$) differences among the interaction between fertilizer treatments and the pigeonpea varieties. The significantly highest soil K content(1.28 meq/100g) was given by ICPL 87091 under PBA treatment. The second significantly highest K content (1.25 meq/100g) was given by ICPL 87091 under PK treated plots, and the significantly lowest P content (0.84 meq/100 g was given by ICPL 87091 in the control plots. There were significant differences among the fertilizer treatments with respect to K concentration (Appendix 32). PBA–treated soils were found to have given the significantly highest K concentration (1.17meq/100 g) , followed by PK-treated plots, and the least was recorded by those in the control (0.94 meq/100 g). There were significant ($p \leq 0.05$) differences among the varieties in terms of K concentration. Plots with ICPL 87091 gave the highest soil K content (1.13 meq/100 g), while plots with ICPL 88034 and ICPL 88039 gave 1.05 meq/100g each.

Table 4.21: Effect of variety and fertilizer on soil potassium concentration (meq/100 g).

Variety	**Fertilizer**			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	0.84	1.28	1.25	1.13
ICPL 88034	0.96	1.14	1.06	1.05
ICPL 88039	1.01	1.10	1.06	1.05
Mean	**0.94**	**1.17**	**1.12**	

LSD (0.05); variety: 0.038 Fertilizer : 0.065 Variety × Treatment: 0.097

4.5.5 Effect of variety and fertilizer on soil magnesium concentration

Table 4.22 shows the results of the effect of variety and fertilization on soil exchangeable Mg. Soil Mg concentration was significantly ($p \leq 0.05$) different among the varieties, fertilizer treatments and interaction of variety and fertilizer (Appendix 33). PBA–treated plots gave the highest concentration of Mg (3.47 meq/100 g), followed by PK (2.54 meq/100 g) and control plots (1.52 meq/100 g). There were significant ($p \leq 0.05$) differences in the soil Mg content as a result of the interactive effect of variety and treatment, with PBA–treated fields recording higher soil Mg for all varieties (Table 4.22).

Table 4.22: Effect of variety and fertilizer on soil magnesium concentration (meq/100 g).

Variety	**Fertilizer**			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	1.79	3.46	2.75	**2.67**
ICPL 88034	1.41	3.52	2.38	**2.44**
ICPL 88039	1.37	3.44	2.50	**2.43**
Mean	**1.52**	**3.47**	**2.54**	

LSD (0.05); Variety: 0.060 Fertilizer: 0.073 Variety × Fertilizer: 0.114

4.5.6 Effect of variety and fertilizer on soil exchangeable calcium concentration

Table 4.23 shows the results of the effect of variety and fertilization on soil exchangeable calcium content. The results show that the interaction between the pigeonpea varieties and the fertilizer treatments was significantly ($p \leq 0.05$) different for soil Ca concentration. The significantly highest soil Ca content (4.14 meq/100g) was given by ICPL 87091 under PBA treatment. The second significantly highest Ca content (4.08 meq/100g) was given by ICPL 88034 under PK treated plots, and the significantly lowest Ca content (2.95 meq/100 g) was given by ICPL 88039 in the control plots. The Ca concentration among the varieties was significantly ($p \leq 0.05$) different from each other (Appendix 34). Plots planted with variety ICPL 88034 gave the highest Ca value (3.58 meq/100 g), compared to ICPL 87091 (3.48 meq/100 g) and ICPL 88039 (3.35 meq/100 g). There were also significant ($p \leq 0.05$) differences in Ca concentration among the fertilizer applications. The highest Ca concentration was recorded in soil from fields amended with PBA (4.03 meq/100 g), followed by those amended with PK (3.30 meq/100g) and the least was found in the plots with control treatments (3.07 meq/100g).

Table 4.23: Effect of variety and fertilizer on soil calcium concentration (meq/100 g).

Variety	Fertilizer			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	3.10	4.14	3.20	**3.48**
ICPL 88034	3.16	4.08	3.49	**3.58**
ICPL 88039	2.95	3.88	3.22	**3.35**
Mean	**3.07**	**4.03**	**3.30**	

LSD (0.05); Variety: 0.126 Fertilizer: 0.089 Variety × Fertilizer: 0.164

4.5.7 Effect of variety and fertilizer on soil organic matter content

Soil Organic Matter (OM) was significantly influenced by fertiliser application but was not affected by the varieties of pigeonpea (Appendix 35). The results show that the interaction between the pigeonpea varieties and the fertilizer treatments was significantly ($p \leq 0.05$) different for soil OM content. The significantly highest soil OM content (2.70%) was given by ICPL 88034 under PBA treatment. The second significantly highest soil OM content (2.64%) was given by ICPL 88039 under PBA treated plots, and the significantly lowest soil OM content (2.25%) was given by ICPL 88039 in the control plots. Soil OM content was significantly affected by fertilizer treatments. PBA- treated soils gave the highest (2.47%) OM content, followed by PK- treated plots (2.46%) and the least was given by the control plots (2.29%). The varieties did not give any significant difference with regards to soil OM. The soil OM content of the varieties ranged from 2.44%

Table 4.24: Effect of variety and fertilizer on soil organic matter (%) OM.

Variety	**Fertilizer**			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	2.31	2.61	2.40	2.44
ICPL 88034	2.31	2.70	2.41	2.47
ICPL 88039	2.25	2.64	2.49	2.46
Mean	**2.29**	**2.47**	**2.46**	

LSD (0.05): Fertilizer: 0.035 Variety × Fertilizer: 0.058

4.6 Experiment II: Pot experiment

4.6.1 Soil Nutrient composition

Table 4.25: Chemical properties of the soil used for the Pot Experiment.

Soil Property	**Level**
pH_w	5.05
Total N (%)	0.26
Available P (ppm)	7.49
Organic matter (%)	4.4
Exchangeable Cations (meq/100 g soil)	
K^+	0.44
Ca^{++}	3.14
Mg^{++}	4.31

4.6.2 Effect of variety and fertilizer on soil nitrogen concentration

Table 4.26 shows the results of the effect of variety and fertilization on total soil nitrogen content. There were significant ($p \leq 0.05$) differences in the soil nitrogen content among the varieties, fertilizer treatments and the interaction of variety and fertilizer (Appendix 36). The significantly highest soil N content (0.42%) was given by ICPL 87091 under PBA treatment. The second significantly highest soil N content (0.37%) was given by ICPL 87091 under PK treated plots, and the significantly lowest soil N content (0.28%) was given by ICPL 88034 and ICPL 88039 in the control plots. There were significant differences ($p \leq 0.05$) among the fertilizer applications with regards to soil N content at 157 Days after fertilizer application (Appendix 36). PBA application gave the highest (0.37 %) soil N concentration, followed by the PK fertilizer treatment (0.36 %) and the least soil N concentration was recorded in the control plots (0.29 %).

Varietal differences also resulted in significant differences in the soil N content after 157 days of planting, with soils from pots planted with ICPL 87091 recording the highest (0.36%) N content., followed by ICPL 88034 (0.33%) and ICPL 88039 (0.32%)

Table 4.26: Effect of variety and fertilizer on soil Nitrogen concentration (%).

Variety	**Fertilizer**			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	0.31	0.42	0.37	**0.36**
ICPL 88034	0.28	0.36	0.36	**0.33**
ICPL 88039	0.28	0.34	0.35	**0.32**
Mean	**0.28**	**0.37**	**0.36**	

Lsd (0.05); Variety: 0.007 Fertilizer: 0.0059 Variety × Fertilizer: 0.011

4.6.3 Effect of variety and fertilizer on soil available phosphorus concentration

The results show that the interaction between the pigeonpea varieties and the fertilizer treatments was significantly ($p \leq 0.05$) different for soil available P content. The significantly highest soil available P content (9.70 ppm) was given by ICPL 87091 under PBA treatment. The second significantly highest soil available P content (9.09ppm) was given by ICPL 88034 under PBA treated plots, and the significantly lowest soil available P content (7.47ppm) was given by ICPL 88034 in the control plots. Soil available P content was significantly affected by fertilizer application. Plants from plots amended with PBA gave the highest (9.03 ppm) soil P concentration and the least available soil P concentration was recorded in the control plots (7.62 ppm). Plants from the PK- treated plots gave the second significantly highest available soil P (8.24ppm). Significant ($p \leq 0.05$) differences in soil P content was found among the different varieties of pigeonpea. Among the three varieties, the highest P content was attained in variety ICPL 87091 (8.59 ppm), and the least in ICPL 88039 (8.04ppm).

Table 4.27: Effect of variety and fertilizer on soil available phosphorus concentration (ppm).

Variety	**Fertilizer**			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	7.86	9.70	8.21	**8.59**
ICPL 88034	7.47	9.09	8.21	**8.25**
ICPL 88039	7.52	8.29	8.31	**8.04**
Mean	**7.62**	**9.03**	**8.24**	

Lsd (0.05); Variety: 0.008 Fertilizer: 0.035 Variety × Fertilizer: 0.049

4.6.4 Effect of variety and fertilizer on soil exchangeable potassium concentration

The interactive effect of variety and fertilizer and the independent effect of fertilizer resulted in a significant ($p \leq 0.05$) soil exchangeable potassium content (Appendix 38). The significantly highest soil exchangeable K content (1.30 meq/100g) was given by ICPL 87091 under PBA treatment. The second significantly highest soil exchangeable K content (1.29 meq/100g) was given by ICPL 88034 under PBA treated plots, and the significantly lowest soil exchangeable K content (1.14 meq/100g) was given by ICPL 88034 and ICPL 88039 in the control plots. PBA–amended soils gave significantly ($p \leq 0.05$) higher K concentration (1.29 meq/100 g), with the second highest given by PK (1.26 meq/100 g), and the least was recorded in the control (1.14 meq/100 g). There were no significant ($p \leq 0.05$) differences among the varieties in terms of soil K concentration.

Table 4.28: Effect of variety and fertilizer on soil exchangeable potassium concentration.

Variety	**Fertilizer**			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	1.15	1.30	1.26	1.24
ICPL 88034	1.14	1.29	1.24	1.22
ICPL 88039	1.14	1.28	1.28	1.23
Mean	**1.14**	**1.29**	**1.26**	

Lsd (0.05); Fertilizer: 0.0109 Variety × Fertilizer: 0.024

4.6.5 Effect of variety and fertilizer on soil exchangeable magnesium concentration

Table 4.29 shows the results of the effect of fertilization on soil exchangeable magnesium content in the soil. There were significant ($p \leq 0.05$) differences among the fertilizer applications in terms of soil Mg concentration (Table 4.29). Plots with PBA application gave significantly higher Mg concentrations compared with the PK and control plots. However varietal differences and the interactive effect of variety and fertilizer were not significant for soil exchangeable Mg (Appendix 39).

Table 4.29: Effect of fertilizer on soil exchangeable magnesium concentration.

Fertilizer	Soil Mg concentration (meq/100 g soil)
Control	2.73
PBA	4.69
PK	3.14

Lsd (0.05); Fertilizer: 0.516

4.6.6 Effect of variety and fertilizer on soil exchangeable calcium content

The results of the effect of variety and fertilization on Ca concentration are presented in Table 4.30. There were significant ($p \leq 0.05$) differences in Ca concentration among the fertilizer treatments (Appendix 40). The highest concentration was attained in soils treated with PBA (4.49 meq/100 g). The results also show that the Ca concentration in the soils under the different varieties of pigeonpea were not significantly ($p \leq 0.05$) different from each other. The interaction between the variety and fertilizer application was however significant in terms of exchangeable calcium contents.

Table 4.30: Effect of variety and fertilizer on soil exchangeable Ca content.

Variety	Fertilizer			
	Control	**PBA**	**PK**	**Mean**
ICPL 87091	4.19	4.61	4.19	4.33
ICPL 88034	4.25	4.41	4.37	4.34
ICPL 88039	4.20	4.44	4.32	4.32
Mean	**4.21**	**4.49**	**4.29**	

Lsd (0.05); Variety: 0.053 Fertilizer: 0.056 Variety × Fertilizer: 0.089

4.6.7 Effect of variety and fertilizer on soil organic matter – Pot Experiment

Soil Organic Matter (OM) was significantly influenced by fertilizer application but was not affected by the varietal differences and the interactive effect of variety and fertilizer (Appendix 41). Soil OM content ranged from 2.65% in the control plots to 3.09% in PBA amended plots. Plots treated with PBA had OM content which was significantly greater than those from the PK and control plots (Table 4.31). The soil OM ranged from 2.80% to 2.85%.

Table 4.31: Effect of fertilizer on soil organic matter content of pigeonpea fields.

Fertilizer	Soil OM Content (%)
Control	2.65
PBA	3.09
PK	2.79

Lsd (0.05); Fertilizer: 0.068

4.7 Plant nutrient analyses (Pot Experiment)

4.7.1 Effect of variety and fertilizer on plant nitrogen content at flowering

The results of the effect of fertilization on plant nitrogen content are presented in Table 4.32. Fertilizer application significantly ($p \leq 0.05$) increased the plant N content. Plants grown on PBA treated plots recorded the highest plant N (2.34%) with the control plots recording the least plant N content of 1.74% (Table 4.32). There were no significant ($p \leq 0.05$) differences among the three varieties, and the interaction between variety and fertilizer was also not significant (Appendix 42).

Table 4.32: Effect of fertilizer on plant nitrogen content at flowering.

Fertilizer	Plant N content (%) at flowering
Control	1.74
PBA	2.34
PK	1.99

Lsd (0.05); Fertilizer: 0.291

4.7.2 Effect of variety and fertilizer on plant phosphorus content at flowering

The results of the effect of fertilization on plant phosphorus content are presented in Table 4.33. Fertilizer application significantly affected plant phosphorus content. PBA application significantly ($p \leq 0.05$) increased the plant P content and gave the highest plant P (0.735%) compared to PK (0.559%) and the Control (0.393%). The differences in phosphorus content among the different varieties were not significant. There were also no significant interactive effect between the varieties and the fertilizer application (Appendix 43).

Table 4.33: Effect of fertilizer on plant phosphorus content.

Fertilizer	Plant P content (%) at flowering
Control	0.39
PBA	0.74
PK	0.56

Lsd (0.05); Fertilizer: 0.067

4.7.3 Effect of variety and fertilizer on plant potassium content

Varietal differences, fertilization as well as the interaction between variety and fertilizer all had a significant effect on the plant K content (Appendix 44). Table 4.34 shows the results of the effect of variety and fertilization on plant potassium content. Fertilizer application significantly affected plant potassium content. PBA–treated plants recorded the highest K level (1.58 %) compared to PK (1.42%) and the control (1.27%). Among the varieties, ICPL 87091 recorded the highest K content (1.47%), with ICPL 88039 recording the least (1.37%).

Table 4.34: Effect of variety and fertilizer on plant potassium content (%).

Variety	Fertilizer			
	Control	PBA	PK	Mean
ICPL 87091	1.34	1.62	1.46	**1.47**
ICPL 88034	1.23	1.56	1.49	**1.42**
ICPL 88039	1.24	1.56	1.32	**1.37**
Mean	**1.27**	**1.58**	**1.42**	

LSD (0.05); variety: 0.039 Fertilizer: 0.052 Variety × Fertilizer: 0.080

4.7.4 Effect of variety and fertilizer on plant magnesium content

Table 4.35 shows the results of the effect of fertilization on plant magnesium content. There were significant differences ($p \leq 0.05$) among the treatments but not among the varieties. Also the interaction of variety and fertilizer application did not have any significant effect on the plant Mg content (Appendix 45).

Table 4.35: Effect of fertilizer on plant magnesium content at flowering.

Fertilizer	Plant Mg content (%) at flowering
Control	0.25
PBA	0.30
PK	0.27

Lsd (0.05); Fertilizer: 0.017

4.7.5 Effect of variety and fertilizer on plant calcium content

Table 4.36 shows the results of the effect of fertilization on plant Calcium content. Fertilizer application significantly influenced plant Ca content. PBA application significantly ($p \leq 0.05$) increased plant Ca content (0.64%) compared to PK (0.60%) and the Control (0.44%). However the variety and fertilizer interaction effect as well as the effect of variety alone were not significant (Appendix 46).

Table 4.36: Effect of fertilizer on Ca content of three pigeonpea varieties.

Fertilizer	Plant Calcium content (%) at flowering
Control	0.44
PBA	0.64
PK	0.60

Lsd (0.05); Fertilizer: 0.077

4.7.6 Nitrogen fixation in pigeonpea as affected by varietal differences and fertilization

Fertilization had a significant effect on the percent nitrogen fixed (Appendix 46). Table 4.37 shows the effects of fertilization on N fixation in the pot experiment. Table 4.37 indicated that the highest percent nitrogen derived from fixation was by plants that received the PBA treatment (56.4%). The second highest was given by PK-treated plots (48.4%) and the least was given by the control (39.9%) plots. Varietal differences and the interaction between variety and fertilizer did not have any significant effect on the percent nitrogen derived from fixation (Appendix 46).

Table 4.37: Percent N fixed by pigeonpea as affected by fertilizer.

Fertilizer	Nitrogen fixed (%)
Control	39.9
PBA	56.4
PK	48.4

Lsd (0.05); Fertilizer: 8.54

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

The optimum growth and yield of every crop is generally affected by several factors that may be classified as edaphic, environmental and or climatic as well as the genetic composition of the plant. Generally, the growth and yield of plants are influenced by such factors as the pH of the soil during the growth period of the plants and the availability of absorbable plant nutrients during the vegetative and reproductive growth stages of the plants. One important factor that contributes to optimum yield in plants is the production of photosynthates through the process of photosynthesis by the leaves and the appropriate distribution of the produced matter to all parts of the plant.

This chapter captures the discussion on the results of the influence of palm bunch ash application on growth, plant nutrient composition, nitrogen fixation and yield of three pigeonpea varieties and also on soil chemical properties both in a field and pot experiment.

5.2 Initial properties of soil and Palm Bunch Ash (PBA) used for the experiment

The soil at the experimental site was moderately acidic, low in organic matter and high in exchangeable K (Hazelton and Murphy, 2007). It was also high in N, low in exchangeable Ca and moderately high in Mg (Hazelton and Murphy, 2007). The soil pH (5.09) at the start of the experiment suggests that the soil was moderately acidic according to Hoskins (1997) which provided the basis for researching into the possible use of PBA to raise the pH of such a soil. The PBA used in this study which was alkaline with pH of 10.89 contained relatively high amounts of K, P, Ca and Mg but low in N (Table 4.2).

The pH value of 10.89 obtained in this study is not different from that reported by Adjei–Nsiah (2012) who reported a pH value of about 10.9. This value, however, is higher than that obtained by Awodun *et al*. (2007) who reported pH value of 8.8 for the PBA used in their studies. The high values of the pH and the exchangeable cations of the PBA used in this and other studies (Adjei–Nsiah, 2012; Awudun *et al*., 2007; Safo *et al*., 1997) justifies the use of PBA as a liming material and as source of other nutrients for plants.

5.3 Effects of fertilizer application and pigeonpea varieties on soil chemical properties

The PBA applied increased soil pH, N, P, Ca, and Mg relative to the control. Soil pH value was increased significantly ($p \leq 0.05$) by PBA compared to PK and control . The pH of the experimental plot at the start of the experiment was 5.09 compared to 5.82 and 5.19 obtained at 110 days after application of PBA and PK fertilizers respectively. The increase in the pH of the soil after the application of the PBA was due to the high pH (10.89) level of the PBA as well as the relatively high levels of Ca and Mg in the ash (Table 4.2) which had a liming effect on the soil (Hoskins, 1997). Teoh *et al*. (1986) reported that equal rates of limestone and PBA application produced essentially the same increase in top soil pH, indicating that PBA may be as effective as limestone in ameliorating acidity in poorly buffered soils. The high concentrations of Ca, Mg and K recorded in the PBA amended fields could also be due to low exchangeable acidity as a result of precipitation of Al as hydroxyl–Al (Ikpe *et al*., 1997; Adekayode and Olojugba, 2010; Hazelton and Murphy, 2007) thereby releasing these cations in the soil.

The increase in available P content of the soil from 6.81 mg kg^{-1} (initial) to 11.18 mg kg^{-1} and 11.39 mg kg^{-1} for PBA and PK fertilizers respectively could be attributed to release of P from complexes of Al and Fe under increasing soil pH (Adjei–Nsiah, 2012). A study by Ikpe *et al.* (1997) attributed increased available P in soil with application of oil palm bunch ash to release of P from complexes of Al and Fe under increasing soil pH. Additionally this improved soil nutrients content as a result of application of ash is in agreement with the findings of Ayeni *et al.* (2008b) who reported that addition of wood ash to soil increased its OM, N, P, K and Ca. Likewise, Ayeni *et al.* (2009) also found that ash derived from cocoa pod husk increased soil nutrients.

5.4 Effects of fertilizer application and pigeonpea varieties on plant nutrient composition

Plant nutrient analysis indicated that application of PBA increased the amounts of all the nutrients in the fertilised plots relative to the control plots. Adjei–Nsiah *et al.* (2012) reported of a high uptake of P and K but lower uptake of Mg and N with increasing rate of PBA application beyond 2 t ha^{-1}. Ojeniyi *et al*. (2009) have also reported a reduced uptake of plant nutrient such as N, Mg and Ca with increasing application rate of PBA, compared with the control. Ojeniyi *et al*. (2009) attributed the reduction in plant nutrient content, especially for N, Mg and Ca with increasing application of PBA to excessive uptake of K. Their findings agree with the findings of Hazelton and Murphy (2007) and Awodum *et al*. (2007) who indicated that application of higher PBA rates increases soil pH which negatively affect the uptake of most essential nutrients. In this experiment however, the application rate of the PBA was not very high (2 tons ha^{-1}) enough to negatively affect the uptake of N and Mg. The results of this experiment was different from that of Hazelton and Murphy (2007) whose results followed a decreasing trend of plant nutrients with the increasing application of PBA.

5.5 Effects of fertilizer application on Nodulation and Nitrogen fixation of three pigeonpea varieties

Nodulation in the different pigeonpea varieties differed significantly ($p \leq 0.05$) with variety ICPL 88039 producing the highest number of nodules while variety ICPL 87091 produced the lowest number of nodules. Nodule dry weights also varied significantly among the different varieties with the ICPL 88039 having the highest weight while the ICPL 87091 had the lowest dry weight. The existence of genetic variability in tolerance to most environmental stress factors has been shown in both legume host plants and their respective rhizobial strains and acid tolerant host cultivars and inoculants strains are practices that are used to limit the negative effects of environmental stress on nodulation and nitrogen fixation in legumes (Serraj and Adu–Gyamfi, 2004).

Number of nodules and nodule mass were also significantly influenced by fertilizer application. Nodule number and nodule dry weights were lowest in the control plots and highest in the PBA amended plots. The results showed that the higher the number of nodules, the heavier they were. This result is substantiated by the assertion that a simple relationship exists between nodule number and nodule dry weight, and they are indices of N_2 fixation.

Several factors including soil acidity and mineral nutrition might have accounted for the differences in nodulation in the different treatments. Several studies (Cooper, 1989; Brauer *et al.*, 2002) have demonstrated that acid soils reduce nodulation and N_2–fixation in legumes. Thus PBA amended plots which had relatively higher pH, had both higher number of nodules and higher nodule dry weight. Reduced nodulation in acid soils is partly attributed to lowered number of rhizobia and also because acidity affects attachment of nodules to the roots (Brauer *et al.,* 2002). Thus N_2–fixation in acid soils can be markedly reduced with the effect of soil acidity due to H^+ concentration, toxic levels of Aluminium and manganese and deficiencies of Ca, P and Molybdenum (Giller, 2001; Serraj and Adu–Gyamfi, 2004). Nodules are known to be important sink for P and commonly have the highest concentration of that element in the plant (Sinclair and Vadez, 2002). Giller and Cadisch (1995) reported that deficiency of phosphorus in legumes depressed the activity of nitrogen fixing bacteria. Under deficient conditions, P fertilization will usually result in enhanced nodule number and mass and also increased N_2–fixation per plant and per gram of nodules (Serraj and Adu–Gyamfi, 2004). Combined application of PK has also been reported to have increased the weight of individual nodules in clover by 4 times over control (Lynda *et al*., 1984). In this study, the PBA amended plots which had high levels of P, K and Ca also had high nodule number and nodule mass.

Plants from plots that received either PBA or PK application gave higher percent of nitrogen derived from fixation, compared to the control plants even though the PBA–treated plants fixed the highest percent of Nitrogen. This is because the PBA neutralized the acidic soil thereby making P more available for plant uptake. The availability of P enhanced the activity of the nitrogen fixing bacteria (Giller and Cadisch, 1995; Rahman *et al*., 2008). Thus the increased levels of nutrients such as P, K and Mg in the PBA amended plots also enhanced nitrogen fixation. Cadish *et al.* (1989), evaluating the effects of K fertilizer on N_2 fixation of a number of forage legumes reported that, the plants that were treated with K fertiliser fixed a higher amount of Nitrogen than the control plants. In their research, they realised that all the legumes that were treated with K fertilizer derived at least 70% of their N from symbiosis whereas without K application, both lower values and larger differences in N fixed between species were observed. Cadish *et al.* (1989) then concluded that the application of P and K fertilizer increases the amount of Nitrogen fixed by legumes. Thus the high P, K and Mg content of the PBA as well as their subsequent uptake by the plants resulted in the highest amount of N fixed in the plants in the PBA amended plots. The high uptake of nutrients by plants on the PBA amended plots might have also improved photosynthesis which subsequently improved carbohydrate supply to the roots thereby increasing both nodule number and nodule mass (Lindstrom *et al.*, 1952).

5.6 Effects of fertilizer application on vegetative growth parameters of three pigeonpea varieties.

Plant height was higher among plants from plots that were treated with either PBA or PK fertilizer compared with the control plots although the differences were not significant . Similar observations were made in an earlier experiment conducted on cowpea and groundnut respectively by Safo *et al*. (1997) and Oguzor (2007). Increase in plant height as a result of nutrient application is attributed to increased uptake of nutrients by plants leading to enhanced carbohydrate synthesis thereby resulting in increased cell division and enlargement and therefore increase in plant height (Reager *et al*., 2003). In cluster bean, Ayub *et al.* (2012) also reported of similar observations which they attributed to balanced nutrient uptake by the plants. This resulted in enhanced cell division and enlargement leading to the build–up of dry matter (Wange and Kale, 2004).

Palm bunch ash (PBA) application also significantly increased plant girth compared with the PK–treated plots and the control plots respectively. Safo *et al.* (1997) made similar observation in cowpea when they applied PBA to cowpea. The increase in plant girth as a result of PBA application could be attributed to increased availability and uptake of nutrients by the pigeonpea plants which might have resulted in increased carbohydrate synthesis which resulted in active cell division, meristematic activity in the apical tissue, and expansion of the cell. Increased application of nutrients such as N, P and K has been found to increase stem girth in cassava (Ojeniyi *et al.*, 2012) as well as in soybean (Osodeke, 2001).

The plots that were treated with either PBA or PK fertilizer had their plants producing higher number of leaves and flowers per plant compared with the control plots, even though the differences were not significant. This could be due to increased availability of nutrients for plant uptake which promoted cell division (Osodeke, 2001).

Higher shoot dry matter, although not significantly different ($p \geq 0.05$) were recorded for the three pigeonpea varieties for plants from plots amended with either PBA or 20 kg PK ha^{-1} compared with the control plots. This high shoot dry matter could be attributed to availability of nutrients for plant uptake. Similar observations have been made in cowpea (Safo *et al.*, 1997) and garden eggs (Wange and Kale, 2004). Increased shoot dry matter as a result of nutrient application is attributed to balanced nutrient uptake by the plants (Wange and Kale, 2004) which resulted in enhanced cell division and enlargement leading to the build–up of the shoot dry matter. The increased uptake of plant nutrients supplied by the ash and the mineral fertilizer resulted in improved vegetative structure development (Suthar *et al.*, 2005). Balanced nutrition has been found to result in active cell division, cell elongation as well as development of meristematic tissues which consequently results in development of more fruiting branches (Anburani and Manivannan, 2002).

5.7 Effects of fertiliser application on dry matter yields of three pigeonpea at harvest

The grain DM differed among the different varieties although the differences were not significant. The variety ICPL 88034 however gave the highest grain DM while ICPL 87091 gave the lowest grain DM. Grain DM also differed among the different fertiliser treatments with the PBA amended plots producing the highest grain DM of 1.76 t ha^{-1} but not significantly ($p > 0.05$) different from that of the control (1.32 t ha^{-1}) and the PK treated plot (1.48 t ha^{-1}). The grain DM reported in this study however compares favourably with yields reported in other parts of Africa (Hogh–Jenson *et al.*, 2002; Egbe and Vange, 2008).

The dry matter (DM) harvest index (HI) varied significantly among the different varieties. ICPL 87091 which had the lowest grain DM also had the lowest HI while ICPL 88039 which had the least stover and litter DM had the highest HI. Due to its low HI in terms of DM, ICPL 87091could contribute most to the soil fertility due to the higher proportion of its non–edible crop organs especially the stover and the litters that are returned to the soil (Hogh–Jenson *et al.*, 2007). Thus pigeonpea varieties that combine a reasonable grain yield with a large volume of leaf biomass could offer a useful compromise to meeting farmers' food security needs and improving soil fertility.

5.8 Effects of fertilizer application on grain yield of three pigeonpea varieties

Palm bunch application (PBA) resulted in higher grain yields compared with the control even though there were not significant differences among them. Several authors (Owolabi *et al.*, 2003; Adu–Dapaah *et al.*, 1994; Odedina *et al.*, 2003; Ojeniyi *et al.*, 2003; Ojeniyi and Adejobi, 2002; Obi and Ekperigin, 2001) have reported similar results. Cox *et al.* (2001) attributed higher grain yield with ash application to the fact that the ash slightly suppressed phosphatase activity. The dry weight of 100 grains were significantly different among the three varieties (Table 4.15). However application of PBA and PK fertilizers resulted in increased weight of 100 grains of pigeonpea, although the differences were not significantly different (Appendix 21). The weight of 100 grains was observed to be higher in plants in the PBA–amended plots compared to PK–treated and the control plots respectively. Rajiv and Prakash, (2012) who worked on Black Gram (*Vigna mungo*) obtained similar results. They attributed their results to the fact that the liming properties of the ash made it easier for the uptake of nutrients by the plants, thereby improving growth and yield as well as 100 seed weight.

Plants in the PK–treated plots were also observed to have produced higher seed yields as well as 100 seed weight compared to those in the control plots although the differences were not significant. These findings are in conformity to those of Bly *et al.* (1997) who found out that P application increased 100 seeds weight, number of pods per plant and grain yield in cowpea. Increased yield with application of P has also been reported by various workers in pea (Chandra *et al.*, 1989), pigeonpea and French beans (Parma *et al.*, 1999). According to Chiezey *et al*. (2009), application of P stimulates leaf expansion and hence more light interception for photosynthetic activities, leading to high dry matter accumulation, high seed yield, pod yield and higher seeds weight. Working on cowpea, Ullah *et al.* (2007) also found that application of K fertilizer increased pod length and grain weight of the cowpea. They concluded that plants that were treated with K fertilizer gave significantly higher seed weight than those that did not receive K treatment. Mohankumar and Balakrishna Pillai (1979) also reported of increase in grain yield as a result of K fertilization

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

The results of the study show that there was no significant difference in the total grain yield among the three pigeonpea varieties evaluated. However the weight of 100 grains was significantly different among the three varieties. The variety ICPL 88034 gave the highest grain yield while the variety ICPL 87091 gave the lowest grain yield. The variety 88039 which produced the lowest total DM had the highest harvest index while the variety ICPL 87091 which produced the lowest grain DM had the lowest harvest index. Due to its low harvest index in terms of DM, ICPL 87091 could contribute most to the soil fertility due to the higher proportion of its non–edible crop organs especially the stover and the litters that are returned to the soil.

The results of the experiment also indicated that the application of PBA enhanced both the vegetative and reproductive growth of the three varieties of pigeonpea that were used for the study. Application of PBA contributed to improved soil chemical properties of acid soils by increasing the soil pH and increasing the level of macro nutrients such as N, P, K, Ca and Mg in the soil. This has resulted in improved nutrient uptake by the pigeonpea which resulted in enhanced growth, nodulation and nitrogen fixation in the pigeonpea plants.

Application of PBA also resulted in increase in grain yield, although the increase was not significant. However, application of PBA resulted in significantly higher stover, litter and total dry matter of the pigeonpea which could benefit subsequent cereal crop that will follow the pigeonpea in rotation.

Additionally, it can also be concluded from the results of the experiment that PBA can also be used as a liming material to correct pH of acidic soils as well as nutrient supplement in soils that are low in plant nutrients

Thus application of PBA is an effective way of improving the growth and the grain yield of legumes including pigeonpea grown on acid soils, as well as amending acidic soils at a relatively low cost. Thus in rural areas where P and K fertilisers as well as liming materials are not readily available but PBA are in abundance, farmers should be encouraged to use Palm Bunch Ash on their farms in order to achieve higher grain yields at a lower cost, while correcting soil acidity and improving the soil fertility.

It is therefore recommended that, in a subsequent experiment, consideration should be given to a treatment that combines PBA and PK fertilizer since the application of PBA did not significantly increase the grain yield of the pigeonpea varieties.

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APPENDICES

Appendix 1: ANOVA table for mean plant height (cm) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	765.20	255.07	0.76	
Block x Variety stratum					
Variety	2	2024.45	1012.22	3.00	0.125
Residual	6	2026.95	337.82	3.63	
Block x Variety x Treatment					
Treatment	2	37.5	18.78	020	0.819
Variety x Treatment	4	71.06	17.76	0.19	0.940
Residual	18	1673.83	92.99		
Total	35	659903			

Appendix 2: ANOVA table for mean plant girth (cm) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.60556	0.20185	7.68	
Block x Variety stratum					
Variety	2	0.76222	0.38111	14.49	0.005
Residual	6	0.15778	0.02630	0.44	
Block x Variety x Treatment					
Treatment	2	1.00389	0.50194	8.43	0.003
Variety x Treatment	4	0.33778	0.08444	1.42	0.268
Residual	18	1.07167	0.05954		
Total	35	3.93889			

Appendix 3: ANOVA table for shoot dry weight per plant (g) at flowering

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	840.0	280.0	0.70	
Block x Variety stratum					
Variety	2	2264.5	1132.2	2.84	0.136
Residual	6	2391.4	398.6	2.95	
Block x Variety x Treatment					
Treatment	2	649.7	324.8	2.41	0.119
Variety x Treatment	4	661.9	165.5	1.23	0.335

Residual	18	2430.3	135.0		
Total	35	9237.7			

Appendix 4: ANOVA table for root dry weight per plant (g) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	7.612	2.537	0.41	
Block x Variety stratum					
Variety	2	54.491	27.245	4.38	0.067
Residual	6	37.344	6.224	2.76	
Block x Variety x Treatment					
Treatment	2	12.497	6.28	2.77	0.089
Variety x Treatment	4	4.604	1.151	0.51	0.729
Residual	18	40.604	2.256		
Total	35	157.150			

Appendix 5: ANOVA table for total dry weight per plant (g) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	972.4	324.1	0.65	
Block x Variety stratum					
Variety	2	3018.9	1509.4	3.01	0.124
Residual	6	3010.7	501.8	3.00	
Block x Variety x Treatment					
Treatment	2	842.4	421.2	2.52	0.109
Variety x Treatment	4	753.4	188.3	1.13	0.376
Residual	18	3011.6	167.3		
Total	35	11609.3			

Appendix 6: ANOVA table for total above ground dry weight (t/ha) at flowering.

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.26711	0.08904	1.11	
Block x Variety stratum					
Variety	2	0.79248	0.39624	4.94	0.054
Residual	6	0.48153	0.08026	1.12	
Block x Variety x Treatment					
Treatment	2	0.21471	0.10735	1.50	0.249
Variety x Treatment	4	0.37797	0.09449	1.32	0.300

Residual	18	1.28724	0.07151		
Total	35	3.42104			

Appendix 7: ANOVA table for number of leaves per plant at flowering (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	10576	3525.	0.32	
Block x Variety stratum					
Variety	2	27236	13618	1.22	0.359
Residual	6	66887	11148	1.07	
Block x Variety x Treatment					
Treatment	2	18104	9052	0.87	0.437
Variety x Treatment	4	39241	9810	0.94	0.464
Residual	18	187972	187972		
Total	35	350016.			

Appendix 8: ANOVA table for number of flowers per plant at flowering (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	961.	320	0.18	
Block x Variety stratum					
Variety	2	6550	3275	1.80	0.244
Residual	6	10915	1819	1.67	
Block x Variety x Treatment					
Treatment	2	1848	924	0.85	0.444
Variety x Treatment	4	8040	2010	1.85	0.163
Residual	18	19559	1087.		
Total	35	47871.			

Appendix 9: ANOVA table for number of fruiting branches at flowering (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	541.4	180.5	1.04	
Block x Variety stratum					
Variety	2	507.3	253.6	1.46	0.304
Residual	6	1041.3	173.6	0.90	
Block x Variety x Treatment					

Treatment	2	343.9	172.0	0.89	0.426
Variety x Treatment	4	427.2	106.8	0.56	0.698
Residual	18	3460.4	192.2		
Total	35	6321.5			

Appendix 10: ANOVA table for nodule number at flowering (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	1018.78	339.59	73.42	
Block x Variety stratum					
Variety	2	874.66	874.66	94.56	<.001
Residual	6	27.75	4.63	0.36	
Block x Variety x Treatment					
Treatment	2	2285.78	1142.89	89.87	<.001
Variety x Treatment	4	109.90	27.48	2.16	0.115
Residual	18	228.90	12.72		
Total	35	4545.76			

Appendix 11: ANOVA table for nodule dry weight (g) at flowering (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.60855	0.20285	30.36	
Block x Variety stratum					
Variety	2	0.59922	0.29961	44.85	<.001
Residual	6	0.04008	0.00668	0.48	
Block x Variety x Treatment					
Treatment	2	2.92037	1.46018	105.66	<.001
Variety x Treatment	4	0.07572	0.01893	1.37	0.284
Residual	18	0.24875	0.01382		
Total	35	4.49270			

Appendix 12: ANOVA table for number of days to 50% flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	172.083	57.361	0.88	
Block x Variety stratum					
Variety	2	20.667	10.333	0.16	0.856
Residual	6	389.333	64.889	20.92	
Block x Variety x Treatment					
Treatment	2	15.167	7.583	2.44	0.115
Variety x Treatment	4	11.667	2.917	0.94	0.463
Residual	18	55.833	3.102		
Total	35	664.750			

Appendix 13: ANOVA table for number of days from flowering to harvest (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	33.000	11.000	2.41	
Block x Variety stratum					
Variety	2	20.222	10.111	2.22	0.190
Residual	6	27.333	4.556	1.60	
Block x Variety x Treatment					
Treatment	2	35.722	17.861	6.28	0.009
Variety x Treatment	4	11.778	2.944	1.04	0.416
Residual	18	51.167	2.843		
Total	35	179.222			

Appendix 14: ANOVA table for number of days from planting to first harvest

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	88.750	29.583	0.63	
Block x Variety stratum					
Variety	2	4.222	2.111	0.04	0.957
Residual	6	283.333	47.222	7.61	
Block x Variety x Treatment					
Treatment	2	97.389	48.694	7.85	0.004
Variety x Treatment	4	7.611	1.903	0.31	0.870
Residual	18	111.667	6.204		
Total	35	592.972			

Appendix 15: ANOVA table for plant Nitrogen content (%) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.02901	0.00967	0.22	
Block x Variety stratum					
Variety	2	0.11006	0.05503	1.27	0.347
Residual	6	0.26016	0.04336	1.74	
Block x Variety x Treatment					
Treatment	2	15.30790	7.65395	307.13	<.001
Variety x Treatment	4	0.43782	0.10946	4.39	0.012
Residual	18	0.44858	0.02492		
Total	35	16.59353			

Appendix 16: ANOVA table for plant P content (%) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.0007665	0.0002555	0.33	
Block x Variety stratum					
Variety	2	0.0147727	0.0073863	9.41	0.014
Residual	6	0.0047076	0.0007846	1.52	
Block x Variety x Treatment					
Treatment	2	0.4242380	0.2121190	412.19	<.001
Variety x Treatment	4	0.0321508	0.0080377	15.62	<.001
Residual	18	0.0092632	0.0005146		
Total	35	0.4858987			

Appendix 17: ANOVA table for plant Potassium content (%) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.003311	0.001104	1.49	
Block x Variety stratum					
Variety	2	0.097339	0.048669	65.79	<.001
Residual	6	0.004439	0.000740	0.38	
Block x Variety x Treatment					
Treatment	2	0.368672	0.184336	94.40	<.001
Variety x Treatment	4	0.003844	0.000961	0.49	0.742
Residual	18	0.035150	0.001953		

Total	35	0.512756

Appendix 18: ANOVA table for plant Mg content (%) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.00001996	0.00000665	0.02	
Block x Variety stratum					
Variety	2	0.00031362	0.00015681	0.55	0.606
Residual	6	0.00172566	0.00028761	3.82	
Block x Variety x Treatment					
Treatment	2	0.02731741	0.01365871	181.64	<.001
Variety x Treatment	4	0.00089636	0.00022409	2.98	0.047
Residual	18	0.00135356	0.00007520		
Total	35	0.03162658			

Appendix 19: ANOVA table for plant Ca content (%) at flowering (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.0003908	0.0001303	5.14	
Block x Variety stratum					
Variety	2	0.0154201	0.0077100	304.05	<.001
Residual	6	0.0001521	0.0000254	0.07	
Block x Variety x Treatment					
Treatment	2	0.1742323	0.0871161	246.47	<.001
Variety x Treatment	4	0.0426190	0.0106548	30.14	<.001
Residual	18	0.0063622	0.0003535		
Total	35	0.2391765			

Appendix 20: ANOVA table for % nitrogen fixed (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	39.45	13.15	0.48	
Block x Variety stratum					
Variety	2	50.12	25.06	0.92	0.449
Residual	6	163.81	27.30	2.14	

Block x Variety x Treatment					
Treatment	2	11581.90	5790.95	454.73	<.001
Variety x Treatment	4	409.07	102.27	8.03	<.001
Residual	18	229.23	12.73		
Total	35	12473.58			

Appendix 21: ANOVA table for the weight of 100 grains (g) (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	1.1111	0.3704	2.11	
Block x Variety stratum					
Variety	2	30.7222	15.3611	87.32	<.001
Residual	6	1.0556	0.1759	0.83	
Block x Variety x Treatment					
Treatment	2	1.0556	0.5278	2.48	0.112
Variety x Treatment	4	0.4444	0.1111	0.52	0.721
Residual	18	3.8333	0.2130		
Total	35	38.2222			

Appendix 22: ANOVA table for grain yield (t/ha) during the first season (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.1012	0.0337	0.25	
Block x Variety stratum					
Variety	2	0.0300	0.0150	0.11	0.897
Residual	6	0.8109	0.1351	0.86	
Block x Variety × Treatment					
Treatment	2	0.3543	0.1772	1.13	0.346
Variety x Treatment	4	0.1197	0.029	0.19	0.940
Residual	18	2.8338	0.1574		
Total	35	4.2499			

Appendix 23: ANOVA table for grain yield (t/ha) during the second season (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.

Block stratum	3	0.27511	0.0170	0.38	
Block x Variety stratum					
Variety	2	3.23647	1.61824	6.78	0.029
Residual	6	1.43136	0.23856	7.09	
Block x Variety x Treatment					
Treatment	2	0.50324	0.25162	7.48	0.004
Variety x Treatment	4	0.20798	0.05199	1.55	0.232
Residual	18	0.0558	0.03364		
Total	35	6.25973			

Appendix 24: ANOVA table for Total Grain Yield (t/ha) for both seasons (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.7069	0.2356	0.39	
Block x Variety stratum					
Variety	2	2.9985	1.4993	2.50	0.162
Residual	6	3.5955	0.5992	2.51	
Block x Variety x Treatment					
Treatment	2	1.1512	0.5756	2.42	0.118
Variety x Treatment	4	0.5343	0.1336	0.56	0.694
Residual	18	4.2896	0.2383		
Total	35	13.2759			

Appendix 25: ANOVA table for Litter Dry Matter (t/ha) (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	07025	0.2342	1.34	
Block x Variety stratum					
Variety	2	9.0189	4.5094	25.74	0.001
Residual	6	1.0513	0.1752	1.40	
Block x Variety x Treatment					
Treatment	2	0.5287	0.2643	2.11	0.150
Variety x Treatment	4	0.2852	0.0713	0.57	0.688
Residual	18	2.2508	0.1250		
Total	35	13.8373			

Appendix 26: ANOVA table for Stover Dry Matter (t/ha) (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.26711	0.08904	1.11	
Block x Variety stratum					
Variety	2	0.79248	0.39624	4.94	0.054
Residual	6	0.48153	0.08026	1.12	
Block x Variety x Treatment					
Treatment	2	0.21471	0.10735	1.50	0.249
Variety x Treatment	4	0.7797	0.09449	1.32	0.300
Residual	18	1.28724	0.07151		
Total	35	3.42104			

Appendix 27: ANOVA table for Total dry matter (t/ha) (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	4.2532	1.4177	1.06	
Block x Variety stratum					
Variety	2	6.9255	3.4627	2.58	0.156
Residual	6	8.0578	1.430	2.72	
Block x Variety x Treatment					
Treatment	2	4.6466	2.3233	4.70	0.023
Variety x Treatment	4	2.1643	0.5411	1.10	0.389
Residual	18	8.8940	0.4941		
Total	35	34.9414			

Appendix 28: ANOVA table for Harvest Index (t/ha) (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.00252	0.00084	0.08	
Block x Variety stratum					
Variety	2	0.18489	0.09244	8.62	0.017
Residual	6	0.0643	0.01072	0.93	
Block x Variety x Treatment					
Treatment	2	0.00291	0.00146	0.13	0.882
Variety x Treatment	4	0.01067	0.00267	0.23	0.917
Residual	18	0.20704	0.01150		
Total	35	0.47236			

Appendix 29: ANOVA table for soil pH (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.000211	0.000070	0.01	
Block x Variety stratum					
Variety	2	0.027450	0.013725	2.65	0.150
Residual	6	0.031106	0.005184	1.65	
Block x Variety x Treatment					
Treatment	2	3.435650	1.717825	546.95	<.001
Variety x Treatment	4	0.007750	0.001937	0.62	0.656
Residual	18	0.056533	0.001937		
Total	35	3.558700			

Appendix 30: ANOVA table for soil % Nitrogen (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.0170727	0.0056909	10.97	
Block x Variety stratum					
Variety	2	0.0031373	0.0015687	159.61	0.123
Residual	6				
Block x Variety x Treatment					
Treatment	2	0.0968645	0.0484323	159.61	<.001
Variety x Treatment	4	0.0072768	0.0018192	6.00	0.003
Residual	18	0.0054619	0.0003034		
Total	35	0.1329252			

Appendix 31: ANOVA table for soil available Phosphorus (ppm) (Field experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	7.432	2.477	2.17	
Block x Variety stratum					
Variety	2	45.405	22.702	19.87	0.002
Residual	6	6.855	1.143	0.48	
Block x Variety x Treatment					
Treatment	2	185.756	92.878	39.13	<.001
Variety x Treatment	4	22.701	5.675	2.3	0.089
Residual	18	42.726	2.374		
Total	35	310.875			

Appendix 32: ANOVA table for soil potassium concentration (meq/100g) (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.000995	0.000332	0.23	
Block x Variety stratum					
Variety	2	0.042009	0.021005	14.44	0.005
Residual	6	0.008726	0.001454	0.25	
Block x Variety x Treatment					
Treatment	2	0.364026	0.182013	31.26	<.001
Variety x Treatment	4	0.194816	0.048040	8.36	<.001
Residual	18	0.104803	0.005822		
Total	35	0.715750			

Appendix 33: ANOVA table for soil Magnesium concentration (meq/100g) (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.020524	0.006841	1.87	
Block x Variety stratum					
Variety	2	0.428588	0.21429	58.63	<.001
Residual	6	0.021931	0.003655	0.05	
Block x Variety x Treatment					
Treatment	2	22.83809	11.41904	1561.47	<.001
Variety x Treatment	4	0.294383	0.073596	10.06	<.001
Residual	18	0.131634	0.007313		
Total	35	23.735147			

Appendix 34: ANOVA table for soil Calcium concentration (meq/100g) (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.01622	0.00541	0.34	
Block x Variety stratum					
Variety	2	0.31471	0.15736	9.96	0.012
Residual	6	0.09484	0.01581	1.46	
Block x Variety x Treatment					

Treatment	2	6.02285	3.01143	278.55	<.001
Variety x Treatment	4	0.14078	0.03519	3.26	0.036
Residual	18	0.19460	0.01081		
Total	35	6.78400			

Appendix 35: ANOVA table for soil Organic matter (%) (Field experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.0122	0.0041	2.99	
Block x Variety stratum					
Variety	2	0.0049	0.00243	1.79	0.246
Residual	6	0.0820	0.014	0.80	
Block x Variety x Treatment					
Treatment	2	0.7776	0.3889	22.84	<.001
Variety x Treatment	4	0.0385	0.00962	5.64	0.004
Residual	18	0.03072	0.0011		
Total	35	0.8720			

Appendix 36: ANOVA table for soil nitrogen content (%) (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.00075525	0.00025175	4.27	
Block x Variety stratum					
Variety	2	0.01008006	0.00504003	85.40	<.001
Residual	6	0.00035411	0.00005902	1.24	
Block x Variety x Treatment					
Treatment	2	0.04961980	0.02480990	522.58	<.001
Variety x Treatment	4	0.00457290	0.00114322	24.08	<.001
Residual	18	0.00085456	0.00004748		
Total	35	0.06623668			

Appendix 37: ANOVA table for soil Phosphorus content (ppm) (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0001875	0.000625	10.71	
Block x Variety stratum					
Variety	2	1.822672	0.911336	15622.90	<.001

Residual	6	0.000350	0.000058	0.04	
Block x Variety x Treatment					
Treatment	2	11.937006	5.968503	3660.41	<.001
Variety x Treatment	4	2.534444	0.633611	388.59	<.001
Residual	18	0.029530	0.001631		
Total	35	16.325697			

Appendix 38: ANOVA table for soil Exchangeable Potassium (meq/100g) (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.0007064	0.0007064	0.53	
Block x Variety stratum					
Variety	2	0.0014285	0.0007142	1.60	0.277
Residual	6	0.0026720	0.0004453	2.76	
Block x Variety x Treatment					
Treatment	2	0.144431	0.0722154	448.09	<.001
Variety x Treatment	4	0.003326	0.0008314	5.16	0.006
Residual	18	0.0029009	0.0001612		
Total	35	0.1554644			

Appendix 39: ANOVA table for soil exchangeable Magnesium (meq/100g) (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.3279	0.1093	0.55	
Block x Variety stratum					
Variety	2	1.4914	0.7457	3.74	0.088
Residual	6	1.1952	0.1992	0.55	
Block x Variety x Treatment					
Treatment	2	25.592	12.8296	35.40	<.001
Variety x Treatment	4	1.4546	0.36.7	1.00	0.432
Residual	18	6.5237	0.3624		
Total	35	36.6519			

Appendix 40: ANOVA table for soil exchangeable Calcium (meq/100g) (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.

Block stratum	3	0.001531	0.000510	0.18	
Block x Variety stratum					
Variety	2	0.003045	0.001522	0.54	0.609
Residual	6	0.016949	0.002825	0.67	
Block x Variety x Treatment					
Treatment	2	0.486055	0.243027	57.81	<.001
Variety x Treatment	4	0.166034	0.041509	9.87	<.001
Residual	18	0.075667	0.004204		
Total	35	0.749280			

Appendix 41: ANOVA table for soil organic matter (%) (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.013433	0.04478	0.47	
Block x Variety stratum					
Variety	2	0.017150	0.008575	0.91	0.453
Residual	6	0.056850	0.009475	1.52	
Block x Variety x Treatment					
Treatment	2	1.258450	0.629725	100.88	<.001
Variety x Treatment	4	0.024050	0.006012	0.96	0.452
Residual	18	0.011237	0.006243		
Total	35	1.483300			

Appendix 42: ANOVA table for plant nitrogen content (%) at flowering (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.127	0.0409	1.06	
Block x Variety stratum					
Variety	2	0.0957	0.0478	1.24	0.353
Residual	6	0.2308	0.0385	0.34	
Block x Variety x Treatment					
Treatment	2	2.2293	1.1147	9.71	0.001
Variety x Treatment	4	0.0538	0.0134	0.12	0.975
Residual	18	2.060	0.1148		
Total	35	4.7983			

Appendix 43: ANOVA table for plant % Phosphorus (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.424318	0.141439	19.23	
Block x Variety stratum					
Variety	2	0.019293	0.009646	1.31	0.337
Residual	6	0.044138	0.007356	1.20	
Block x Variety x Treatment					
Treatment	2	0.702994	0.351497	57.11	<.001
Variety x Treatment	4	0.024563	0.006141	1.00	0.434
Residual	18	0.110791	0.006155		
Total	35	1.326096			

Appendix 44: ANOVA table for plant % Calcium (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.048641	0.016214	1.07	
Block x Variety stratum					
Variety	2	0.136705	0.068352	4.53	0.063
Residual	6	0.90606	0.015101	1.88	
Block x Variety x Treatment					
Treatment	2	0.257043	0.128522	15.96	<.001
Variety x Treatment	4	0.032667	0.008167	1.01	0.426
Residual	18	0.144923	0.008051		
Total	35	0.710585			

Appendix 45: ANOVA table for plant % Magnesium (Pot experiment)

Source of variation	d.f.	Sum of Squares	Mean Squares	Variance ratio	F pr.
Block stratum	3	0.0206822	0.0068941	26.95	
Block x Variety stratum					
Variety	2	0.0002160	0.0001080	0.42	0.674
Residual	6	0.0015351	0.0002559		
Block x Variety x Treatment					
Treatment	2	0.0162849	0.0081424	20.11	<.001
Variety x Treatment	4	0.0008635	0.0002159	0.53	0.713
Residual	18	0.0072873	0.0004049		

Total	35	0.0468690

Appendix 46: ANOVA table for plant % Potassium (Pot experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.025267	0.008422	5.42	
Block x Variety stratum					
Variety	2	0.062039	0.031019	19.98	0.002
Residual	6	0.009317	0.001553	0.42	
Block x Variety x Treatment					
Treatment	2	0.570506	0.285253	76.50	<.001
Variety x Treatment	4	0.045378	0.011344	76.50	0.044
Residual	18	0.067117	0.011344		
Total	35	0.779622			

Appendix 47: ANOVA table for % nitrogen fixed (Pot experiment)

Source of variation	**d.f.**	**Sum of Squares**	**Mean Squares**	**Variance ratio**	**F pr.**
Block stratum	3	0.01343	0.00449	0.47	
Block x Variety stratum					
Variety	2	0.17150	0.008575	0.91	0.453
Residual	6	0.05685	0.009475	1.52	
Block x Variety x Treatment					
Treatment	2	1.25995	0.62973	100.08	<.001
Variety x Treatment	4	0.02405	0.00012	0.96	0.452
Residual	18	0.11237	0.00624		
Total	35	1.48330			