EFFECT OF PHOSPHATE FERTILIZER ON GROWTH AND YIELD OF COWPEA (*Vigna unguiculata*) IN NANDI SOUTH

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

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I dedicate this thesis to my wife Topister and my sons Brian and Seth and daughter Lisa.

ABSTRACT

Phosphorus deficiency remains a key constraint to cowpea productivity in Kenya. In addition, there exist conflicting results about the effect of leaf harvest on cowpea yield. Therefore, an on-farm and greenhouse study was conducted to establish which local cowpea varieties can positively responds to P fertilizer and produce vegetable without compromising on the dry matter yield. The on farm study was conducted in Bonjoge and Koibem regions of Nandi South during the long rain season in 2009. Three cowpea varieties (Enzegu, Ilanda and Khaki) were assessed against the application of three P rates (0, 15 and 30 kg ha^{-1}) and two leaf management practices (with and without leaf harvests). The on-farm trials were laid out in a Randomized Complete Block Design (RCBD) with three replications. Data collected consisted of seedling survival, above ground biomass (with or without leaf harvests) and P uptake. Thereafter, a greenhouse experiment was conducted for 3 months at the University of Eldoret using the two soils from earlier study. A Complete Randomized Design (CRD) with three replications was adopted with data collected on soil available P (before and after the experiment), plant height, number of pods, and seed weight. Results from this study indicated that Ilanda and Enzegu recorded the highest seedling survival rate at 46% and 64% in Bonjoge and Koibem, respectively. Ilanda (452 kg ha^{-1}) in Bonjoge and Enzegu (712 kg ha^{-1}) in Koibem, produced the largest biomass when fertilizer was applied at 30 kg P ha^{-1} and leaf harvesting was not done. Khaki (with leaf harvesting) in Bonjoge and Enzegu (without leaf harvesting) in Koibem produced the largest P uptake of 1.0 kg ha^{-1} and 1.8 kg ha^{-1} respectively, when fertilizer was applied at 30 kg P ha^{-1}. At 30 kg P ha^{-1}, Ilanda obtained the largest grain weight at 7.7g per plant for Bonjoge soil and 7.0g for Koibem soil. Final soil available P values were significantly *($P<0.05$)* highest with Khaki (8.2 kg ha^{-1}) in Bonjoge and Enzegu (8.3 kg ha^{-1}) in Koibem at 30 kg P ha^{-1} fertilizer application rate. This study, therefore, shows that external addition of P fertilizer is essential for increased cowpea yields. In both sites, Ilanda and Enzegu (without leaf harvesting) are best for dry matter production with highest P fertilizer addition. Ilanda is best for grain yield production. Variations in performance of cowpea varieties provide a basis for selecting cowpea lines that respond to positively to phosphate fertilizers in soils poor in phosphorus.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

ANOVA – Analysis of Variance

FAOSTAT – Food Agricultural Organization Statistics

FURP – Fertilizer Use Recommendation Project

IITA – International Institute of Tropical Agriculture

KALRO – Kenya Agricultural and Livestock Research Organization

MOA – Ministry of Agriculture

NPK – Nitrogen Phosphorus Potassium

SAS – Statistical Analysis System

SED – Standard Error Deviation

USAID - United States of America International Agency

USDA – United States Department of Agriculture

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CHAPTER ONE

INTRODUCTION

Phosphorus (P) deficiency remains a key constraint to agricultural productivity in weathered soils of sub-Saharan Africa (SSA) (Nziguheba *et al.* 2016). Studies reviewed have attributed this to continuous cropping with limited or no fertilizer replenishment (Pezzolla *et al.*, 2013). In western Kenya, the farming system characterized mainly by small-scale subsistence (Odendo *et al.*, 2002), has been subjected to intensified, continuous cultivation with minimum nutrient replenishment (Okalebo *et al.*, 1997). This has consequently resulted to gradual depletion of soil nutrients, a major contributor to declining crop yields. It has been projected that about 0.9 million hectares of land in the western Kenya region has P deficiencies (Woomer *et al.*, 1997, Kanyanjua *et al.*, 2002). Part of this land are Bonjoge and Koibem sites in Nandi South sub-county (Kimetu *et al.*, 2009).

Phosphorus is considered a primary nutrient for plant growth (Hinsinger, 2001) and is used to improve crop quality, to build resistance to diseases, root development and other plant functions (Giller *et al.*, 2011). The element is essential for cell division, reproduction, and plant metabolism; moreover, its role is related to the acquisition, storage, and use of energy (Epstein and Bloom, 2004). Phosphorous is also important for legume symbiosis with rhizobia, di-nitrogen (N_2) fixation will depend on its availability (Vance, 2001). Plants relying on symbiotic N_2 fixation such as cowpea, have adenosine triphosphate (ATP) requirements for nodule development and function (Ribet and Drevon, 1996). Ameliorating P deficiency in soils such as those in Bonjoge and Koibem in Nandi

South sub-county, can be accomplished by recapitalizing soils with P inputs (Buresh *et al.,* 1997; Sanchez *et al.*, 1997). Acidulated P fertilizers such as triple super phosphate (TSP) offer soluble and rapidly available P (Nziguheba *et al.,* 2016). According to FURP (1994), 30 kg P ha^{-1} is the recommended P fertilizer application rate for optimal cowpea production in western Kenya. There is however, need for use of low-cost nutrient rates (Ndung'u *et al.,* 2015) which would be readily accepted for adoption by farmers to restore levels of the widespread low P as well as increase crop yields. In this experiment, phosphorus fertilizer as TSP was also applied at lower levels of 0 and 15 kg P ha^{-1} due to the constraints of fertilizer costs and availability to most of the smallholder farmers in Nandi South. Common legumes grown in Nandi South are common beans, soya beans, green grams, groundnuts, lablab and cowpea. The specific legume whose production was addressed in this study was cowpea.

Cowpea (*Vigna unguiculata*) is one of the highly appreciated species of African leafy vegetables (Kelly, 2003). It belongs to the leguminosae family. Cowpea can be grown under rain fed conditions provided that the range of minimum and maximum temperatures are between 28 and 30°C (night and day) during the growing season (Madamba *et al.,* 2006). In western Kenya, the local brown and black-eye (with prolonged harvesting period and a finer texture) and the improved Ken Kunde (with high hybrid vigour but poor texture) cowpea varieties are commonly grown. Enzegu, Ilanda and Khaki (local brown and black-eye cowpea varieties) were tested in this study. The varieties are preferred by smallholder farmers for they produce both leaves as vegetable and grains. They mature within 105 – 150 days considered of medium to late maturity period (IITA, 2015). The cowpea seeds are a major source of plant proteins and vitamins for humans, feed for animals, and also a source of cash income (TJAI, 2010). The crop also plays an important role in providing soil N to cereal crops when grown in rotation, especially in areas where poor soil fertility is a problem. Its roots have nodules in which soil bacteria called Rhizobia inhabit and help to fix N from the air into the soil in the form of ammonium (Sheahan, 2012). Earlier studies using the N difference method indicated that cowpea fixed between 24 to 29 kg N ha^{-1} in Kenya with TSP fertilizer application at 30 kg P ha^{-1} (Ssali and Keya, 1980). In the same study, incorporation of cowpea residues into soils was estimated to supply the equivalent of 60 kg N ha^{-1} mineral N with an estimated balance of 42 kg N ha^{-1} to a succeeding maize crop. Other benefits include improvements of soil organic matter and structure (Hernanz *et al.,* 2009), P mobilization (Shen *et al.,* 2011), soil water retention and availability (Angus *et al.*, 2015), and reduced pressure from diseases and weeds (Jensen *et al.,* 2012).

Cowpea can be grown either in pure stand or in mixture with other crops such as maize. When produced as a green vegetable, they are commonly grown as a monocrop. During harvesting, sequential leaf harvests are made during the vegetative stage of the crop followed by seed harvesting at the end of the season (Ruto, 2008). Harvesting of leaves is a normal practice done by smallholder farmers in Nandi South sub-county during growth and development stages of cowpea to provide vegetable for the household. Since dry matter and grain yield production of cowpea may be affected as a result of harvesting the leaves or not, these variable was tested in the field trial.

The background of this study was thus to examine the growth, yield and P uptake responses of three local cowpea varieties (with or without leaf harvests) under optimal P supply (recommended), sub-optimal and under no P supply (reflecting the rate applied by peasant farmers) in Nandi South sub-county, western Kenya.

1.1 Statement of the Problem

Cowpea is a multipurpose legume that provides both leaves and grains and thus widen the farmer's food preference and security. In Nandi South, cowpea is grown for both leaves and grain. Average yield of dry cowpea seed of 175 kg ha^{-1} and 400 kg ha^{-1} of leaves has been reported in Kenya against the global average grain yield of 500 kg ha^{-1} and 750 kg ha^{-1} of leaves (FAOSTATS, 2016). The main constraints to high productivity of cowpea is the low level of available phosphorus in Nandi South soils which is widely spread (Sanginga *et al.*, 2000, Keino *et al.*, 2015) and poor leaf management practices (Afutu *et al.*, 2017). Phosphorus losses of 3 – 13 kg/ha/yr in western Kenya have been documented (Woomer *et al.*, 1997), contributing to low crop yields. Poor leaf harvesting methods affects the leaf and grain yield production of cowpea. Fageria *et al.* (2006) reported that partitioning of photosynthates and their effects on dry matter and grain distribution were influenced by leaf harvesting among other factors.

Although it is well recognized that application of mineral fertilizers plays an important role in the intensification of crop production (Ndungu *et al*., 2015), prohibitive and variable costs of mineral P fertilizers have discouraged their continued use by the resource-poor smallholder farmers to replenish soil fertility (Odendo *et al.*, 2002). This study seeks to identify local cowpea varieties that positively respond to fertilizer P application and leaf management practices while maintain high yields and high P uptake values under low soil P condition.

1.2 Justification

Cowpea is the third most important grain legume in Kenya after common bean (*Phaseolus vulgaris* L.) and pigeon pea (*Cajanus cajan* L.) (Kimiti *et al.,* (2009). The crop also provides alternative vegetable to the common leafy vegetables such as cabbage (*Brassica oleracea* L.var.capitata), kale (*Brassica oleracea*. L.var Acephala) and spinach (*Spinacia oleracea*) due to changes in consumer behavior (Abukutsa, 2011). Cowpea provides a cheap source of quality protein. The protein content of cowpea leaves ranges from 27 to 43% and protein concentration of the dry grain range from 21 to 33% (Ddamulira *et al.,* 2015; Abudulai *et al.,* 2016). Although they have a high nutritional value, cowpea grain are a minor component of food diet. That is the reason why efforts have been made to introduce cowpea in the food habits and farmer activities of Nandi South. Short growing period of cowpea, its multi-purpose use among other benefits has widen its preference by farmers in Nandi South. Local cowpea varieties were tested in this study because they are adapted to stressful environment such as high rainfall and more tolerant to soils low in P where many legumes such as (*Phaseolus vulgaris* L.) and pigeon pea (*Cajanus cajan* L.) fail to grow well (Bisikwa *et al.*, 2014; Ddamulira *et al.*, 2015). There has been sufficient evidence that use of inorganic fertilizers along with high-yielding cowpea varieties under good leaf management practices dramatically increase leaf and grain yield production (Mafongoya and Jiri 2016). This study therefore seeks to identify local cowpea varieties that positively respond to fertilizer P application and leaf management practices while maintain high yields and high P uptake values under low soil P condition of Nandi South.

1.3 Objectives

Overall objective

To improve cowpea production through P fertilization in Bonjoge and Koibem sites of Nandi South sub-county.

Specific objectives

1. To determine the effects of P fertilizer and leaf harvesting practices on growth, dry matter and grain yield of cowpea.
2. To determine the effects of P fertilizer and leaf harvesting practices on P uptake of cowpea
3. To investigate the effect of P fertilizer on final soil available P

1.4 Hypotheses

1. Application of P fertilizer and/or leaf harvesting practices improves growth, dry matter and grain yield of cowpea
2. Application of P fertilizer and leaf harvesting practices improves P uptake of cowpea
3. Application of P fertilizer will increase final soil available P

CHAPTER TWO

LITERATURE REVIEW

2.1 Food insecurity in Kenya

About 1.25 million people in Kenya are severely food insecure with 25% of the children being underweight (FAOSTAT, 2016). Cultivation of land has been left to smallholder farmers, who cultivate small plots of land to sustain their immediate family (Kariuki, 2011). Nearly 75% of the rural households in Nandi South are engaged in unproductive low input/low output subsistence farming (Kelly and Gordon, 2003). The farmers grow mainly subsistence crops such as maize, beans, cowpea etc. and one or more cash crops. This has increasingly threatened the food and nutritional security of rural smallholder communities in Nandi South and Kenya as a whole. For instance, on average, the productivity of cowpea in Kenya is less than 175 kg ha^{-1} grain yield and 400 kg ha^{-1} leaf yield against the global average of 500 kg ha^{-1} grain yield and 750 kg ha^{-1} leaves (FAOSTATS, 2016).

2.2 Soil nutrient loss in Nandi South, western Kenya

Studies by Kimetu *et al.*, (2009), showed soil nutrient loss in Nandi South following conversion of forests to croplands. During cultivation, carbon (C) stocks and soil nutrients in the region were rapidly lost from the surface soil. According to Kinyangi *et al.*, (2008), soil carbon and N levels reduced from 6 and 0.6 kg m^2 to 2 and 0.2 kg/m^2, respectively, after 105 years of continuous cultivation. Extractable P after several years of cultivation reduced significantly to values near zero. Massive P losses through P fixation, removal through crop residue and grain harvests, and losses through soil erosion have been reported by Muriuki and Qureshi, (2001). Studies by Woomer *et al.*, (1997), reported P losses ranging between 3 and 13 kg/ha per year in soils of western Kenya. Even with the application of inorganic P fertilizers, the agronomic efficiency has been reported to be only 10–25% within the first year of application, as a large portion of applied fertilizer P is fixed by soil and therefore become unavailable to plant (Thierry, 2008).

2.3 Soil fertility improvement in Nandi South, western Kenya

Organic and inorganic fertilizers are the major categories of fertilizers used by smallholder farmers in Nandi South. The inorganic fertilizers are in the form of ammonium nitrate, urea, rock phosphate, triple superphosphate, potassium chloride and potassium sulfate (Morris, *et al.*, 2007). Seventy percent of the farmers in Nandi South use inorganic fertilizers (GoK, 2007). Triple Super Phosphate is one of the inorganic fertilizers that replenishes the soil with nutrient P. It has the highest P content of dry fertilizers that do not contain N. Over 90 % of the total P in TSP is water soluble, so it becomes rapidly available for plant uptake (IITA 2015). TSP also contains 15 % calcium (Ca), providing an additional plant nutrient and liming effect in the long run.

In addition to the inorganic fertilizers, well-established nutrient management practices undertaken by smallholders include the use of manure and intercropping legumes while composting and agroforestry are relatively new and limited (Place *et al.* 2003). Manure use is widespread in areas where cattle are a component of the mixed cropping systems and more so in those areas that have intensive livestock systems. Manure releases nutrients to the soil slowly and helps soils to build organic matter with long-term benefits (Place *et al.* 2003; Palm *et al.* 1997).

2.4 Phosphorus uptake by plant roots

In plant nutrition, extractable P i.e. the portion of P in soil that readily taken up by plants, is more important than the total P. Plant roots absorb P from the soil solution present as mineral or inorganic P (P_i) i.e. application of TSP fertilizer and organic P (P_o) forms. In comparison to other macronutrients, P concentration in the soil solution is much lower and ranges from 0.001 mg/L to 1 mg/L (Brady and Weil, 2016). In general, roots absorb P in the form of either primary ($H_2PO_4^-$) or secondary (HPO_4^{-2}) orthophosphate, but can also absorb certain forms of organic P (Brady and Weil, 2016). Nutrient P moves to the root surface through diffusion (Brady and Weil, 2016). However, the presence of mycorrhizal fungi, which develop a symbiotic relationship with plant roots and extend threadlike hyphae into the soil, can enhance the uptake of P as well, especially in acidic soils that are low in available P (Tisdale *et al.*, 1990).

2.5 Effect of P on accumulation and partitioning of dry matter and grain

Phosphorus is fairly mobile in plants and will move from older to younger plant tissues (Van Straaten, 2007). Phosphorus plays a series of functions in structural nature in macromolecules such as nucleic acids and of energy transfer in metabolic pathways of biosynthesis and degradation (Brady and Weil, 2016). Phosphorus stimulates the development of roots which proliferate extensively in areas with higher P concentration. It is also needed in the final growth stages of a plant for seed filling and fruit formation. Meena *et al.* (2005) using chickpea and cowpea plants reported that dry matter production increased significantly with each increase in P levels. Singh *et al*., (2011) recorded that applied P increased leaf area and accumulation of more dry matter in cowpea. Phosphorus deficiency leads to early senescence of older leaves and stunting of new leaves (Moot *et al.,* 2007) resulting in reduced leaf area for light interception and consequently reduced dry matter yields. Fageria *et al.* (2006) reported that partitioning of photosynthates and their effects on dry matter distribution in cowpea were influenced by several environmental factors such as low temperature, drought and mineral nutrient deficiency.

2.6 Phosphorus requirement in cowpea production

The low production of cowpea among small-scale farmers in Nandi South can be attributed to the decreasing soil fertility resulting from many years of continuous cropping with little or no additional soil fertility amelioration technologies. Phosphorous is one of the most limiting soil nutrients (Kipkoech *et al*., 2010). Famers in the area, rarely can afford external inputs (Kipkoech *et al*., 2010). The most appropriate technologies for these farmers therefore, are those that require them to manipulate existing and affordable technologies to improve cowpea production. The low amounts of available soil P in Nandi South soils need supplemental P addition (Ndung'u *et al,* 2015). In either straight or compound form, fertilizer application at rates between 15 to 30 kg P ha^{-1} has been reported to significantly increase cowpea grain yield from 175 kg ha^{-1} to 300 kg ha^{-1}, even higher in a sole cropping season relative to no P input control (IITA, 2015).

2.7 Geographical distribution of cowpea in Africa

Today, cowpea is cultivated in the tropical, subtropical and warm temperate regions of the world. In Africa, it is grown mainly in Sub-Saharan lowlands, in East Africa, and from Ethiopia to the Cape (Singh *et al.*, 1997). Cowpea is cultivated extensively in 16 African countries, yielding 2/3 of world output estimated at 2.5 million tonnes of dry cowpea seed. The main African producer countries of cowpea are Nigeria, Niger, Burkina Faso, Ghana, Kenya, Uganda, Malawi and Senegal (Singh *et al.*, 1997). They are well adapted to semi-arid regions (annual precipitation of less than 600 mm) and sub-humid zones (1,000 and 1,500 mm). Most varieties need a minimum rainfall of 200 mm during a growing season (IITA, 2015). It is also a low-altitude plant whereby its flowering is hastened by high temperatures. The optimum temperature to their growth and development is 20 to 35°C higher by 3 to 4°C compared to *Phaseolus vulgaris* (IITA, 2015). Cowpea can grow in a wide range of soils, ranging from the sandy to the heavy clay types. It is well adapted to light sandy soils and well-aerated soils, where most other crops produce poorly and they do well on a slightly acid to neutral soil (Holford, 1997).

2.8 Importance of cowpea

Cowpea is an important crop globally. An estimated 14.5 million ha of land is planted to cowpea each year worldwide (IITA, 2015) while an estimated 38 million households (194 million people) grow cowpea in SSA. The area under cowpea in Kenya is estimated at 1800 ha excluding the area under the crop in home gardens (Muthamia and Kanampiu, 1996). To date, cowpea is the most extensively produced pulse crop in Sub-Saharan

Africa (SSA) (Walker, 2016). Kenya is among the top ten cowpea producing countries in Africa.

Cowpea is a major source of vegetable protein of between 23 - 30 % (Kenya National Academy of Science, 1994) and contains minerals; Ca and Fe and amino acids such as lysine, tryptophan and methionine which improve human nutrition and health status (Davis *et al.*, 2000). In Nandi South, cowpea are grown for seeds (shelled and dried), and for leaves that are consumed as green vegetables (Obiero, 2005). The dual purpose of cowpea makes it an attractive crop where land is becoming scarce (Singh *et al.*, 2003). The crop is used throughout its entire growing period, beginning with highly nutritious tender leaves immediately after emergence through the growing season to the grains after harvesting and lastly livestock fodder from all the above ground biomass (Obiero, 2005). Cowpea also plays a role in improving soil fertility.

Biological nitrogen fixation (BNF) can compensate for low soil N content based on the legume-Rhizobium symbiosis (Wagner, 2011). Cowpea may contribute substantially to the sustainability of cropping systems by fixing nitrogen (Giller, 2001). It is estimated that cowpea can fix up to 200 kg N ha^{-1} (Rusinamhodzi *et al.*, 2006; Adjei-Nsiah *et al.*, 2008) and can leave a positive soil N balance of up to 92 kg ha^{-1} (Rusinamhodzi *et al.*, 2006). Earlier studies using the N difference method indicated that cowpea fixed between 24 to 29 kg N ha^{-1} in Kenya (Ssali and Keya, 1980) and up to 201 kg N ha^{-1} in Ghana (Dakora *et al.*, 1987). In the same study, incorporation of cowpea residues into soils was estimated to supply the equivalent of 60 kg N ha^{-1} mineral nitrogen with an estimated balance of 42 kg N ha^{-1} to a succeeding maize crop.

2.9 Characteristics of cowpea and varieties

Cowpea is an annual herb with a strong principal root and many spreading lateral roots in surface soil. The root system having larges nodules is more extensive than those of soybean (IITA 2015). Growth forms vary and maybe erect, trailing, climbing or bushy, usually indeterminate under favorable conditions. Leaves are alternate and trifoliate usually dark green. The first pair of them is simple and opposite. Stems are striate, smooth or slightly hairy, sometimes tinged with purple. (Aveling, T., 1999). Flowers are self-pollinating and may be white, dirty yellow, pink, pale blue or purple in colour. They are arranged in raceme or intermediate inflorescences in alternate pairs. Flowers open in the early day and close at approximately midday, after blooming they wilt and collapse. Pollinating insect activities are beneficial in increasing the number of pod set, the number of seeds per pod or both; however, there are no recommendations for the use of pollinating insects on cowpeas. (McGregor, S. E., 1976). Fruits are pods that vary in size, shape, color and texture. They may be erect, crescent shaped or coiled. Usually yellow when ripe, but may also be brown or purple in colour. There are usually 8-20 seeds per pod. Seeds vary considerably in size, shape and colour. They are relatively large, 2-12 mm long and weigh 5-30 g/100 seeds. Seed shape could be reniform or globular. The testa may be smooth or wrinkled; white, green, red, brown, black, speckled, blotched, eyed or mottled in colour.

In western Kenya, the local brown and black-eye (with prolonged harvesting period and a finer texture) and the improved Ken Kunde (with high hybrid vigor but poor texture) cowpea varieties are commonly grown. There also exist improved cowpea varieties in Kenya developed in research institutions and universities. In this study, three local cowpea varieties were tested namely; Enzegu, Ilanda and Khaki. Enzegu and Khaki grow more upright and are bush-type cultivars better suited for intercropping. The varieties flower within 75 – 80 days and matures within 105 – 135 days considered of medium maturity period (IITA, 2015). Ilanda however, have a vining or spreading growth habit preferred mainly for cover crop use. The variety flower within 90 – 95 days and matures within 120 – 150 days considered of late maturity period (IITA, 2015).The color of Enzegu is brown with grey speckles, Khaki is cream and Ilanda black.

2.10 Cowpea propagation, planting, husbandry and harvesting

Cowpea seeds are planted about 20 to 45 cm apart and are often grown as an intercrop with pearl millet, sorghum or maize at a wide spacing (total plant population 10,000 – 20,000 plants ha^{-1}) (IITA, 2015). When produced as a green vegetable, they have commonly grown as a monocrop in rows 30 to 45 cm apart with 8 to 15 cm between plants. Some very drought resistant types may grow for two seasons in the farm. When sown in rows, the seed-rate is 10 – 40 kg ha^{-1} (Singh *et al.*, 1997). Most cowpea crops are rain-fed, a few are irrigated and others use residual moisture in the soil after harvest of a rice crop (IITA, 2015). Losses due to weeds such as *Strigagesnerioides* (Purple witchweed) can be 30 – 65% (Singh *et al.*, 1997). Cowpea field is thus weeded at least three times in the crop cycle before flowering. However, fast growth and spreading habit of traditional cowpea varieties suppress weeds. During harvesting, sequential leaf harvests are made during the vegetative stage of the crop followed by seed harvesting at the end of the season (Obiero, 2005).

2.11 Effect of harvesting regimes on cowpea yields

Productivity and yield efficiency must be considered in leaf harvesting strategies in order to obtain cowpea leaves as vegetables and grain. Bubenheim *et al.* (1990) suggested that a given cowpea crop should be grown to supply either leaves or seeds, but not both. For the two cultivars they studied, yield efficiency was suppressed by a combination of leaf and seed harvest. However, other researchers have shown that, within limits, leaves can be harvested from cowpea without adversely affecting seed yield (Imungi and Potter, 1983; Oomen and Grubben, 1977). The relationship between leaf harvest and seed yield varies among cultivars; although some cultivars show adverse effects, leaf harvest does not appear to compromise seed yield of other cultivars (Bittenbender *et al.,* 1984). These conflicting results about the effect of leaf harvest on seed yield have been attributed to differences between cultivars. Gaps identified in the study is to select a local cowpea cultivar that can produce vegetable yield without compromising on the grain yield and positively responds to P fertilizer in soils of Nandi South.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was conducted in two phases: on-farm and greenhouse experiments. On-farm trials were set during the long-rains cropping season between March and July in the year 2009, on smallholder farms in Bonjoge and Koibem, Nandi South sub-county, western Kenya (Figure 1). Thereafter, a greenhouse experiment was conducted for 3 months, between February and April 2016, at the school of Agriculture and Biotechnology, University of Eldoret. The time difference between the on-farm and greenhouse experiments was due to financial challenges. In particular, there was a financial constraint that hindered the achievement of the third objective of this study. The greenhouse experiment was, therefore, conducted to provide soil residual P data that would reflect the effect of P application after cowpea growth and development. The experiment used soils obtained from sites studied during the on-farm experiment.

According to earlier studies by Kimetu *et al.,* (2009), Bonjoge and Koibem sites in Nandi South sub-county were reported as having soils with soil pH less than 6, with limiting N and P, as a result of continuous cultivation coupled with the use of acidifying fertilizers, mainly DAP and urea. The county has favorable climatic conditions for crop production. Both Bonjoge and Koibem areas receive two rainy seasons: long and short rains that starts from March to June and from August to October, respectively. Bonjoge area receives an average of 2000 mm while Koibem area receives an average of 2024 mm. Mean monthly temperatures of the two study areas ranges between 18 °C and 19 °C.

Meteorological Station, Kakamega, (2009). The on-farm trial in Bonjoge was in Mr. Fredrick Kiptanui's farm that lies between latitude E 034° 54' 42.6"and longitude N 00° 06' 52.2", elevated at 1674 m above sea level. The on-farm trial in Koibem was at Mrs. Lilian Koech's farm that lies between latitude E 024° 54' 31.9".and longitude N 00° 09' 28.2", elevated at 1700 m above sea level. The predominant soil type in Bonjoge and Koibem area are mainly Ferralo-chromic Acrisols and Humic Acrisols, respectively, according to Jaetzold and Schimdt (2011).

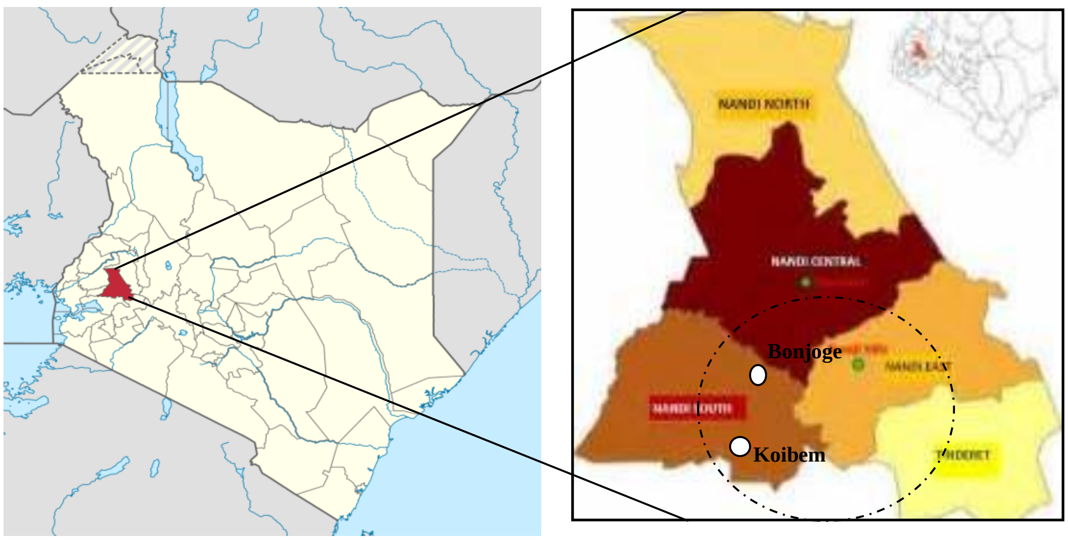

Figure 1: Map showing study areas in Nandi South sub-county, western Kenya

(Source: Jaetzold and Schimdt, 2011)

3.2 On-farm Experimental structure

3.2.1 Cowpea varieties and source

Three local cowpea varieties namely; Enzegu, Ilanda and Khaki (Table 1), were tested in the study. These varieties are widely preferred by smallholder farmers in Nandi South for they produce both leaves as vegetable and grains, and are adapted to heavy rainfall areas (Personal communication farmers, 2009). The seeds were sourced from vendors at Kakamega.

Table 1. General description of the cowpea varieties tested

Variety	Seed Code	Cropping Season	Maturity Period	Growth Habit	Seed Size
Enzegu	EN	LR	Medium	Erect	small
Ilanda	IL	LR	Late	Spreading	small
Khaki	KH	LR	Medium	Erect	small

Source: www.kalro.org/cowpea

3.2.2 Treatment description and experimental design

The on-farm experiment comprised a factorial combinations of 3 cowpea varieties, 3 levels of P and two leaf management practices, laid out in Randomized Complete Block Design (RCBD) with three replications. The three cowpea varieties were tested at different P levels of 0, 15, and 30 kg ha^{-1}. According to FURP (1994), 30 kg P ha^{-1} is the recommended P fertilizer application rate for optimal legume production in Nandi South. However, due to the constraints associated with fertilizer costs, lower fertilizer application rates at 0 and 15 kg P ha^{-1} were also experimented. Forty-five days after planting, 2 leaf management practices, were employed on the cowpea stand; with leaf harvesting and without leaf harvesting. In Nandi South, it is normal practice for smallholder farmers to pick young leaves for vegetable purposes. Older leaves accumulate dust or get spattered with mud from raindrops if not harvested. Table 2 shows the treatment description of the on-farm experiment. The effective plot size measured 5.67 m^2 with a plant and row spacing of 15 cm and 45 cm, respectively.

Table 2. Treatment description for the on-farm experiment

Cowpea varieties	Phosphorus rates	Leaf harvesting	Treatment code
Enzegu	0	+	EN P1 L1
	15	+	EN P2 L1
	30	+	EN P3 L1
	0	-	EN P1 L2
	15	-	EN P2 L2
	30	-	EN P3 L2
Ilanda	0	+	IL P1 L1
	15	+	IL P2 L1
	30	+	IL P3 L1
	0	-	IL P1 L2
	15	-	IL P2 L2
	30	-	IL P3 L2
Khaki	0	+	KH P1 L1
	15	+	KH P2 L1
	30	+	KH P3 L1
	0	-	KH P1 L2
	15	-	KH P2 L2
	30	-	KH P3 L2

Where; EN- Enzegu, IL- Ilanda, KH- Khaki, P- Phosphorus, L1- Leaf harvesting, L2- Without leaf harvesting. Minus sign (-) indicates where a variable was not considered in a specific treatment while a plus (+) implies the opposite.

3.2.3 Installation and management of the experiment

3.2.3.1 Land preparation

In all the plots, land was prepared using manual labor with the main activities being slashing of vegetation and digging and leveling the ground. The site was staked into individual plots to conform to the actual field measurements in the experimental layout in figure 2.

	+LH			-LH		
	EN	IL	KH	EN	IL	KH
P1	T1	T2	T3	T1	T2	T3
P2	T4	T5	T6	T4	T5	T6
P3	T7	T8	T9	T7	T8	T9

Figure 2: Diagram of a field replicate used in 2009 long rain season on-farm experiment

Key:
Bold lines: Show long rain season 2009 experimental area
Fertilizer factor: P rates {No P (P1), 15 kg P ha^{-1} (P2) and 30 kg P ha^{-1} (P3)}.
Leaf harvesting factor: {With leaf harvest (+LH), without leaf harvest (-LH).
Varietal factor: Enzegu (EN), Khaki (KH) and Ilanda (IL)
T1 – T9: Treatment 1 to 9
Plot size: 2.7 m x 2.1 m. Each plot separated by 1 m paths

3.2.3.2 Planting

Cowpea seeds were planted along furrows spaced 45 cm apart. Within the furrows, holes were spaced 15 cm apart using marked sisal twine. Two seeds were placed in each hole, about 1-inch-deep and covered with soil. Upon emergence, one seedling was thinned leaving one per hole.

3.2.3.3 Fertilizer application

Phosphorus fertilizer as Triple superphosphate (TSP) was applied at the rates of 0 (control), 67.2, 134.1 g per plot equivalent to 0 (control), 15 and 30 kg P ha^{-1} respectively. Spot application of TSP fertilizer per planting hole was done using calibrated scoops.

3.2.3.4 Weed control

Weeding of the plots was done manually once every two weeks and stopped at flower initiation.

3.2.3.5 Pest and disease control

Upon emergence, the cowpea was sprayed with Diazinon to control aphids (*Aphia craccivora*) (10 ml to 20 litres of water) at intervals of two weeks. Spraying was stopped when the seedlings had developed four leaves but the same was continued using Dithane M 45 (15g to 20 litres of water) to control fungal diseases like Anthracnose (*Colletotrichum lindermuthianum*).

3.2.3.6 Soil sampling for initial characterization

A total of 15 samples were taken randomly from each study site for soil initial characterization before the onset of the on-farm and greenhouse experiments. Auguring of soil (5 cores /replicate / site) was done to a depth of 0 – 20 cm and the soil was thoroughly mixed to make a composite and air-dried in the greenhouse at the soil science department, University of Eldoret.

3.2.4 Field data collection

3.2.4.1 Seedling survival

Seedling population was recorded at 7 days and at 35 days after emergence. This was done by counting the plants manually. The cowpea seedling survival rate was determined by the formula:

$$\%\text{ seedling survival} = \frac{\text{P1} - \text{P2}}{\text{P1}} X100$$

Where P1; Seedling population at 7 days, P2; Seedling population at 35 days

3.2.4.2 Leaf harvesting

Leaf harvesting was done 42 days after seedling emergence from half the number of the total number of plots (54), to compare cowpea dry matter yields between leaf harvested and non-leaf harvested plots. The harvesting was done by tipping off the apical part of the crop leaving behind three primary branches (Obiero, 2005). Fresh weight of the leaf harvested per plot was recorded. Samples of the fresh leaf harvested was later weighed and dried in an oven (65^{o} C) until a constant weight was achieved. The leaf weight would later be added to give the total dry aboveground biomass at the end of the study.

3.2.4.3 Cowpea biomass

During on-farm trial, hailstone severely damaged cowpea at flowering stage at both sites. As a result, grain yield was not determined. Fresh weight of the total aboveground biomass was determined 84 days after emergence. This was done by discarding two outer rows per plot and two plants per row at the end of each plot. Thus, four inner rows of cowpea per plot were harvested giving an effective harvest area of 5.67 m^2. The cowpea plants were cut at ground level. The fresh weights were recorded and samples of well-mixed fresh biomass placed into paper bags. The samples were weighed fresh and dried in an oven (65^{o} C) until a constant weight was achieved. The constant weight of the dry matter yields that included the dry weight of leaf harvested and dry weight of aboveground biomass was then recorded and used to compute dry matter yields per plot. The yield was calculated using the relationships:

$$\text{Yields/plot} = \frac{(\text{Total fresh weight x Sample dry weight})}{\text{Sample fresh weight}}$$

$$\text{Yields } \left(\frac{\text{Kg}}{\text{ha}}\right) = \frac{(\text{Yields per plot x 10,000})}{\text{Effective area harvested}}$$

3.3. Greenhouse experimental structure

3.3.1 General description of the location and agro-ecological conditions

The greenhouse experiment was carried out at the School of Agriculture and Biotechnology, University of Eldoret, Uasin Gishu county, Rift valley. The site IS located at an altitude of 2120 m above sea level, between 00° 34' N latitude and 35°18' E longitude and receives average annual rainfall of 900 – 1300 mm.

3.3.2 Cowpea varieties and source

The three local cowpea varieties namely; Enzegu, Ilanda and Khaki previously tested during the on-farm experiment were tested during the greenhouse experiment to assess the effect of P fertilizer and the cowpea varieties on soil residual P. The seeds were sourced from vendors at Kakamega Municipal Market.

3.3.3 Treatment description and experimental design

The greenhouse experiment was laid out as a factorial in Complete Randomized Design (CRD) with three replications. The experiment comprised of 9 treatment combinations of 3 cowpea varieties and 3 levels of P; 0, 15 and 30 kg ha^{-1} (Table 3).

Table 3. Treatment description during greenhouse experiment

Cowpea varieties	Phosphorus rates	Treatment code
Enzegu	0	EN P1
	15	EN P2
	30	EN P3
Ilanda	0	IL P1
	15	IL P2
	30	IL P3
Khaki	0	KH P1
	15	KH P2
	30	KH P3

Where; EN- Enzegu, IL- Ilanda, KH- Khaki, P- Phosphorus.

3.3.4 Installation and management of the experiment

3.3.4.1 Soil sampling, preparation and potting

Soils were randomly collected adjacent to the experimental fields during the 2009 long rains on-farm experiments at Bonjoge and Koibem. The soils were dug at 0 – 30 cm depth. They were air-dried under shade, ground with a wooden roller and then passed through a 5 mm mesh to fill 2 kg plastic pots. The pots were spaced 10 cm from each other in the greenhouse to conform to the actual greenhouse experimental layout in figure 3

	EN	IL	KH
P1	T1	T2	T3
P2	T4	T5	T6
P3	T7	T8	T9

Figure 3: Diagram of greenhouse replicate

Key:
Bold lines: Show greenhouse 2016 experimental pots
Fertilizer factor: P rates {No P (P1), 15 kg P ha^{-1} (P2) and 30 kg P ha^{-1} (P3)}.
Varietal factor: Enzegu (EZ), Khaki (KH) and Ilanda (IL)
T1 – T9: Treatment 1 to 9,
Pot size: 2 kg plastic pots. The pots were spaced 10 cm from each

3.3.4.2 Planting

Two cowpea seeds were sown at the center of each pot, one-inch-deep and covered with soil. Upon emergence, one seedling was thinned leaving one per hole.

3.3.4.3 Fertilizer application

Granules of phosphorus fertilizer as TSP was crushed into powder and applied to pots in quantities equivalent to the rates of 0 control, 15 and 30 kg P ha^{-1}.

3.3.4.4 Watering

After sowing, soils were maintained at 75 % of field capacity by frequent watering using deionized water. The pots were randomized in the greenhouse after each watering to eliminate any environmental effects, especially solar radiation.

3.3.4.5 Weed control

Weeding of the pots was done by hand picking once every week until the end of the cropping cycle.

3.3.4.6 Pest and disease control

Upon emergence, the cowpea was sprayed with Diazinon to control aphids (*Aphia craccivora*) (10 ml to 20 litres of water) regularly at intervals of two weeks. Spraying was stopped when the seedlings had developed four leaves but the same was continued using Dithane M 45 (15g to 20 litres of water) to control fungal diseases like Anthracnose (*Colletrotricum lindermuthianum*).

3.3.5 Greenhouse data collection

3.3.5.1 Plant measurement of crop height

Plant height measurement was taken 35 days after sowing to capture the response of P fertilizer application in regard to growth habits of the cowpea tested. A meter rule was used to take measurements from ground level to the tip of the main stem. The plant height in centimeters was then recorded.

3.3.5.2 Determination of number of pods per pot

During greenhouse experiment, grain yield was harvested at physiological maturity. Cowpea pods were picked to ascertain the number of pods per plant at 105 days after seed emergence. The pods on each cowpea plant per pot were extracted manually, counted and the mean obtained per pot basis (ISTA 1995a).

3.3.5.3 Determination of 50 – seed weight

Determination of 50 – seed weight was done seventy days after emergence when the plant had attained physiological maturity. The pods were sun-dried for 24 hours and threshed. Three replicates of 50 seeds were obtained from each pot seed yield, weighed and the average weight determined to obtain 50 seed weight (ISTA, 1995b).

3.4 Laboratory analyses

Soil sample weighing about 500 g was taken to the laboratory for analysis. The soil was air dried and lumps crushed gently to separate the soil from foreign matter. The analyses were carried out according to the procedures outlined in Okalebo *et al.,* (2002).

3.4.1 Soil analysis

3.4.1.1 Soil pH

Soil pH was determined by adding 50 ml of distilled water into 20 g of soil (< 2.0 mm) in a beaker and the suspension shaken for 10 minutes. The suspension was allowed to stand for 30 minutes and then shaken again for 2 minutes. The pH reading was taken using a glass electrode on a digital pH meter.

3.4.1.2 Determination of organic carbon (% C) in soils

This was determined using the Walkey and Black (1934) oxidation method. This method involves complete oxidation of soil organic carbon using sulphuric acid (H_2SO_4) and dichromate solution. The excess of unreacted dichromate is then determined by titration using ferrous ammonium sulphate. Thus, 0.3 g of ground (0.02 mm) soil was weighed into a block digestion tube and 5 ml of standard potassium dichromate solution and 7.5 ml concentrated H_2SO_4 added. The tube was placed in a preheated block at 145 - 155 °C for 30 minutes. It was then removed and allowed to cool. The digest was quantitatively transferred into a 100-ml conical flask and 0.3 ml of 1, 10 phenanthroline monohydrate indicator solution added and mixed thoroughly. The digest was titrated using standard ferrous ammonium sulphate solution to end-point with a colour change from greenish to brown. The titre was recorded and the mean of the two reagent blanks recorded. Organic carbon was calculated using the formula:

$$\% \text{ Organic carbon} = \frac{\text{T} \times 0.2 \text{ X } 0.3}{\text{Sample weight}}$$

Where T= Titre volume (Okalebo *et al.*, 2002).

3.4.1.3 Determination of soil particle size composition (Hydrometer method)

This involved the dispersion of soil particles into different constituents using sodium hexametaphosphate solution (Calgon) and subsequent sedimentation of the particles. This allowed the particles to settle at the bottom of the cylinder according to their sizes, density, viscosity and temperature of the liquid (Stokes law). Sand particles settled first (at 40 seconds) then silt (at 2 hours) and lastly clay. Fifty g of air-dried soil (<2 mm) was saturated with water and 10 ml of Calgon. The mixture was then allowed to stand for 10 minutes and further dispersion was done with use of an electric high-speed stirrer for 2 minutes. After this, the mixture was transferred into a graduated cylinder and the hydrometer carefully inserted. Water was then added up to the 1130 ml mark. The hydrometer was removed and the cylinder covered by hand which was then inverted 10 times. The hydrometer reading was then taken at exactly 40 seconds after which the hydrometer was removed. The cylinder was again inverted 10 times and left to stand for 2 hours before the final readings for both temperature and hydrometer were taken. Percent of sand silt and clay was determined by the following formulae:

$$\% \text{ Sand} = \frac{\text{H1 X 100}}{50}$$

$$\% \text{ Clay} = \frac{\text{H2 X 100}}{50}$$

$$\% \text{ Silt} = 100 - \frac{(\% \text{ Sand} + \% \text{ Clay})}{50}$$

Where; H1 = Hydrometer reading after 40 seconds

H2 = Hydrometer reading after 2 hours

A textural triangle was then used to assign the soil into its textural class.

3.4.1.4 Determination of available P (Olsen Procedure)

a) Soil extraction

Two and a half grams of air-dry soil was weighed into a 150 ml polythene shaking bottle. Fifty ml of the Olsen extracting solution (0.5 M, $NaHCO_3$, pH 8.5) was added to each shaking bottle. The contents were stoppered and shaken on a mechanical- electric shaker for 30 minutes. The suspension was filtered through the Whatman No. 42 filter paper. The filtrate was used for the calorimetric P measurement.

b) Calorimetric P measurements

Ten ml of each P standard solution (0. 0.5, 1, 2.5, 5, 7.5, 10 and 12.5 ppm P), 10 ml of sample filtrate and two reagent blanks were pipetted into 50 ml volumetric flasks. Five ml of boric acid was added to each flask to suppress the interference of fluorides and sulphates. Beginning with the standards and blanks, 10 ml of the ascorbic acid reducing agent was added to each flask and the contents made to mark with distilled water. The flasks were then stoppered, shaken well and allowed to stand for one hour for full-color development. The absorbance of the solution was measured at a wavelength setting of 880 nm (Murphy and Riley, 1962) using a spectrophotometer. P was calculated using the following formula:

Taking a 10 ml aliquot of the sample

ppm in soil = ppm in solution x 100

3.4.1.5 Determination exchangeable cations in soils

In the determination of exchangeable cations, a soil sample is extracted with an excess of 1 M NH_4OAc (ammonium acetate) solution such that the maximum exchange occurs between the NH_4^+ and the cations originally occupying the exchange sites on the soil surface. The amounts of exchangeable Na, K, Ca and Mg in the extract are determined by flame photometry (Na and K) and by atomic absorption spectrophotometry (Ca and Mg). Lanthanum (La) or strontium (Sr) is added as a releasing agent to prevent formation of refractory compounds, which may interfere with the determinations, for instance, phosphate.

a) Soil extraction

Five g of air-dry soil (<2 mm) were weighed into a clean plastic bottle with a stopper. 100 ml of 1 M NH_4OAc solution at pH 7 was added and the contents shaken for 30 minutes. Suspensions were filtered through Whatman No. 42 filter paper. This soil extract (A) was later used for the determination of Ca, Mg, and K cations.

b) Determination of Ca, and K

Exchangeable Ca, and K was determined on 5 ml aliquot of the solution A above by adding 1 ml of 26.8% lanthanum chloride solution to minimize the interference of PO_4^{3-} and SO_4^{2-}. The solution was made to 50 ml mark with 1 M NH_4OAc extractant solution and then sprayed into the atomic absorption spectrophotometer (AAS) flame for Ca determination and into the flame of the flame photometer for Na and K determinations. The titre reading was read off from the graph and blank corrections made.

Calculation

Ca/ K (cmol kg^{-1} air dry soil) = graph reading from AAS or Flame photometer, respectively.

c) Determination of Mg

Two ml of the soil-extractant solution A was pipetted into a 50-ml volumetric flask. Five ml of 5000 ppm Sr was added to suppress interference of PO_4^{3-} and SO_4^{2-} and the contents filled up to the mark with 1 M NH_4OAc extracting solution. The solution was sprayed into the flame of the atomic absorption spectrophotometer. The titre reading was read off from the graph and blank corrections made.

Calculation

Mg (cmol kg^{-1} air-dry soil) = graph reading x 17.

3.4.2 Plant tissue analysis

Plant samples weighing 0.5 g was taken to the laboratory for analysis. The plant samples were oven-dried and then ground (0.02 mm) for plant tissue analysis. The analyses were carried out according to the procedures outlined in Okalebo *et al.*, (2002).

3.4.2.1 Digestion Procedure for Total P in plants

The principle involved in the digestion of plant materials was the oxidation of organic into inorganic soluble P components (phosphates) in H_2SO_4/Se/$LiSO_4$/H_2O_2 mixture. Plant samples weighing 0.3 g were used. Into a dry digestion tube, 4.4 ml of the digestion mixture was added to the sample. Two reagent blanks were also included. The samples were digested at 360 ^{0}C in the block digester for 3 hours until the solution became clear. After cooling, 25 ml of distilled water was added to the tubes to enhance sedimentation and then transferred quantitatively into 50-ml volumetric flasks. Contents were allowed to settle and made to mark with distilled water for P determination.

3.4.2.2 Determination of total Phosphorus (P %)

Standard phosphate solutions of 0, 1, 2, 3, 4, 5, 6 ml of the working solution (10 ppm), 5 ml of plant digest and two reagent blanks were pipetted into 50-ml volumetric flasks. Ten ml of the ascorbic acid reducing agent was added to each flask and topped to 50 ml mark with distilled water and the contents shaken well. The contents were then left to stand for 1 hour for blue colour development. Absorbance was measured at 880 nm wavelength using a spectrophotometer. A blank correction was made. A graph of absorbance against P concentration was plotted and solution concentration for each sample calculated. Percent P in the sample was obtained using the formula:

$$\% \text{ P in sample} = \frac{C \times 0.025}{W}$$

Where W = Weight of sample used, C = blank corrected concentration for sample solution in ppm P.

3.5 Statistical analysis of data

To assess the effect of P fertilizer and leaf management practices on cowpea production and residual P during the experiments, the following General Linear Model (GLM) models were used for analysis of variance (ANOVA) with use of Statistical Analysis System (SAS), windows version 8, computer software package (Table 4). Means of yields, soil and plant data were compared using Standard Error difference (SED) and significant difference detected at 95% confidence level for all variables.

Table 4. Models used for the on-farm and greenhouse experiments

Experiment	**Dependent Variable**	**Model**
On-farm	Survival	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + \sum_{ijk}$
	Dry matter yield	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + L_k + P_iL_k + V_jL_k + P_iV_kL_j + \sum_{ijkl}$
	P uptake	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + L_k + P_iL_k + V_jL_k + P_iV_kL_j + \sum_{ijkl}$
Greenhouse	Plant Height	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + \sum_{ijk}$
	Number of pods	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + \sum_{ijk}$
	Weight of 50 seeds	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + \sum_{ijk}$
	Final soil P	$X_{ijkl} = \mu + P_i + V_j + P_iV_j + \sum_{ijk}$

Where:

X_{ijkl} = Plot or pot observations

E_{ijkl}= Error during on–farm experiment

E_{ijk}= Error during greenhouse experiment

μ = Overall mean of plot observations,

P_i = phosphorus fertilizer effect,

V_j= varietal effect,

P_iV_j = interaction effect of phosphorus fertilizer and variety

L_k =leaf management effect

P_iL_k=interaction effect of phosphorus fertilizer and leaf management

V_jL_k= interaction effect of variety and leaf management

$P_iV_kL_j$= interaction effect of phosphorus fertilizer, variety and leaf management

$\sum_{ijkl}$ = Experimental error

Y = Residual available phosphorus

X = Phosphorus application rates

CHAPTER FOUR

RESULTS

4.1. Soil characteristics of the study sites

Table 5 shows the results of the soil samples taken from the study sites in Bonjoge and Koibem before the on-farm and greenhouse experiments. Slight differences in Soil pH, available P, organic C, total N, exchangeable bases (K, Ca, Mg) and soil particle size (sand, silt and clay) were observed between sites for both experiments.

Soil pH values were 5.81 and 6.12 during on-farm experiment and 5.42 and 5.76 during greenhouse experiment in Bonjoge and Koibem sites, respectively.

Soil available P was 1.4 % and 8.3 % higher in Koibem than in Bonjoge during the on-farm and greenhouse experiments, respectively.

Carbon to Nitrogen ratios of 11:1 and 10:1 were observed during the on-farm experiment while C: N ratios of 10:1 and 9:1 were observed during the greenhouse experiment in Bonjoge and Koibem sites, respectively.

In both experiments, the soil exchangeable bases were generally low. During on-farm experiment, Ca and Mg in Koibem increased by 25 % and 33 % respectively, while K reduced by 13 % compared to Bonjoge. However, during the greenhouse experiment, Ca, Mg and K in Koibem increased by 22 %, 20 % and 141 %, respectively compared to Bonjoge.

From the soil particle size analysis, the soils at Bonjoge and Koibem were classified as sandy loam and sandy clay loam, respectively.

Table 5. Soil physicochemical characteristics of surface horizon (0 – 20 cm) taken before the on-farm and the greenhouse experiments

Soil Parameters	**On-farm**		**Greenhouse**	
	Bonjoge	Koibem	Bonjoge	Koibem
Soil pH (H_2O)	5.81	6.12	5.42	5.76
Available Phosphorus (mg kg^{-1})	9.25	9.38	7.95	8.61
Carbon (%)	3.53	3.91	2.49	3.53
Nitrogen (%)	0.31	0.38	0.26	0.41
Exchangeable bases (cmol$_c$ kg^{-1})				
Calcium	7.20	9.00	1.66	2.02
Magnesium	4.80	6.40	3.58	4.29
Potassium	1.01	0.88	0.51	1.23
Soil particle size (%)				
Sand	71	67	65	69
Silt	22	24	23	18
Clay	7	9	12	13

Soils analyzed for greenhouse experiment were sampled 7 years after the on-farm experiment using the two soils from the on-farm experiment.

4.2 On-farm experiment

4.2.1 Effect of P fertilizer and leaf harvesting on cowpea growth (Survival count)

Table 6 shows mean survival rate (%) of cowpea at 35 days after emergence as influenced by P application levels and leaf harvesting practices on three cowpea varieties during the on-farm experiment. There was significant difference *($P \leq 0.05$)* on mean survival count among cowpea varieties tested in terms of P fertilizer applied and leaf harvesting practices employed. In Bonjoge, Ilanda (with or without leaf harvesting) gave significant *($P \leq 0.05$)* survival counts with fertilizer application at 0 and 15 kg ha^{-1}. Ilanda without leaf harvesting and with no fertilizer application gave significantly *($P \leq 0.05$)* highest survival count at 62 %. At the highest fertilizer application rate, significant *($P \leq 0.05$)* survival count were also observed with the same variety when leaves were harvested. Khaki (without leaf harvesting) gave significantly lowest survival count at 16 % with fertilizer application at 15 kg ha^{-1}.

In Koibem, significantly *($P \leq 0.05$)* highest survival count at 81 % was observed with Enzegu (without leaf harvesting) and with fertilizer application at 30 kg ha^{-1}. Other treatments that gave significant *($P \leq 0.05$)* survival counts were Ilanda with leaf harvesting at fertilizer application rate of 0 kg ha^{-1}, Khaki with leaf harvesting at fertilizer application rate of 15 kg ha^{-1} and lastly Khaki without leaf harvesting at fertilizer application rate of 30 kg ha^{-1}.

Table 6. Survival rate (%) of cowpea at 35 days after emergence as affected by P application rates and leaf harvesting practices

Cowpea varieties	Phosphorus rates (kg P ha^{-1})	Leaf harvesting	Mean survival rate (%)	
			Bonjoge	Koibem
Enzegu	0	+	31	53
		-	39	63
	15	+	37	59
		-	41	63
	30	+	39	67
		-	43	81*
Ilanda	0	+	49*	49*
		-	62*	64
	15	+	48*	55
		-	49*	69
	30	+	25*	68
		-	42	57
Khaki	0	+	30	58
		-	34	68
	15	+	38	40*
		-	16*	56
	30	+	42	61
		-	26*	70*
Means			38	61
SE			8.1	8.3

**-Significant values at 0.05, SE: Standard Error at 0.05, Minus sign (-) indicates where a variable was not considered in the specific treatment while a plus (+) implies the opposite.*

There was significant *($P \leq 0.05$)* interaction between varieties and fertilizer application on survival count (Table 7). In Bonjoge, Ilanda at 56 % and 49 % gave significantly *($P \leq 0.05$)* higher survival counts compared to Khaki at 32 % and 27 % at fertilizer application rate of 0 and 15 kg ha^{-1}. In Koibem, Enzegu (74 %) and Khaki (48 %) gave significantly *($P \leq 0.05$)* highest and lowest survival counts with fertilizer application at 30 and 15 kg ha^{-1}. There was significant *($P \leq 0.05$)* interaction between cowpea varieties and leaf harvesting practices on survival count (Table 8).

Table 7. Survival rate (%) of cowpea at 35 days after emergence as affected by the interaction between varieties and P application rates

Cowpea varieties	Phosphorus rates (kg P ha^{-1})	Bonjoge	Koibem
Enzegu	0	35	58
	15	39	61
	30	41	74*
Ilanda	0	56*	57
	15	49*	62
	30	34	63
Khaki	0	32*	63
	15	27*	48*
	30	34	66
Means		38	61
SE		5.8	5.9

**-Significant values at 0.05, SE: Standard Error at 0.05*

Table 8. Survival rate (%) of cowpea at 35 days after emergence as affected by interaction between cowpea varieties and leaf harvesting practices

Cowpea varieties	Leaf harvesting	Bonjoge	Koibem
Enzegu	+	36	60
	-	41	69*
Ilanda	+	41	57
	-	51*	64
Khaki	+	36	53*
	-	26	65
Means		38	61
SE		4.7	4.8

**-Significant values at 0.05, SE: Standard Error at 0.05, Minus sign (-) indicates where a variable was not considered in the specific treatment while a plus (+) implies the opposite.*

In Bonjoge, Ilanda (without leaf harvesting) gave significantly *($P \leq 0.05$)* highest survival count at 51%. In Koibem, Enzegu (without leaf harvesting) and Khaki (with leaf harvesting) gave highest and lowest significant *($P \leq 0.05$)* survival count value at 69 % and 53 % respectively.

4.2.2 Dry matter yields as influenced by P fertilizer rates and leaf harvesting practices

Mean cowpea dry matter yield (consisting of above ground matter biomass with leaf yields) were significantly *($P \leq 0.05$)* influenced by the application of P fertilizer and leaf harvesting practices (Table 9). In Bonjoge, Ilanda (without leaf harvesting) gave significant *($P \leq 0.05$)* dry matter yield with fertilizer application at 0 and 30 kg ha^{-1}. However, Khaki (with or without leaf harvesting) gave significant *($P \leq 0.05$)* dry matter yield at no fertilizer application. Significantly *($P \leq 0.05$)* largest dry matter yields (442 kg ha^{-1}) were observed at fertilizer application rate of 15 kg ha^{-1} with the same variety (without leaf harvesting).

In Koibem, Enzegu (with leaf harvesting) gave significant *($P \leq 0.05$)* dry matter yield at no fertilizer application. However, the same variety (with or without leaf harvesting) gave significant *($P \leq 0.05$)* dry matter yield with fertilizer application at 15 and 30 kg ha^{-1}. Ilanda (with or without leaf harvesting) gave significant *($P \leq 0.05$)* dry matter yield with no fertilizer application. The same variety (without leaf harvesting) gave significantly *($P > 0.05$)* smallest dry matter yield with fertilizer application at 15. Khaki (without leaf harvesting) gave significantly *($P \leq 0.05$)* largest dry matter yield (712 kg ha^{-1}) with fertilizer application at 15 kg ha^{-1}.

Table 9. Dry matter yield (*kg ha*$^{-1}$) of cowpea as affected by P application rates and leaf harvesting practices during the on-farm experiment

Cowpea varieties	Phosphorus rates	Leaf management practices	Bonjoge	Koibem
Enzegu	0	+	75	220*
		-	203	429
	15	+	75	498*
		-	40	276*
	30	+	107	225*
		-	70	508*
Ilanda	0	+	133	262*
		-	315*	647*
	15	+	151	433
		-	52	187*
	30	+	72	203*
		-	16*	370
Khaki	0	+	346*	342
		-	452*	450
	15	+	190	712*
		-	442*	248*
	30	+	50	274*
		-	105	474*
Means			161	375
SE			135	85

**-Significant values at 0.05, SE: Standard Error at 0.05, Minus sign (-) indicates where a variable was not considered in the specific treatment while a plus (+) implies the opposite.*

There was significant *($P \leq 0.05$)* interaction between cowpea varieties and P fertilizer application on dry matter yield (Table 10). In Bonjoge, Enzegu gave significant *($P \leq 0.05$)* dry matter yield with fertilizer application at 30 kg ha^{-1}. Significantly *($P \leq 0.05$)* largest and lowest dry matter of 273 kg ha^{-1} and 55 kg ha^{-1} were observed with Khaki with fertilizer rate at 30 kg ha^{-1} and the control, respectively. In Koibem, Enzegu and Khaki gave significant *($P \leq 0.05$)* dry matter yields with fertilizer application at 30 and 15 kg ha^{-1}, respectively.

Table 10. Dry matter yield (*kg ha*$^{-1}$) of cowpea as affected by the interaction between varieties and P application rates during the on-farm experiment

Cowpea varieties	Phosphorus rates (kg P ha^{-1})	Bonjoge	Koibem
Enzegu	0	75	359
	15	142	348
	30	268*	527*
Ilanda	0	155	327
	15	194	425
	30	251	362
Khaki	0	55*	392
	15	34*	279*
	30	273*	361
Means		161	375
SE		95	60

**-Significant values at 0.05, SE: Standard Error at 0.05*

Table 11. Dry matter yield (**kg ha**$^{-1}$***) of cowpea as affected by interaction between varieties and leaf harvesting practices during on-farm experiment***

Cowpea varieties	Leaf harvesting	Bonjoge	Koibem
Enzegu	+	184	275*
	-	139	548*
Ilanda	+	77*	234*
	-	324*	509*
Khaki	+	178	237*
	-	64*	451*
Means		161	375
SE		78	49

**-Significant values at 0.05, SE: Standard Error at 0.05, Minus sign (-) indicates where a variable was not considered in the specific treatment while a plus (+) implies the opposite.*

Enzegu gave significantly *($P \leq 0.05$)* largest dry matter yields at 527 kg ha^{-1} with fertilizer application at 30 kg ha^{-1}.

There was significant *($P \leq 0.05$)* interaction between cowpea varieties and leaf harvesting practices on dry matter yield (Table 11). In Bonjoge, Ilanda (with or without leaf harvesting) and Khaki (without leaf harvesting) gave significant *($P \leq 0.05$)* dry matter yield. In Koibem, Enzegu gave significantly *($P \leq 0.05$)* largest dry matter yield at 548 kg ha^{-1}.

4.2.3 Uptake of P on cowpea dry matter as influenced by P fertilizer rates and leaf harvesting practices

Table 12 show the treatment means of mean P uptake values as affected by P rates and leaf management practices on three cowpea varieties in study sites. In Bonjoge, Ilanda (without leaf harvesting) gave significant *($P \leq 0.05$)* P uptake values with fertilizer application at 30 kg ha^{-1}. However, Khaki (with leaf harvesting) gave significantly *($P \leq 0.05$)* largest P uptake value (1.07 kg ha^{-1}) with the same fertilizer application rate.

In Koibem, Enzegu (with leaf harvesting) gave significant *($P \leq 0.05$)* P uptake values with fertilizer application at 0 and 15 kg ha^{-1}. The same variety without leaf harvesting gave significantly *($P \leq 0.05$)* largest P uptake values (1.8 kg ha^{-1}) with fertilizer application at 30 kg ha^{-1}. Ilanda (with or without leaf harvesting) gave significant *($P \leq 0.05$)* P uptake values with fertilizer application at 15 kg ha^{-1}. At fertilizer application of 30 kg ha^{-1} however, the variety gave significant *($P \leq 0.05$)* P uptake values with leaf harvesting. Khaki (without leaf harvesting) gave significant *($P \leq 0.05$)* P uptake values with no fertilizer application. However, the same variety with leaf harvesting gave significant *($P \leq 0.05$)* P uptake values with fertilizer application at 15 and 30 kg ha^{-1}.

Table 12. Phosphorus uptake (*kg ha^{-1}*) as affected by P application rates and leaf harvesting practices during the on-farm experiment

Cowpea varieties	Phosphorus rates	Leaf management practices	Bonjoge	Koibem
Enzegu	0	+	0.13	0.40*
		-	0.17	0.97
	15	+	0.30	0.53*
		-	0.27	1.00
	30	+	0.53	0.90
		-	0.30	1.80*
Ilanda	0	+	0.20	0.50
		-	0.43	0.97
	15	+	0.17	0.47*
		-	0.53	1.43*
	30	+	0.10	0.63*
		-	0.63*	0.93
Khaki	0	+	0.07	0.73
		-	0.17	1.07*
	15	+	0.10	0.43*
		-	0.03	0.70
	30	+	1.07*	0.57*
		-	0.17	0.93
Means			0.30	0.83
SE			0.23	0.19

**-Significant values at 0.05, SE: Standard Error at 0.05, Minus sign (-) indicates where a variable was not considered in the specific treatment while a plus (+) implies the opposite*

There was significant *($P \leq 0.05$)* interaction between cowpea varieties and P fertilizer application on P uptake (Table 13). In Bonjoge, Khaki gave significant *($P \leq 0.05$)* P uptake values with all fertilizer application levels. At fertilizer application rate of 30 kg ha^{-1} the variety gave significantly *($P \leq 0.05$)* largest P uptake value at 0.62 kg ha^{-1}. In Koibem, Enzegu gave significant *($P \leq 0.05$)* P uptake values with fertilizer application at 0 and 30 kg ha^{-1} while Khaki gave significant *($P \leq 0.05$)* P uptake values with fertilizer application at 15 kg ha^{-1}.

Table 13. Phosphorus uptake (*kg ha^{-1}*) as affected by the interaction between varieties and P application rates during the on-farm experiment

Cowpea varieties	Phosphorus rates (kg P ha^{-1})	Bonjoge	Koibem
Enzegu	0	0.15	0.68*
	15	0.28	0.77
	30	0.42	1.35*
Ilanda	0	0.32	0.73
	15	0.35	0.95
	30	0.38	0.78
Khaki	0	0.12*	0.90
	15	0.07*	0.57*
	30	0.62*	0.75
Means		0.30	0.83
SE		0.16	0.13

**-Significant values at 0.05, SE: Standard Error at 0.05*

Table 14. Phosphorus uptake (*kg ha^{-1}*) as affected by interaction between varieties and leaf harvesting practices during on-farm experiment

Cowpea varieties	Leaf harvesting	Bonjoge	Koibem
Enzegu	+	0.32	0.61*
	-	0.24	1.26*
Ilanda	+	0.16*	0.53*
	-	0.53*	1.11*
Khaki	+	0.41	0.58*
	-	0.12*	0.90
Means		0.30	0.83
SE		0.13	0.11

**-Significant values at 0.05, SE: Standard Error at 0.05. Minus sign (-) indicates where a variable was not considered in the specific treatment while a plus (+) implies the opposite*

There was significant *($P \leq 0.05$)* interaction between cowpea varieties and leaf harvesting practices on P uptake (Table 14). In Bonjoge, Ilanda (with or without leaf harvesting) and Khaki (without leaf harvesting) gave significant *($P \leq 0.05$)* P uptake values. However the largest P uptake value of 0.53 kg ha^{-1} was observed with Ilanda without leaf harvesting.

In Koibem, Enzegu and Ilanda (with or without leaf harvesting) gave significant *($P \leq 0.05$)* P uptake values. Khaki however, gave significant *($P \leq 0.05$)* P uptake values when leaf harvesting was done. The largest P uptake value of 1.26 kg ha^{-1} was observed with Enzegu without leaf harvesting.

4.3 Greenhouse experiment

4.3.1 Effect of P fertilizer rates on cowpea growth (Height)

Table 15 shows the treatment means of mean plant height as influenced by P application rates on three cowpea varieties during the greenhouse experiment. In Bonjoge, Enzegu and Ilanda gave significant *($P \leq 0.05$)* plant height values with fertilizer application at 30 kg ha^{-1}. However, plant height of Khaki was significant *($P \leq 0.05$)* at the three fertilizer application rates. Ilanda gave significantly *($P \leq 0.05$)* highest plant height value at 30.3 cm. In Koibem, Enzegu and Khaki gave significant *($P \leq 0.05$)* plant height values at no fertilizer application. However, Ilanda gave significantly *($P \leq 0.05$)* higher plant height values of 29.9 cm and 32.5 cm with fertilizer application rates at 15 and 30 kg ha^{-1}, respectively.

Table 15. Mean height (cm) as affected by P application during the greenhouse Experiment

	Bonjoge				Koibem			
Varieties	P (Kgha^{-1})			Variety	P (Kgha^{-1})			Variety
	0	*15*	*30*	Means	*0*	*15*	*30*	Means
Enzegu	24.6	25.2	29.6*	26.5ab	22.6*	27.2	27.8	25.9b
Ilanda	25.0	28.8	30.3*	28.1a	26.0	29.9*	32.5*	29.5a
Khaki	23.4*	23.3*	29.6*	25.4b	24.3*	26.5	27.0	25.9b
Fertilizer Means	24.3b	25.8b	29.8a		24.3b	27.9a	29.1a	
Grand Means	26.6				27.1			
$SE_{(Pho)}$	1.2				0.8			
$SE_{(Var)}$	1.2				0.8			
$SE_{(Pho*Var)}$	2.2				1.5			

**-Significant values at 0.05, ns – not significant at 0.05, SE: Standard Error at 0.05, Pho: Phosphorus, Var: Variety*

There was significant *($P \leq 0.05$)* interaction between cowpea varieties and P fertilizer application on plant height. Ilanda gave significantly *($P \leq 0.05$)* higher plant height at 28.1

cm and 29.5 cm compared to Khaki at 25.4 cm and 25.9 cm in Bonjoge and Koibem, respectively.

4.3.2 Grain yields as influenced by P fertilizer (number of pods and grain weight)

Table 16 and 17 shows the treatment means of grain yields in terms of the number of pods and grain weight as influenced by P application rates on three cowpea varieties during the greenhouse experiment. Fertilizer addition significantly *($P<0.05$)* influenced the mean number of pods per plant. In Bonjoge, Enzegu gave significant *($P\leq0.05$)* number of pods with all the fertilizer application rates. Ilanda and Khaki gave significantly *($P\leq0.05$)* highest number of pods at 7 with fertilizer application rate at 30 kg ha^{-1}. In Koibem, Enzegu and Ilanda gave significantly *($P\leq0.05$)* lowest and highest number of pods at 5 and 8, with fertilizer application rate at 15 and 30 kg ha^{-1}, respectively.

Fertilizer addition significantly *($P<0.05$)* influenced the average weight of 50 seeds per plant. In Bonjoge, Enzegu (4.1g) gave significantly *($P\leq0.05$)* lowest weight of 50 seeds per plant with no fertilizer application. However, Ilanda (7.7g) and Khaki (6.6g) gave significantly *($P\leq0.05$)* higher weight of 50 seeds per plant with fertilizer application rate at 30 kg ha^{-1} compared to the other rates. In Koibem, Enzegu gave significant *($P\leq0.05$)* lower weight of 50 seeds per plant with fertilizer application rate at 0 and 15 kg ha^{-1} compared to the other varieties. Ilanda on the other hand, gave significantly higher *($P\leq0.05$)* weight of 50 seeds per plant at 6.8g and 7g with fertilizer application rate at 15 and 30 kg ha^{-1}, respectively. Khaki (7g) gave significantly *($P\leq0.05$)* highest weight of 50 seeds per plant with fertilizer application rate at 30 kg ha^{-1}

Table 16. Average number of cowpea pods per plant as affected by P application rates during greenhouse experiment

Varieties	Bonjoge				Koibem			
	P (K gha^{-1})			Variety Means	P (K gha^{-1})			Variety Means
	0	*15*	*30*		*0*	*15*	*30*	
Enzegu	4*	4*	4*	4b	5*	6	6	6b
Ilanda	5	5	7*	6a	7	8*	8*	8a
Khaki	4*	5	7*	5a	6	6	7	6b
Fertilizer Means	4a	5ab	6a		6b	7a	7a	
Grand Means	5				7			
$SE_{(Pho)}$	0.4				0.5			
$SE_{(Var)}$	0.4				0.5			
$SE_{(Pho*Var)}$	0.7				0.8			

**-Significant values at 0.05, ns – not significant at 0.05, SE: Standard Error at 0.05, Pho: Phosphorus, Var: Variety*

Table 17. Average weight of 50 cowpea seeds per plant (g) as affected by P application rates during greenhouse experiment

Varieties	Bonjoge				Koibem			
	P (Kg ha^{-1})			Variety Means	P (Kg ha^{-1})			Variety Means
	0	*15*	*30*		*0*	*15*	*30*	
Enzegu	4.1*	4.9	5.0	4.7b	5.2*	5.3*	6.5	5.7b
Ilanda	5.5	6.1	7.7*	6.4a	6.0	6.8*	7.0*	6.6a
Khaki	5.0	5.8	6.6*	5.8a	5.5*	5.8	7.0*	6.1ab
Fertilizer Means	4.9b	5.6ab	6.4a		5.6b	6.0b	6.8a	
Grand Means	5.6				6.1			
$SE_{(Pho)}$	0.4				0.3			
$SE_{(Var)}$	0.4				0.3			
$SE_{(Pho*Var)}$	0.6				0.5			

**-Significant values at 0.05, ns – not significant at 0.05, SE: Standard Error at 0.05, Pho: Phosphorus, Var: Variety*

4.3.3 Effect of final soil available P as influenced by treatments during greenhouse experiment

The result on the final available soil P as influenced by P fertilizer rates and cowpea varieties is presented in Table 18. Fertilizer addition significantly *(P<0.05)* influenced the final soil available P.

In Bonjoge, significant *(P≤0.05)* available P values were observed with Enzegu and Ilanda at fertilizer application rate of 15 kg ha^{-1}. Significantly *(P≤0.05)* highest available P value of 8.56 mg kg^{-1} were observed with Khaki at fertilizer application rate of 30 kg ha^{-1}.

In Koibem, Enzegu gave significant *(P≤0.05)* available P values with fertilizer application rate of 30 kg ha^{-1} while Ilanda gave significantly highest available P values of 8.48 mg kg^{-1} with fertilizer application rate of 15 kg ha^{-1}.

Table 18. Final soil available P as influenced by treatments during greenhouse experiment

	Bonjoge				Koibem			
Varieties	P (Kg ha^{-1})			Variety Means	P (Kg ha^{-1})			Variety Means
	0	*15*	*30*		*0*	*15*	*30*	
Enzegu	7.75	6.54*	8.00	7.73ab	7.83	7.96	7.64*	7.89a
Ilanda	7.78	7.05*	7.45	7.03b	7.98	8.48*	8.20	8.25a
Khaki	7.69	7.50	8.56*	8.00a	7.85	8.33	8.16	8.00a
Fertilizer Means	7.43a	7.43a	7.92a		7.81a	8.22a	8.11a	
Grand Means	7.59				8.05			
$SE_{(Pho)}$	0.29				0.21			
$SE_{(Var)}$	0.29				0.21			
$SE_{(Pho*Var)}$	0.50				0.37			

**-Significant values at 0.05, ns – not significant at 0.05, SE: Standard Error at 0.05, Pho: Phosphorus, Var: Variety*

CHAPTER FIVE

DISCUSSION

5.1 Soil characteristic of the study sites

Initial soil analysis confirmed low nutrient status and fertility variations of the study sites. The soils were limiting in N, P, K and exchangeable bases. According to KARI's National Agricultural Research Laboratories (Kanyanjua *et al.,* 2002), soil pH values ranged from moderately acidic to slightly acidic. Soil pH between 6 and 7 is the most suitable with cowpea, since most nutrients are readily available for the crop (Kanyanjua *et al.,* 2002).

According to the Agronomy Guide, 2009 – 2010, soil available P were limiting; below the critical level of 10 mg kg^{-1} considered available for crop use. Due to the acidic nature of the soils, soluble sources of P, such as those in fertilizers may have been fixed, and in time, form highly insoluble compounds of Fe and Al compounds (Sanchez *et al.*, 1997). The low amounts of available soil P in these soils need supplemental P addition (Ndung'u *et al,* 2015).

The sites showed moderate to high levels of organic C and total N (Kanyanjua *et al.*, 2002). Moderate levels of C:N ratio may have resulted from residual effects of maize stover incorporation, a common land management practice by smallholder farmers in these sites, perceived to be a means of replenishing soil fertility (Nekesa *et al.,* 1999).

Cations were below the critical level considered available for cowpea use (Agronomy Guide, 2009 – 2010). The low levels of cations suggest possible leaching down the horizons, and their place taken up by Fe and Al ions. The main soil classes found in the region are the Acrisols (Ultisols) (FAO/UNESCO, 1996). The textural class indicated that the soil had a high capacity to store nutrients (Kolay, 1993).

5.2 On-farm experiment

5.2.1 Effect of P fertilizer rates and leaf harvesting practices on growth (survival) and dry matter yield of cowpea

Cowpea survival rate was affected by P fertilizer application and leaf harvesting practices. According to Haruna and Usman, (2013), P application adds the assimilative capacity of the plants by increasing the leaf area or photosynthetic activity, ensuring an effect on the roots. This may partly explain the positive responses of phosphate fertilizer on survival count. Recent studies also showed that the nutrition information on phosphorus has strong effects on photosynthesis (Haruna and Usman, 2013). However, other than P fertilizer application survival count may be affected by many factors such as soil characteristics, varieties grown, climate, tillage systems, crop management, fertilizer management and interactions with other nutrients (Bordeleau and Prevost, 1994) that a crop depends upon.

There were in inconsistencies in survival count as influenced by interaction of variety and leaf harvesting practices. Since leaf removal affects cowpea's ability to recover from defoliation (Barrett, 1987), this may have resulted into the inconsistencies in survival count.

Significant increases in dry matter yield following P fertilizer application confirmed the role of P as an important nutrient element that affects dry matter accumulation in crops

(Vance, 2001). Studies by Meena *et al.* (2005) using chickpea plants, reported that dry matter production increased significantly with each increase in P fertilizer levels. Singh *et al.,* (2011) recorded that applied P increased leaf area and accumulation of more dry matter in cowpea. Many other experiments made with P showed that there is usually a linear relationship between increments of P and yield of cowpea (Haruna and Usman, 2013; Ndor *et al.,* 2012).

There were in inconsistencies in dry matter yield as influenced by interaction of variety and leaf harvesting practices. Studies by Bubenheim *et al.* (1990) showed that yield efficiency was suppressed by a combination of leaf and seed harvest. However, other researchers have shown that, within limits, leaves can be harvested from cowpea without adversely affecting dry matter yield (Imungi and Potter, 1983; Oomen and Grubben, 1977). The green portions of the plant, including leaves, form the photosynthetic machinery of the plant. Removal of leaves, therefore, constitutes the reduction in photosynthetic tissue, hence reduction in photo-assimilates used for growth. The reduction in photo-assimilation rate is even more pronounced if tender leaves are removed (Saidi *et al.,* 2007). The timing of leaf removal affects cowpea's ability to recover from defoliation (Barrett, 1987). This partly explains the reduction in dry matter yield of some varieties following leaf harvesting.

5.2.2 Uptake of P on cowpea dry matter as influenced by P fertilizer rates and or leaf harvesting practices

Fertilizer P application resulted in a positive effect on the mean P uptake values of cowpea. This may partly be attributed to the inherent soil properties, the addition of supplemental fertilizer and climate conditions that affect crop growth and how crops respond to applied P fertilizer (Brady and Weil, 2016). In the highly weathered soils of western Kenya, crops often respond positively to P addition (Kisinyo, 2011).

Leaf harvesting directly reduced the amount of P accumulated in the dry matter hence the low P uptake values. Variation in P uptake among varieties when leaf management practices were employed may partly be explained by the differences in the rooting characteristics, vegetative growth and time of maturity (Singh *et al.*, 1997, CSIR/CR1, (2012).

5.3 Greenhouse experiment

5.3.1 Effect of P fertilizer rates on cowpea growth (plant height) and grain yield

Cowpea height was significantly increased by the application of P fertilizer. According to Tisdale *et al.,* (1990), P in particular, is needed in plants at early stages of growth since it is involved in the shoot and root development. This result is in conformity to the results observed by Krasilnikoff *et al*. (2003) and Nyoki *et al*. (2013). This could be attributed to the fact that P is required in large quantities in the shoot and root tips where metabolism is high and cell division is rapid (Ndakidemi and Dakora, 2007). Thus, an indication that the cowpea varieties utilized the P fertilizer applied judiciously in the growth and development processes. Phosphorus forms an important component in all living cells and promotes the growth of root systems (Dube *et al.,* 2013). This results in efficient plant nutrient absorption from the soil, which eventually translates into increased height growth through cell division of meristematic tissues (Dube *et al.,* 2013).

The number of pods per plant and weight of 50 seeds per plant were directly proportional to P fertilizer application rates, with the control treatment producing the least values compared to the other P rates. This compares favorably with reports by other researchers (Haruna and Usman, 2013; Ndor *et al.,* 2012; Singh *et al.,* 2011), who also discovered a significant increase in pod number and seed weight of cowpea in response to P application. The positive response of the measured yield characters of cowpea to P application could be attributed to the role of P in seed formation and grain filling (Haruna, 2011). Numerous studies have shown that P fertilizers can significantly increase grain yields (Bationo *et al.,* 1995; Kolawale *et al.,* 2000).

5.3.2 Effect of P fertilizer application on final soil available P

Addition of P fertilizer and varietal effect of cowpea influenced the final soil available P in both sites. Application of P provided higher levels of soil available P in both soils. According to Coutinho *et al.*, (2014), the soil available P depended on factors such as the doses and sources of phosphorus used, a method of application of phosphate fertilizers, management, temperature, soil type, application time, soil moisture and type of crop. In this sense, the soil available P effect in the soil has been evaluated by several authors in common bean as a function of soil pH (Rosa *et al.*, 2016). This partly explains the variation in soil available P treatments tested.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

6.1.1 On-farm experiment

- Soil available P is limiting in both Bonjoge and Koibem sites. Application of P is, therefore, recommended for improved cowpea production on these soils.

- The survival count of cowpea was influenced by P fertilizer addition. In Bonjoge and Koibem, Ilanda and Enzegu (without leaf harvesting) produced the largest biomass at the highest P fertilizer rates. This suggest that the two cowpea varieties would be efficient in dry matter accumulation when no leaves are harvested.

- Khaki (with leaf harvesting) in Bonjoge and Enzegu (without leaf harvesting) in Koibem at the highest P fertilizer rate produced the largest P uptake. This suggest that the two cowpea varieties would be efficient in P uptake while employing appropriate leaf harvesting practice.

6.2.1 Greenhouse experiment

- Growth of cowpea (plant height) was enhanced following P application, a reflection of its effect on vegetative growth. Ilanda with highest P fertilizer application produced the highest number of pods and grain weight at both sites. This suggests the need for P fertilizer addition for improved grain yields.

- Treatment with Enzegu at the highest P fertilizer application gave higher final soil available P values.

6.2 RECOMMENDATION

- Ilanda and Enzegu (without leaf harvests) are best producers of dry matter yield in smallholder farms of Nandi South when P is applied at 30 kg P ha^{-1} rate. Ilanda is the best overall in grain yield production.

- Khaki (with leaf harvest) in Bonjoge and Enzegu (without leaf harvest) in Koibem are best at P uptake when P is applied at 30 kg P ha^{-1} rate.

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APPENDICES

On-farm experiment

1. ANOVA Tests of Between-Subjects Effects in Bonjoge

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	Survival	85544.000[a]	18	4752.444	23.683	.000
	Drymatter	2361586.000[b]	18	131199.222	2.406	.012
	Paccumulation	8.223[c]	18	.457	2.902	.003
Phosphorus	Survival	193.444	2	96.722	.482	.621
	Drymatter	295806.778	2	147903.389	2.712	.080
	Paccumulation	.780	2	.390	2.479	.098
Variety	Survival	2010.111	2	1005.056	5.009	.012
	Drymatter	56819.111	2	28409.556	.521	.598
	Paccumulation	.060	2	.030	.192	.826
Management	Survival	35.852	1	35.852	.179	.675
	Drymatter	11324.519	1	11324.519	.208	.651
	Paccumulation	.000	1	.000	.001	.973
Phosphorus * Variety	Survival	1569.111	4	392.278	1.955	.122
	Drymatter	58762.111	4	14690.528	.269	.896
	Paccumulation	.551	4	.138	.875	.489
Phosphorus * Management	Survival	449.593	2	224.796	1.120	.337
	Drymatter	26039.148	2	13019.574	.239	.789
	Paccumulation	.283	2	.141	.898	.416
Variety * Management	Survival	1111.593	2	555.796	2.770	.076
	Drymatter	331109.481	2	165554.741	3.036	.060
	Paccumulation	1.045	2	.522	3.319	.048
Phosphorus * Variety * Management	Survival	363.630	4	90.907	.453	.770
	Drymatter	185852.185	4	46463.046	.852	.502
	Paccumulation	.704	4	.176	1.118	.363
Error	Survival	7224.000	36	200.667		
	Drymatter	1963292.000	36	54535.889		
	Paccumulation	5.667	36	.157		
Total	Survival	92768.000	54			
	Drymatter	4324878.000	54			
	Paccumulation	13.890	54			

2. ANOVA Tests of Between-Subjects Effects in Koibem

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Model	Survival	206566.667[a]	18	11475.926	54.957	.000
	Drymatter	8820468.667[b]	18	490026.037	22.425	.000
	Paccumulation	44.110[c]	18	2.451	23.463	.000
Phosphorus	Survival	1093.815	2	546.907	2.619	.087
	Drymatter	46312.259	2	23156.130	1.060	.357
	Paccumulation	.455	2	.227	2.177	.128
Variety	Survival	300.481	2	150.241	.719	.494
	Drymatter	41411.704	2	20705.852	.948	.397
	Paccumulation	.343	2	.171	1.640	.208
Management	Survival	1157.407	1	1157.407	5.543	.024
	Drymatter	869950.296	1	869950.296	39.812	.000
	Paccumulation	3.578	1	3.578	34.257	.000
Phosphorus * Variety	Survival	994.185	4	248.546	1.190	.332
	Drymatter	145011.407	4	36252.852	1.659	.181
	Paccumulation	1.617	4	.404	3.871	.010
Phosphorus * Management	Survival	187.148	2	93.574	.448	.642
	Drymatter	1792.926	2	896.463	.041	.960
	Paccumulation	.028	2	.014	.135	.874
Variety * Management	Survival	67.815	2	33.907	.162	.851
	Drymatter	10845.481	2	5422.741	.248	.782
	Paccumulation	.260	2	.130	1.246	.300
Phosphorus * Variety * Management	Survival	609.963	4	152.491	.730	.577
	Drymatter	94885.630	4	23721.407	1.086	.378
	Paccumulation	.495	4	.124	1.185	.334
Error	Survival	7517.333	36	208.815		
	Drymatter	786659.333	36	21851.648		
	Paccumulation	3.760	36	.104		
Total	Survival	214084.000	54			
	Drymatter	9607128.000	54			
	Paccumulation	47.870	54			

a. R Squared = .965 (Adjusted R Squared = .947)

b. R Squared = .918 (Adjusted R Squared = .877)

c. R Squared = .921 (Adjusted R Squared = .882)

Greenhouse experiment

1. Bonjoge

Dependent Variable: **Plant Height**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	223.4600000	37.2433333	6.59	0.0006
Error	20	113.0274074	5.6513704		
Corrected Total	26	336.4874074			

R-Square	Coeff Var	Root MSE	Height Mean
0.664096	8.920924	2.377261	26.64815

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	44.6096296	22.3048148	3.95	0.0359
pho	2	146.8807407	73.4403704	13.00	0.0002
var	2	31.9696296	15.9848148	2.83	0.0828

Dependent Variable: **Number of pods**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	27.11111111	4.51851852	3.28	0.0206
Error	20	27.55555556	1.37777778		
Corrected Total	26	54.66666667			

R-Square	Coeff Var	Root MSE	noofpods Mean
0.495935	22.96541	1.173788	5.111111

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	1.55555556	0.77777778	0.56	0.5774
pho	2	11.55555556	5.77777778	4.19	0.0301
var	2	14.00000000	7.00000000	5.08	0.0164

Dependent Variable: **Weight of 50 seeds**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	25.64888889	4.27481481	5.15	0.0024
Error	20	16.61407407	0.83070370		
Corrected Total	26	42.26296296			

R-Square	Coeff Var	Root MSE	weight of 50seeds Mean
0.606888	16.16859	0.911429	5.637037

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	0.85851852	0.42925926	0.52	0.6042
pho	2	10.45851852	5.22925926	6.29	0.0076
var	2	14.33185185	7.16592593	8.63	0.0020

Dependent Variable: FINAL **Soil Available Phosphorus**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	12.06315556	2.01052593	3.00	0.0295
Error	20	13.40045185	0.67002259		
Corrected Total	26	25.46360741			

R-Square	Coeff Var	Root MSE	soilP Mean
0.473741	11.57475	0.818549	7.071852

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	2.61765185	1.30882593	1.95	0.1679
pho	2	3.33347407	1.66673704	2.49	0.1084
var	2	6.11202963	3.05601481	4.56	0.0233

2. Koibem

Dependent Variable: **Plant Height**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	210.6088889	35.1014815	11.28	<.0001
Error	20	62.2607407	3.1130370		
Corrected Total	26	272.8696296			

R-Square	Coeff Var	Root MSE	Height Mean
0.771830	6.511517	1.764380	27.09630

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	22.3251852	11.1625926	3.59	0.0467
pho	2	111.6918519	55.8459259	17.94	<.0001
var	2	76.5918519	38.2959259	12.30	0.0003

Dependent Variable: **Number of pods**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	33.11111111	5.51851852	5.62	0.0015
Error	20	19.62962963	0.98148148		
Corrected Total	26	52.74074074			

R-Square	Coeff Var	Root MSE	noofpods Mean
0.627809	15.28505	0.990697	6.481481

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	5.40740741	2.70370370	2.75	0.0878
pho	2	6.74074074	3.37037037	3.43	0.0522
var	2	20.96296296	10.48148148	10.68	0.0007

Dependent Variable: Weight of 50 seeds

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	11.50000000	1.91666667	4.01	0.0085
Error	20	9.55185185	0.47759259		
Corrected Total	26	21.05185185			

R-Square	Coeff Var	Root MSE	weight of 50 seeds Mean
0.546270	11.28125	0.691081	6.125926

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	0.15629630	0.07814815	0.16	0.8502
pho	2	7.51629630	3.75814815	7.87	0.0030
var	2	3.82740741	1.91370370	4.01	0.0344

Dependent Variable: FINAL **Soil Available Phosphorus**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	19.43546667	3.23924444	14.10	<.0001
Error	20	4.59305185	0.22965259		
Corrected Total	26	24.02851852			

R-Square	Coeff Var	Root MSE	soilP Mean
0.808850	6.603196	0.479221	7.257407

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	1.23342963	0.61671481	2.69	0.0927
pho	2	3.62580741	1.81290370	7.89	0.0030
var	2	14.57622963	7.28811481	31.74	<.0001