EVALUATION OF DRYLAND MAIZE/ PIGEONPEA INTERCROPPING UNDER VARIABLE PHOSPHORUS APPLICATION RATES

by

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DECLARATION

I declare that the Full-dissertation hereby submitted to the University of Limpopo, for the degree of Master of Agricultural Management in Plant Production has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

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Nndwambi, FH (Mr) Date

DEDICATION

I dedicate this piece of work to beloved parents Mr. Robert Ndanganeni and Grace Naledzani Nndwambi. I also dedicate this dissertation to my wife Manthakha Lufuno and my kids, Ndodzo, Vino and Fhatuwani Herman Junior Nndwambi who have supported me throughout the process.

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ABSTRACT

Information on the performance of the maize and pigeonpea intercropping system under dryland conditions of South Africa is scanty. The aim of this study was to determine the optimum P level and productivity of pigeonpea and maize under the dryland intercropping system. Five P rates (0, 15, 30, 45, and 60 kg P ha^{-1}) were applied to both sole and pigeonpea intercropped with maize in a randomized complete block design with 4 replicates. Growth parameters and yield and yield attributes of pigeonpea and maize were measured to determine performance of both crops.

There were significant differences in grain yield of pigeonpea as influenced by P rates in both seasons. Highest grain yields of 781 kg ha^{-1} during 2009/10 and 894 kg ha^{-1} during 2010/11 were obtained at P rate of 45 kg ha^{-1}. Cropping system significantly influenced grain yield of pigeonpea in 2010/11 season with 37.1% higher pigeonpea grain yield from intercropped plots than in sole pigeonpea plots. There was 21.8% increase in grain yield of pigeonpea across two seasons as influenced by P rate. Maize grain yield showed little response to P rate only during the first season. However, highest maize grain yield of 1699 kg ha^{-1} was obtained at 60 kg P ha^{-1} during the 2009/10 season. Maize grain yield was only significantly influenced by cropping system during the 2010/11 season where sole plots achieved higher grain yield of 4148 kg ha^{-1} compared to 3297 kg ha^{-1} from intercrop plots. The results revealed that P application increased grain yield of pigeonpea significantly, especially in intercropped plots. The calculated total land equivalent ratio (LER) for the two crops gave positive and higher than one values, which suggests a favourable grain yield advantage for maize/pigeon pea intercrop.

Key words: Maize, Pigeonpea, Grain yield, Intercropping, Phosphorus rates, Dryland

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Background to the study

Intercropping of legumes with cereals is an age-long practice, particularly among rural smallholder (SH) farmers. Cereal/legume intercropping is widely practiced in South Africa, including Limpopo province. The practice is often employed for the purpose of economizing inorganic nitrogen fertilizer use thereby increasing and sustaining productivity and profitability per unit area (Lingaraju *et al*., 2008). In South Africa, cereal/legume intercrop trials have been reported by different authors. These include maize (*Zea mays*) and pigeonpea (*Cajanus cajan*) intercropping systems in Mpumalanga, South Africa (Mathews *et al*., 2001b), and maize and drybean intercrop (Kutu and Asiwe, 2010). However, the success of such intercrop studies have largely depended on the compatibility of the component crops to clearly lessen the negative effects of shading and resource-use constraints arising from competition. Moisture stress is one likely adverse effect of cereal/legume intercropping in Limpopo due to the fact that most SH farmers who practise it are located in marginal rainfall areas. Pigeonpea, a drought tolerant, deep rooted and slow-growing plant (Willey and Reddy, 1981) is thus a potential grain legume crop that may be successfully intercropped with maize by resource-poor farmers in low rainfall areas. Regrettably, little agronomic research work has been conducted in South Africa on the crop to date despite its adaptation to drought conditions and nutritional value.

1.2 RESEARCH PROBLEM

Despite the high nutritional value of pigeonpea grain (Nwokolo, 1987), limited studies have been reported on its compatibility for intercropping with maize under dryland conditions typical of Limpopo province, South Africa. Reports on the performance of maize and pigeonpea intercropping system under dryland conditions of South Africa are scanty and presently limited to the work of Mathews *et al.* (2011). In addition, the high phosphorus (P) demand of most leguminous crops coupled with the complex chemistry of P in many soils often results in P management crises on most croplands (Kutu FR; personal communication). Furthermore, the dearth of research information on appropriate P management strategy that is compatible with SH farmers' practice of intercropping remains a major challenge to increasing crop productivity of this important farming practice. Thus, crop yield on such farmers' fields remains low and hence impacts negatively on the food security situation in many rural areas.

1.3 Hypotheses

a) The productivity of maize and pigeonpea in maize/pigeonpea intercrops does not differ from sole crops.

b) Phosphorus application has no influence on the performance of maize/pigeonpea intercrops.

1.4 Motivation for the study

Maize is a major staple food in South Africa; but low soil fertility, limited resources and droughts keep yields low, particularly in smallholding farmlands. Regrettably, the use of inorganic fertilizers has not been attractive to SH farmers due to inherent problems of high costs, frequent unavailability of the material at the time of intended use and above all, resource constraints on the part of the farmers. Intercropping maize and pigeonpea is considered to be a good option since pigeonpea is drought-tolerant, can fix nitrogen and uses its deep root system to bring up minerals from horizons inaccessible by other crops (especially cereal crops). It is also able to increase the availability of soluble iron-bound P to maize and is needed to provide energy in biological nitrogen fixation (Yeboah *et al*., 2004). The introduction of this crop in many rural homes will constitute additional protein-rich food on the menu that can help to alleviate hunger and malnutrition.

1.5 Purpose of the study

1.5.1 Aim

The aim of this study was to determine the optimum P level and productivity of pigeonpea and maize under dryland intercropping system.

1.5.2 Objectives

The objectives of the study were to:

a) evaluate maize/pigeonpea productivity under dryland conditions.

b) evaluate the effect of P rates on maize/pigeonpea intercrop performance.

CHAPTER 2

LITERATURE REVIEW

2.1 General information on pigeonpea

Pigeonpea belongs to the genus *Cajanus*, subtribe *Cajaninae*, tribe Phaseoleae, and family Fabaceae. Pigeonpea, is also known as red gram, Congo pea, gungo pea, no eye pea; occurs in several varieties. It is believed to have originated from India, but may have come from Africa (Singh and Oswalt, 1992). Based on the range of genetic diversity of the crop in India, Vavilov (1951) concluded that pigeonpea originated from India.

Pigeonpea is a perennial erect bush, 0.5 to 4 m tall that has a strong woody stem. The leaves have three leaflets that are green and pubescent above and silvery greyish-green with longer hairs on the underside (Valenzuela and Smith, 2002). The flowers are clustered at the top of the peduncle. The flowers are mostly yellow and papileonaceous or completely bisexual and zygomorphous (Sundaraj and Thulasidas, 1980). It is often a cross pollinated crop that has a deep taproot system; wide spreading roots in the soil and well-developed lateral roots. Pigeonpea is also nodulated by the cowpea group of rhizobia, mainly on the upper 30 cm of the root system (Singh and Oswalt, 1992).

Pigeonpea is hardy, warm-season, drought tolerant, widely adaptable and tolerant to temperatures as high as 35ºC (Vittal *et al.,* 2004). The preferred temperature range is between 18 and 30ºC during rainy season; and 17 - 22°C during post rainy season (Reddy and Virmani, 1981). An average annual rainfall of between 600 and 1000 mm is most suitable for pigeonpea production (Green Harvest, 2013). The crop can be grown in a wide range of soil textures, from sandy soils to heavy clays; and is well suited for soil with pH range of between 4.5 and 8.4 (Singh and Oswalt, 1992).

Pigeonpea is normally sown directly into prepared ground. Seeding rates for pure stands are 12 to 25 kg of seed ha^{-1} (Smartt, 1976). Recommended planting depth of pure stand (sole) of pigeonpea varied from 2.5 to 5 cm (Duke, 1983). Germination is hypogeal and there is no known dormancy in pigeonpea; thus, no pre-germination treatment of the seed is needed.

2.2 Maize production in South Africa

Maize is a staple food for a large section of the black population of South Africa that accounts for 94 percent of white maize meal consumption (Elliott, 1991). It is the most important cereal crop produced by resource-poor farmers in Southern Africa. Approximately 10-12 million tons of maize is produced annually in South Africa on more-or-less 2.5 million hectares of land (Syngenta, 2012). Maize is produced by nearly all resource - poor farmers in South Africa from within the semi-arid regions to the high rainfall provinces. Dryland production of maize takes place mainly in the Free State (34%), North West (32%), Mpumalanga (24%), Limpopo (17%) and KwaZulu-Natal (3%) provinces (Department of Agriculture, 2010). Maize production in South Africa is constrained by both biotic and abiotic factors. According to Meyer (1998), the economy of maize production in the summer - grain areas has deteriorated over the last few decades because the prices of maize inputs rose more rapidly than the producer price of maize grain.

Furthermore, the impact of droughts has weakened the producers' ability to make structural adjustments. According to ICRISAT (2008), the SH farming areas of the Limpopo Province are subject to frequent droughts and poor soil fertility thus keeping SH farmers in a cycle of poverty. In a survey carried out in Vhembe district of Limpopo Province in 2004, inadequate rainfall (49%), weed infestation (23%) and low soil fertility (20%) were reported as the most important factors limiting the grain yields of maize (Nemutshili and Ogola, 2010).

2.3 Importance of pigeonpea in human diet

Pigeonpea grains constitute an important component of human diet in developing countries, particularly those located in tropical and subtropical areas (Singh, 1993). The grain is wonderfully abundant in protein, making it an ideal supplement to traditional cereal- banana or tuber-based diets of most Africans that are generally protein-deficient (Odeny, 2007). The protein quality of pigeonpea is primarily expressed in terms of its content, the levels of amino acids, and protein digestibility (Singh and Eggum, 1984). For use as a vegetable, pigeonpea is normally picked when the seeds reach physiological maturity, i.e., when they are fully grown, but just before they lose their green colour (Faris *et al*., 1987). At this stage, the green seed is more nutritious than the dry seed because it contains more protein, sugar, and fat than the mature seed (Singh, 1991). Pigeonpea is a rich source of carbohydrates, minerals and vitamins. The seeds contain approximately 51–59% carbohydrates (Faris and Singh, 1990); 1.2–8.1% crude fibre, 18–26% protein and 0.6–3.8% lipids (Sinha, 1977).

When compared to soybean (*Glycine max*), pea (*Pisum sativum*) and common bean (*Phaseolus vulgaris*), pigeonpea offers fewer anti-nutritional factor problems (Singh, 1991). Pigeonpea contains considerably higher levels of protease inhibitors than the other commonly consumed Indian grain legumes, but much lower levels than those of soybean (Sumathi and Patabhiraman, 1976).

2.4 World Pigeonpea production statistics

According to FAO statistics, global pigeonpea cultivation increased at an annual rate of 1.3% from about 2.7 million hectares in 1961 to about 4.6 million hectares in 2007 (Franklin *et al*., 2009). About 90% of the global pigeonpea area falls in India (Sarika *et al*., 2013). Pigeonpea in India is grown on 3.36 million hectares with a total production of 2.31 million tons (M t.); with an average productivity of 0.69 t ha^{-1} and a range from 0.60 ha^{-1} in the primary zone to 0.80 t ha^{-1} in the tertiary zone (Singh, 2006). Over 80% of pigeonpea production in Africa takes place in Malawi, Mozambique, Tanzania, Uganda and Kenya which together have over 800,000 ha of arable land under the crop, and it is often grown as an intercrop with maize (AGRA communications, 2012). Nearly all the production is by SH farmers and mainly as a subsistence crop under rain-fed conditions. Additionally, the production areas are mainly those that are prone to drought, thus giving farmers an opportunity to make a living from it when other crops fail. Production in African countries contributes 9.3% of world production, which is very little compared to the 74% contribution from India alone (Odeny, 2007).

In South Africa, pigeonpea is not widely grown as a field crop. However, pigeonpea can also serve as an important grain legume crop that can be used in rural areas for human consumption and supplements the range of food crops available. In addition, pigeonpea is usually grown singly or as a hedge plant in home gardens or around the sugarcane (*Saccharum officinarum*) fields (Saxena *et al.,* 2001). Production areas in Limpopo Province are Bohlabela and Mopani districts while in Mpumalanga it is grown in Gert Sibande, Enkangala and Ehlanzeni districts (Department of Agriculture, 2009).

2.5 Maize/pigeonpea intercrop performance

Pigeonpea is becoming increasingly important in SH farming systems in Eastern and Southern Africa partly due to its ability to produce food grain under harsh conditions that are imposed by moisture stress, high temperatures and infertile soils (Gwata and Siambi, 2009). A study conducted in Tanzania demonstrated that the yield of unfertilized maize intercropped with pigeonpea generally equalled the yield of a moderately fertilized sole maize crop (Myaka *et al.*, 2006). However, an earlier study by Valenzuela and Smith (2002) revealed that the initial growth of pigeonpea is slow, and thus as an intercrop it is initially less competitive for light, water, and soil nutrients when grown as a companion crop with short-season cash crops.

Willey *et al.* (1980) observed that as a sole crop, pigeonpea is relatively inefficient because of its slow initial growth rate and low harvest index. Hence, they recommended intercropping of pigeonpea with more rapid growing crops such as cereals such as maize, sorghum or legumes such as greengram, cowpea, soybean etc., in order to obtain a substantial yield advantage (Marer, 2005). Furthermore, a study conducted in the northern transitional zone of Karnataka in South West India revealed that intercropping of maize and pigeonpea at 4:2 row ratio is more productive and remunerative than sole crops of either maize or pigeonpea and other intercropping systems under rainfed conditions (Lingaraju *et al*., 2008).

Sivakumar and Virmani (1980) revealed that dry matter accumulation by pigeonpea in intercropping of maize and pigeonpea was less than half of that of sole pigeonpea during first 90 days after planting whereas the dry matter of intercropped maize was on par with sole maize crop. The result further indicated that when the maize matured, its competitiveness was reduced and growth of the intercropped pigeonpea thereafter was sufficient to produce dry matter comparable to that of a sole crop.

Kumar Rao *et al*. (1983) and Wani *et al*. (1991; 1994) revealed that legumes grown either as intercrops or in rotation with cereals often increase the yield of a subsequent cereal crop grown on the same soil. The superior performance of a subsequent maize crop was reported after pigeonpea (sole or intercrop) in plant height, dry grain and stover yields over maize from plots that previously had sole maize or fallow systems (Egbe *et al*., 2007). A study conducted in Tanzania and Malawi showed mean grain yields of pigeonpea ranging from 172 to 740 kg ha^{-1} across several environments (Høgh-Jensen *et al*., 2007).

2.6 Nitrogen fixation by pigeonpea

Pigeonpea has the ability to fix up to 235 kg N ha^{-1} (Peoples *et al.*, 1995) and produces more N per unit area from plant biomass than many other legumes. Egbe (2005), as cited in Egbe and Idoko (2012), reported that pigeonpea can fix between 36.10 and 114.04 kg N ha^{-1} when intercropped with maize and 35.94-164.82 kg N ha^{-1} under intercropping with sorghum. The total nitrogen uptake and net nitrogen fixation by pigeonpea generally increased with crop duration (Kumar and Dart, 1987). For example, early-maturing determinate cultivars apparently fixed little nitrogen with a maximum of 7 kg N ha^{-1} whereas the indeterminate early- and medium-maturing cultivars fixed more nitrogen, the amount increasing with days to 50% flowering rather than to final harvest date (Kumar and Dart, 1987).

According to Onim (1987), pigeonpea produces more N from plant biomass per unit area of land than many other legumes although it usually produces fewer nodules than other legumes (Phatak *et al*., 1993). MacColl (1989) further reported that summed over three successive maize crops, N left by two year crops of pigeonpea varied from 23.5 to 109.6 kg ha^{-1}. The cereals benefit from the enhanced soil fertility through N_2 fixation and crop residues which improve the levels of organic matter content in the soil (Gwata and Siambi, 2009).

2.7 Influence of phosphorus in pigeonpea growth and productivity

Positive response to P application by pigeonpea has been observed and in some cases was highly significant (Pathak, 1970). A study conducted in India concluded that applications of 17-26 kg P ha^{-1} increased seed yield by 300-600 kg ha^{-1} (Singh and Oswalt, 1992). Graham and Rosas (1979) revealed that P increases symbiotic nitrogen fixation by stimulating host plant growth rather than exerting a direct effect on nodule initiation, growth, development and function.

AGRA communication (2012) reported that application of 20 kg P ha^{-1} increased pigeonpea yields by between 0.7 and 1.0 tons ha^{-1} in a demonstration that was conducted in Tanzania. The demonstration study also revealed that besides the increase of grain yield due to P application, the pigeonpea crop produced between 2 and 3 tons ha^{-1} of leaf biomass that was recycled into the soil.

2.8 Pigeonpea performance in low P soil

Pigeonpea root exudates have been found to contain phenolic compound piscidic acid, which chelates Fe to free P in Fe bound P in soils for crop uptake (Yeboah *et al*., 2004). Pigeonpea was also reported to be more efficient at utilizing iron-bound P (Fe-P) than several other crop species (Ae *et al*., 1990). For example, Otani *et al.* (1996) indicated that the crude root exudates of pigeonpea had a higher ability to dissolve Fe- and Al-bound P than those from other crops, especially at 4 and 5 weeks after transfer to the nutrient solution. In addition, pigeonpea is also known for its ability to access insoluble phosphates in soils low in P, and thus increasing the availability of soluble P for the following cash crops in the rotation.

Rotation systems indicated that planting of pigeonpea increases the amount of P available for the follow-up crops in the rotation (FFTC, 2000). Sinclair (2004) revealed that in soils with a high P fixation rate, pigeonpea was better able to take up P and to maintain adequate growth while other crops, such as maize and soybeans, were not even able to survive under the low P conditions.

2.9 Effect of P application on legume crops

Phosphorus plays a key role in the build-up and maintenance of soil productivity through its effects on legume growth and on the growth and survival of rhizobia (MClaughlin *et al*., 1990). It is the second most critical plant nutrient overall, but for pulses it assumes primary importance owing to its important role in root proliferation and atmospheric nitrogen assimilation (Thiyagarajan *et al*., 2003). Okuda and Yamaguchi (1955) showed that P added to a flooded soil in beakers increased photodependent N_2 fixation but not heterotrophic N_2 fixation, indicating that photodependent or aquatic N_2-fixing agents are limited by the P supply more severely than are N_2-fixing agents in soil.

Application of inorganic P fertilizers to arable crops has greatly increased grain (seed) production. In addition, P is an essential nutrient in soils for healthy crop growth and high yields. For example, highest seed yields were recorded (1755 kg ha^{-1}) when 60 kg P ha^{-1} was applied to pigeonpea and groundnut and it was also significantly higher by 5.3 and 1.6 percent than the control and 30 kg P ha^{-1}, respectively (Bheemasenrao, 2007; Adhikary and Sarkar, 2000).

The response to P application by grain legumes may vary with the soil P status. For example, Akhtar *et al*. (2003) reported that minimum and maximum vine lengths were obtained from pea (*Pisum sativum* L.) plants when 0 and 69 kg P ha^{-1} were applied to a soil with intial soil P status of 10.17 mg kg^{-1}, respectively. Ogoke *et al*. (2004) reported increment of pod number of soybean from 32 to 208% when P fertilizer was applied compared to the control. The grain yield of lentil increased from 717 to 911 kg ha^{-1} as P increased from 0 to 60 kg P ha^{-1} (Ryan et al., 2008). Application of P significantly increased the shoot dry matter yield (DMY) of both soybean and cowpea (Nwoke, *et al*., 2008). Adu-gyamfi, *et al*. (1989) reported the maximum whole plant dry weight of pigeonpea in a P-deficient soil at 100 kg P ha^{-1} application. Higher fresh biomass yield of green manure crops was observed with the application 36 kg P ha^{-1} (Pramanik *et al*., 2009). Application of 40 Kg P ha^{-1} increased N fixation in cowpea, groundnut and Bambara groundnut by 378, 169 and 138% respectively, over the control (Yakubu, *et al*., 2010). Application of 30 kg P

ha^{-1} increased crop biomass by 154% (103 kg ha^{-1}) for soyabean cultivar (LS 555) (Mabapa, *et al*., 2010).

Phosphorous use has become increasingly prevalent during recent decades due to its depletion in soils used for crop production (Norfleet, 1998). However, some studies indicate that legumes can mobilise more P from poorly soluble P compared to non-legumes (Hasnuri *et al.,* 2011, Kamh *et al*., 1999). According to Nuruzzaman *et al* (2005), legume crops such as white lupin (*Lupinus albus* L.), mobilise soil-bound P through root exudates.

2.10 Phosphorus availability in the soil

Phosphorus is an essential element classified as a macronutrient because of the relatively large amount required by plants (Busman *et al*., 2009). An adequate supply of P to plants is essential for seed formation, root development and the maturing of crops. However, much of the phosphate in soils is not available to growing plants due to fixation by iron (Fe) and aluminium (Al) oxides/hydroxides predominantly present in highly weathered soils, (Dubinsky *et al*., 2010; Igwe *et al*., 2010).

According to the Soil Association of UK (2010) the amount of P that is found naturally in soils varies greatly and can range from around 500 to 2500 kg ha^{-1}. However, only a small proportion of this phosphorus will be in the right form (soluble organophosphates in the soil solution) for it to be available for uptake by plants. In comparison, often less than 10 g ha^{-1} of P is in the soil solution as soluble orthophosphates ($H_2PO_4^-$, HPO_4^{2-}) at any one time; and it is these forms which are plant available (Stockdale and Atkinson, 2010).

Phosphorus is deficient in most soils in South Africa (Farmers' weekly, 2013). Low availability of soil phosphorus (P) caused by strong sorption of P is a major constraint to agricultural production in most South African soils, particularly those from the high rainfall areas (Gichangi, 2007).

2.11 Crop combinations for intercropping systems

Intercropping is the practice of growing two or more crops in proximity. Intercropping was defined as the practice of growing more than one crop simultaneously in alternating rows of the same field (Carlson, 2008). Intercropping can involve purely cash crops or a mixture of cash crops and fertility building crops.

Crop combination for intercropping may depend on the growth habits, maturity date and resource use patterns, so that crops make good use of available resources without competing with each other. Wolfswinkel (2012) reported the advantage of intercropping system for different crops in the mixture that have different maturity dates, with different times of peak demand of nutrients, water and sunlight thereby reducing competition. However, combinations vary from place to place. For example, in Malawi, the predominant intercropping crop combinations involve grain legumes namely cowpeas (*Vigna unguiculata*), groundnuts (*Arachis hypogeae*), peas (*Pisum sativa*), or pigeonpeas grown in association with maize, sorghum, or millet (*Pennisetum typhoides*) (Edje, 1980). Groundnut has also been reported to be commonly intercropped with maize in Southeast Asia and Africa (Reddy *et al*., 1980).

One of the advantages frequently claimed for intercropping combinations that include a legume, is that the nitrogen economy of the system is improved because of symbiotic fixation (Willey *et al*., 1986). For example, Adu-Gyamfi *et al*., (2007) reported that when nitrogen fertilizer is not applied, intercropped legumes will fix most of their nitrogen from the atmosphere and not compete with maize for nitrogen resources. It was also reported that intercropping of maize and cowpeas is especially beneficial on nitrogen poor soils (Carlson, 2008).

2.12 Effect of intercropping on weed suppression

Weed management is a critical component of any farming system (Piri *et al*., 2011). In successful intercrops, weed suppression is usually superior to that of either of the component crops when grown alone. Intercropping has been associated with greater yields and pest, and weed control compared with sole cropping (Szumigalski, 2005).

Maize is usually intercropped with a variety of crops, such as amaranth (*Amaranthus* spp.), for a variety of purposes such as cultural weed control, fertility and moisture conservation, land use maximization, vitamin generation and improved cash returns from limited land holdings (Awe and Abegunrin, 2009). In addition, Cowpea, pigeonpea, beans, sunn hemp (*Crotolaria* spp), and groundnuts have all been intercropped with maize by farmers in Africa with various successes (IRRI, 2008).

Carruthers *et al*. (1998) found that maize and soybean were quite successful at reducing weed populations. Maina and Drennan (1997) reported the increase in the yield of maize and suppression of weeds when Phaseolus bean was grown together with maize in Kenya. Hugar (2006) indicated that when soybean and groundnut were intercropped with corn, there was marked reduction in weed growth. The least number of weeds was found in rice (*Oryza sativa*) grown after cassava (*Manihot esculenta*) intercrops (Gbanguba *et al.*, 2011). Eskandari (2011) reported that wheat (*Triticum aestivum*) intercropped with bean was more effective in weed suppression than sole wheat, due to lower availability of environmental resources for weeds in the intercropping system.

CHAPTER 3
MATERIALS AND METHODS

3.1Experimental site

Two similar experiments were conducted at University of Limpopo Experimental farm, Syferkuil (23°51'S, 29°42'E, 1250 masl) during the 2009/10 and 2010/11 growing seasons. The soil at Syferkuil is predominately sandy loam in texture and belongs to Hutton form. Available P and pH measured in water from soil samples collected before planting the two trials are given in Table 1. Mean average summer day temperature at Syferkuil varies from 28 to 30°C while the area receives mean annual rainfall ranging from 400 to 600 mm (Figure 1 and 2).

3.2 Experimental design and treatments

Treatments were laid out as a 2×5 factorial arrangement in a randomised complete block design with 4 replications. The experiments comprised of two treatment factors:

Cropping system: Sole pigeonpea (C1), Intercropping (C2), and

P rates (kg ha^{-1}): 0 (P1), 15 (P2), 30 (P3), 45 (P4), 60 (P5)

The resultant treatment combinations were

a) Sole maize
b) C1P1
c) C1P2
d) C1P3
e) C1P4
f) C1P5
g) C2P1
h) C2P2
i) C2P3
j) C2P4
k) C2P5

Table 1: Physical and chemical properties at test sites in the 2009/10 and 2010/11 growing seasons

Soil properties	2009/10 season Depth (cm)		2010/11 season Depth (cm)	
Physical parameters	0-15	15-30	0-15	15-30
% sand	26.2	19.6	30.0	24.8
% clay	3.8	6.6	12.5	6.6
% silt	70.0	73.8	57.5	68.6
Textural class	Silt loam	Silt loam	Silt loam	Silt loam
Chemical parameters				
%OC	0.24	0.98	0.26	1.27
pH(H20)	6.67	6.61	6.63	6.67
pH(kcl)	5.57	5.85	5.71	5.58
EC (mS cm^{-1})	7.33	8.05	6.63	6.43
Total N (mg kg^{-1})	426	343	389	421
P(Bray1) (mg kg^{-1})	28	31	30	34
K (mg kg^{-1})	220	103	155	115
Ca (mg kg^{-1})	518	505	560	668
Mg (mg kg^{-1})	348	328	380	415
Na (mg kg^{-1})	35	63	35	70
Zn (mg kg^{-1})	2.64	2.48	2.76	2.84
S-value	6.182	5.774	6.490	7.369

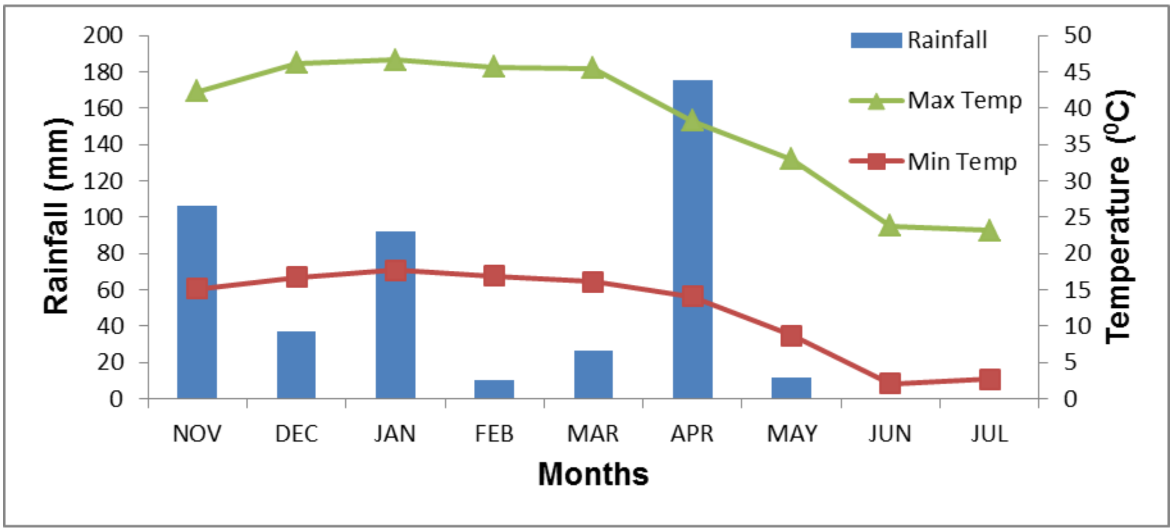

Figure: 1 Monthly rainfall and mean monthly minimum and maximum temperature during the 2009/10 growing season at Syferkuil.

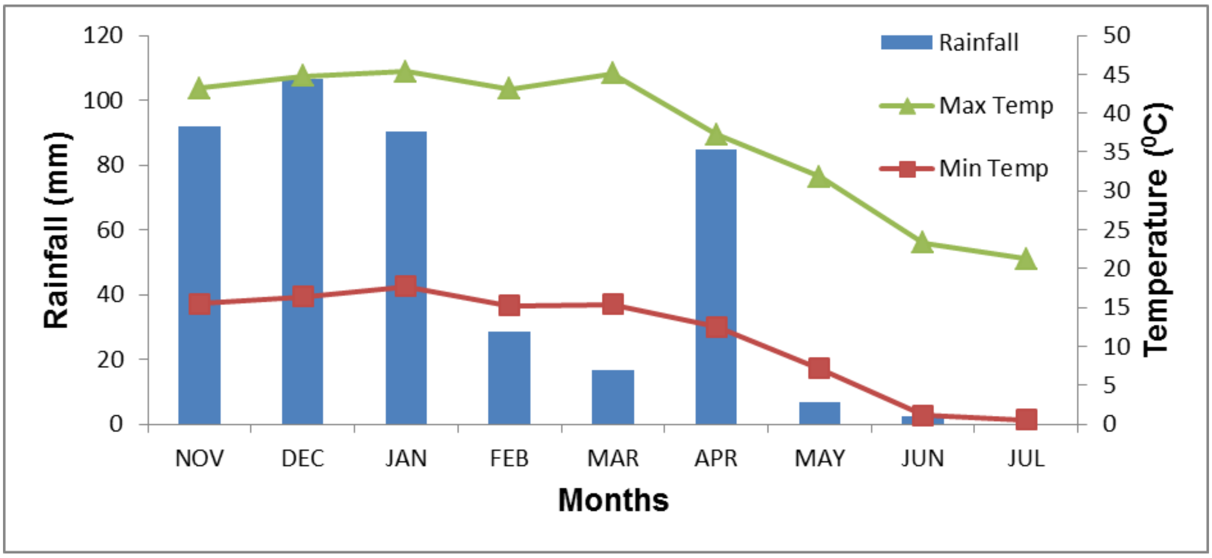

Figure 2: Monthly rainfall and mean monthly minimum and maximum temperature during the 2010/11 growing season at Syferkuil.

Maize variety (SNK 2147) and pigeonpea (ICPL 87091) were used as test crops in the experiments. Between row spacing of 90 and 60 cm were used for the maize and sole pigeonpea, respectively, while in-row spacing of 25 and 15 cm were maintained for maize and pigeonpea, respectively. Sole maize plots had 4 rows each with 5 m length while those of sole pigeonpea had 6 rows. Maize/pigeonpea intercropping had 4 rows of maize and 3 rows of pigeonpea. The gross plot size for both sole and intercropped maize as well as the sole pigeonpea plot was 18 m^2 while the net plot size for both sole and intercropped maize was 5.4 m^2 (2 central rows x 3m). On the other hand, the net plot sizes for sole and intercropped pigeonpea were 3.6 m^2 (2 central rows x 3 m) and 2.7 m^2 (the central row x 3 m), respectively.

3.3 Cultural practices

Maize and pigeonpea seeds were sown manually and simultaneously and the trials were planted on 8 January 2010 and 01 December 2010 in the first and second year plantings, respectively. All P treatments were applied through banding method during planting as single superphosphate (10.5% P) while experimental plots were kept weed-free by hand hoeing. The plots received establishment irrigation of 4 mm immediately after planting.

3.4 Data collection

3.4.1 Soil sampling and laboratory analysis

Representative soil samples were taken from the trial site using a soil auger at 0-15 cm and 15-30 cm soil depths before planting the experiment. Laboratory analyses were done on the soil samples to determine pH, N, P, K, Mg, Ca and percentage organic carbon. Soil pH measurements was done in soil: water ratio of 1:2.5 as described by Eckert (1988) while total N was determined by macro-Kjeldahl digestion method as described by Bremner (1955). Available P was extracted using Bray1 extractable P as described by Kuo (1996). Organic carbon was determined by Walkley-Black method as described by Jackson (1967) while K, Mg and Ca were extracted using ammonium acetate (1N) as described by Chapman (1965).

Data on the following parameters were recorded during the course of the study:

3.4.2 Agronomic characteristics of pigeonpea

i. Plant density (m^{-2})
ii. Plant height at harvest (m)
iii. Number of pods $plant^{-1}$
iv. Pod length (cm)
v. Number of seeds pod^{-1}
vi. 100 seed weight (g)
vii. Number of branches plant $^{-1}$
viii. Biological yield (kg ha^{-1})
ix. Seed yield (kg ha^{-1})
x. Chlorophyll content

3.4.3 Agronomic characteristics of maize

i. Plant density (m^{-2})
ii. Plant height (cm)
iii. Length of a cob (cm)
iv. Number of cobs $plant^{-1}$
v. Biological yield (kg ha^{-1})
vi. Weight of 100 grains (g)
vii. Grain yield (kg ha^{-1})
viii. Leaf chlorophyll content

3.4.4 Procedure for data collection

a. Pigeonpea

Plant density (m^{-2}) - Plants in the net plot were counted for each plot at harvest.
Plant height at harvest (m) - 6 consecutive plants in the net plot were selected and the height was measured with a measuring tape. Then the average was calculated.
Number of pods $plant^{-1}$- Fully developed pods from 6 plants were counted.

Pod length (cm) – Pod length was measured from 10 pods collected from each of 6 consecutive plants. Then the average was calculated.

Number of seeds pod^{-1} - Seeds per pods from 6 consecutive plants were counted. This figure was then divided by the number of pods from those 6 plants.

100 seed weight (g) - The weight of two samples of 100 seeds was recorded (g) from the grain samples drawn from the produce obtained from each of the net plot and averaged.

Number of branches plant $^{-1}$- The number of primary and secondary branches of 6 consecutive plants were counted and the average calculated.

Biological yield (kg ha^{-1}) - Crop was harvested with no roots at physiology maturity, exposed to sun drying and then weighed using a 22 Adam CBK 8h weighing balance before threshing to record the total biomass per plot.

Seed yield (kg ha^{-1}) - Sun dried sample was threshed manually in order to record grain yield per plot using a 22 Adam CBK 8h weighing balance and then converted to kgha^{-1}.

Chlorophyll content - Chlorophyll content was recorded on 6 consecutive plants (the readings were taken on the top fully grown leaf) at flower initiation using chlorophyll meter (CM100, Spectrum Technologies Inc, USA) and the average calculated.

Monetary value

Monetary value was calculated using the price of R 4625/ton for pigeonpea in 2009/10 and R 4989/ton in 2010/11 (Govindan, 2010) .

b. Maize

Plant density (m^{-2}) - Plants in the net plot were counted for each plot and recorded.

Plant height at harvest (m) – Six consecutive plants in the net plot were selected and the height measured with a measuring tape and recorded. Then the average was calculated.

Length of a cob (cm) - 6 cobs (each plot) from consecutive 6 plants were selected and then measured using a measuring ruler. Then the average was calculated.

Number of cobs plant^{-1} – The number of cobs on the 6 consecutive plants were counted also recorded and averaged.

Biological yield (kg ha^{-1}) - Crop was harvested at physiological maturity, exposed to sun drying and then weighed with the help of a 22 Adam CBK 8h weighing balance before threshing to record the total biomass per plot.

Weight of 100 grains (g) – Two samples of 100 grains from 6 randomly selected cobs were counted and weighed.

Grain yield (kg ha^{-1}) – Sun-dried sample was threshed manually in order to record grain yield per plot. This was used to extrapolate yield on a hectare basis.

Chlorophyll content - Chlorophyll content was measured and recorded on 6 consecutive plants. The readings were taken on the flag leaf at tasselling using chlorophyll meter (CM100, Spectrum Technologies Inc, USA). Then the average was calculated.

Monetary value

Monetary value was calculated using the price of R1118/ton for maize in 2009/10 and R1851/ton in 2010/11 (SAGIS, 2012).

c. Common to both crops

Harvest index (HI) % – Harvesting Index was calculated by dividing the grain yield with above-ground biomas and multiplying by 100.

HI=grain yield (kg)/ above-ground biomas (kg) × 100

Land equivalent ratio (LER) - the land equivalent ratio (LER) value, which measures the productivity of the intercrop system, was calculated using the equation:

LER=PLERM +PLERP

PLERM = YIM/YSM; PLERP=YIP/YSP

where, PLERM = partial land equivalent ratio for maize, YIM = grain yield per unit area of intercropped maize, YSM = grain yield per unit area of sole crop maize and

PLERP=partial land equivalent ratio for pigeonpea, YIP= grain yield per unit area of intercropped pigeonpea, YSP= grain yield per unit area of sole crop pigeonpea (Ofori and Stern, 1987).

Shelling percentage

The shelling percentage of both maize and pigeonpea was calculated as:

Shelling percentage (%) = shelled grain weight (kg)/unshelled cobs or unshelled pods weight × 100.

3.5 Data analysis

The data generated were subjected to analysis of variance using Statistix 9.0 version (Statistix, 2008). Tukey $HSD_{0.05}$ procedure was applied to separate mean values, while a quadratic function model through a regression analysis was developed to determine the optimum rate of P.

CHAPTER 4
RESULTS

The results of the experiment conducted to investigate the performance of maize and pigeonpea in an intercropping system under variable P rates at Syferkuil during 2009/10 and 2010/11 growing seasons are presented in this chapter.

4.1 Performance of pigeonpea

4.1.1 Treatment effect on phenological development of pigeonpea

Phosphorus rates and cropping system effect did not affect number of days to 50% flowering and physiological maturity during both seasons (Table 2). It took 92 and 157 days on average to 50% flowering and physiological maturity during two seasons, respectively.

4.1.2. Treatment effect on growth parameters of pigeonpea

4.1.2.1 Plant density (plants/m^2)

Data pertaining to plant density obtained at harvest as influenced by P rates of application and cropping system for both seasons are presented in the Table 3. The results showed that the main effects for cropping system were only significant ($P<0.001$) in 2009/10. P rate x cropping system interaction effect on planting density was significant during 2009/10 season. In 2009/10 season, plant density was significantly increased with increasing rates of P application under intercrop plots while under sole plots no positive response was observed (Figure 3). Higher plant density was achieved under intercrop plots at a P rate of 45 kg ha^{-1} while the lowest plant density was noticed under intercropped pigeonpea plots when no P was applied.

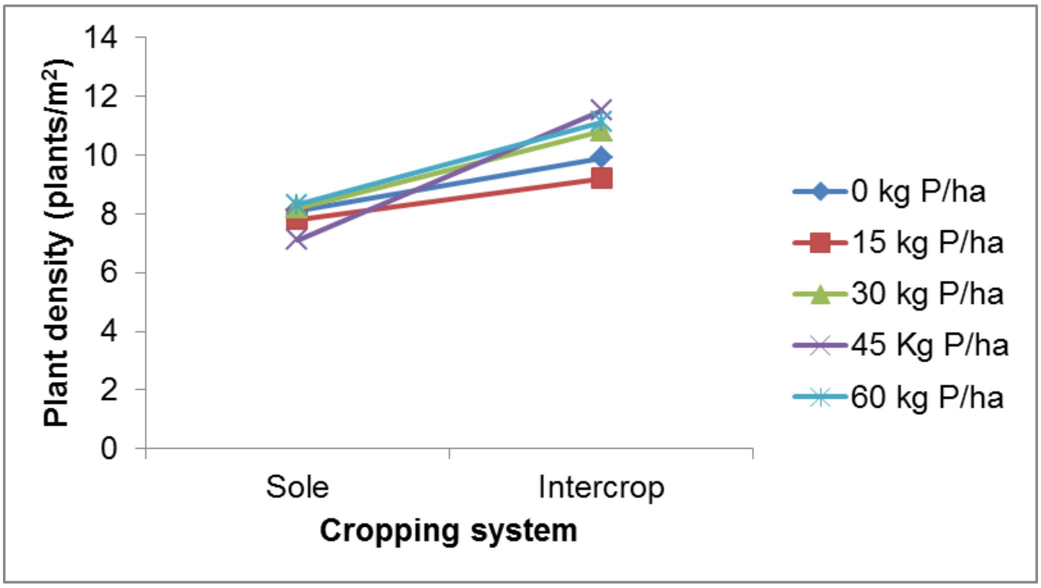

Figure 3: Plant density of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10season

Table 2: Phenological development of pigeonpea as influenced by cropping system and P application rate in 2009/10 and 2010/11

Treatment effect	2009/10			2010/11	
	50% flowering	50% PM		50% flowering	50% PM
P rates					
0	92^{a}	157^{a}		92^{a}	157^{a}
15	92^{a}	157^{a}		92^{a}	156^{a}
30	91^{a}	156^{a}		92^{a}	157^{a}
45	92^{a}	157^{a}		92^{a}	157^{a}
60	92^{a}	157^{a}		92^{a}	157^{a}
P value	ns	ns		ns	ns
Tukey HSD	-		-	-	-
Cropping system					
Sole	92^{a}	157^{a}		92^{a}	157^{a}
Intercropping	92^{a}	157^{a}		91^{a}	156^{a}
P value	ns	ns		ns	ns
Tukey $HSD_{0.05}$	-	-		-	-
CV%	1.15	2.01		1.50	1.52

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$. ns=not significant, ns=not significant, CV=coefficient variation, PM=physiological maturity

4.1.2.2 Number of branches per plant

The rates of P application exerted no significant effect on the number of branches per plant of pigeonpea during 2009/10 and 2010/11 seasons (Table 3). However, cropping system showed significant differences during 2010/11 season (Figure 4). Higher number of branches per plant was recorded under sole cropping than intercropping system in 2010/11 season. There was a significant cropping system × P interaction effect on the number of branches per plant during 2010/11 season (Table 4). For interaction between P rates and cropping system, results obtained in 2010/11 revealed that increasing of P rates in both sole and intercrop pigeonpea plots did not significantly influence the number of branches per plant (Figure 4). Highest number of branches per plant was observed under sole pigeonpea plots applied with 15 kg P ha^{-1} while lowest was noticed under intercropped pigeonpea plots with 15 kg P ha^{-1} (Table4).

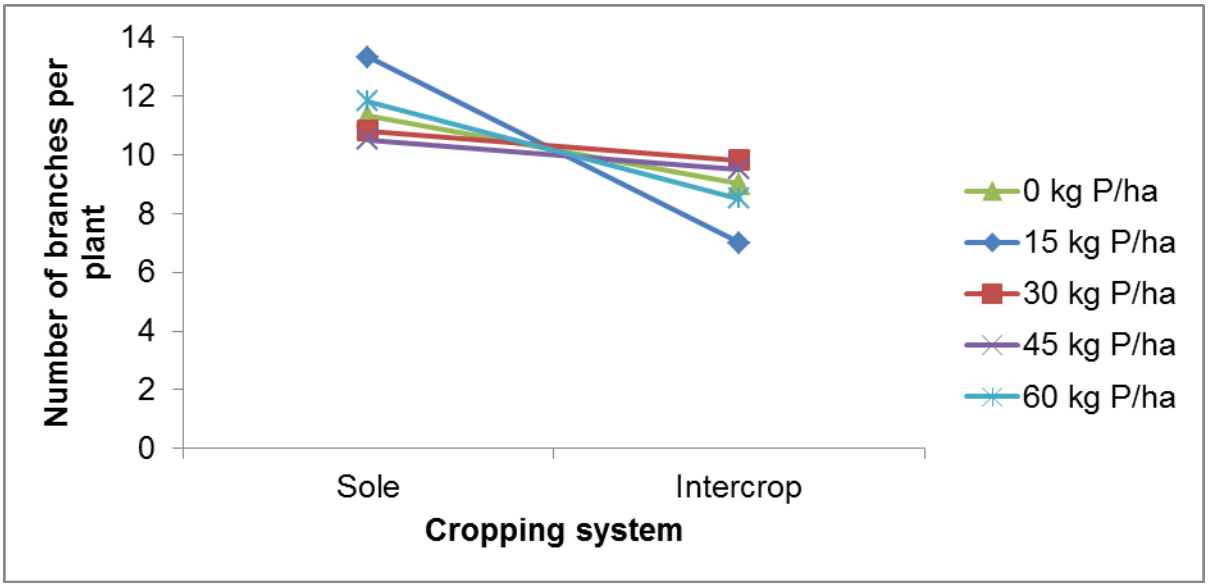

Figure 4: Number of branches/plant of pigeonpea as influenced by interaction of P rate and cropping system during 2010/11 season

Table 3: Plant density, number of branches per plant, leaf chlorophyll content and plant height of pigeon pea as influenced by cropping system and P application rate

P rates (kg ha^{-1})	2009/10				2010/11			
	Plant density (plants m^{-2})#	Number of branches $plant^{-1}$	Plant height (m)	Leaf Chlorophyll content (CCI)	Plant density (plants m^{-2})	Number of branches $plant^{-1}$	Plant height (m)	Leaf Chlorophyll content (CCI)
0	8.10[a]	11.5[a]	0.96[a]	107.4[a]	9.7[a]	10.1[a]	0.91[a]	102.4[a]
15	8.5[a]	10.8[a]	0.94[a]	93.8[a]	9.4[a]	10.1[a]	0.90[a]	97.0[a]
30	9.5[a]	10.9[a]	0.99[a]	89.3[a]	9.8[a]	10.3[a]	0.89[a]	97.9[a]
45	9.7[a]	10.9[a]	0.98[a]	90.6[a]	9.4[a]	10.0[a]	0.91[a]	94.7[a]
60	9.7[a]	10.8[a]	1.01[a]	94.2[a]	9.6[a]	9.9[a]	0.89[a]	97.1[a]
P values	ns	ns	ns	ns	ns	ns	ns	ns
Tukey $HSD_{(0.05)}$	-	-	-	-	-	-	-	-
Cropping systems								
Sole	8.1[b]	10.1[a]	0.80[b]	96.7[a]	9.3[a]	11.5[a]	0.88[a]	99.10[a]
Intercropping	10.5[a]	10.1[a]	1.15[a]	93.4[a]	9.9[a]	8.7[b]	0.93[a]	95.7[a]
P value	0.0000	ns	0.0000	ns	ns	0.0000	ns	ns
Tukey $HSD_{0.05}$	0.88	-	0.07	-	-	0.98	-	-
CV (%)	14.63		11.68	19.21	15.49	15.00	9.85	8.57

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, ns=not significant, $P<0.001$= highly significant, CV=coefficient variation, CCI=Chlorophyll Concentration Index; # implies count at harvest

Table 4: Plant density, number of branches per plant, leaf chlorophyll content and plant height of pigeon pea as influenced by interaction between cropping system and P application rates

Cropping system	P rates (kg ha^{-1})	2009/10 Plant density (plants m^{-2})	2009/10 Number of branches plant^{-1}	2009/10 Plant height (m)	2009/10 Leaf Chlorophyll content (CCI)	2010/11 Plant density (plants m^{-2})	2010/11 Number of branches plant^{-1}	2010/11 Plant height (m)	2010/11 Leaf Chlorophyll content (CCI)
Sole	0	8.1^{bc}	11.0^{a}	0.73^{c}	109.5^{a}	9.5^{a}	11.3^{abc}	0.90^{a}	106.6^{a}
	15	7.8^{c}	10.8^{a}	0.75^{bc}	97.9^{ab}	9.7^{a}	13.3^{a}	0.85^{a}	100.6^{ab}
	30	8.2^{abc}	11.0^{a}	0.80^{bc}	102.0^{ab}	9.2^{a}	10.8^{bcd}	0.85^{a}	101.7^{ab}
	45	7.10^{bc}	11.5^{a}	0.83^{bc}	86.8^{ab}	8.7^{a}	10.5^{bcd}	0.90^{a}	95.5^{ab}
	60	8.3^{abc}	10.5^{a}	0.90^{b}	87.1^{ab}	9.7^{a}	11.8^{ab}	0.88^{a}	95.6^{ab}
Intercropping	0	9.9^{abc}	12.0^{a}	1.20^{a}	105.2^{a}	9.9^{a}	9.0^{def}	0.93^{a}	98.2^{ab}
	15	9.2^{abc}	10.8^{a}	1.13^{a}	89.6^{ab}	9.2^{a}	7.0^{f}	0.95^{a}	93.5^{b}
	30	10.8^{abc}	10.8^{a}	1.18^{a}	76.6^{b}	10.5^{a}	9.8^{bcde}	0.93^{a}	94.1^{b}
	45	11.5^{a}	10.3^{a}	1.13^{a}	94.4^{ab}	10.2^{a}	9.5^{cde}	0.93^{a}	93.9^{b}
	60	11.1^{ab}	11.0^{a}	1.13^{a}	101.4^{ab}	9.6^{a}	8.5^{ef}	0.90^{a}	98.7^{ab}
P value		0.0000	ns	0.0000	0.0571	ns	0.0082	ns	0.0473
Tukey HSD$_{0.05}$		3.30	-	0.17	26.5	-	2.19	-	12.2
CV%		14.63	9.45	11.68	19.21	15.49	15.00	9.85	8.57

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, $P<0.001$= highly significant, ns=not significant, CV=coefficient variation

4.1.2.3 Plant height

Phosphorus rate did not affect plant height during both seasons. During 2009/10 there were significant differences ($P<0.001$) in plant height as influenced by cropping system where taller plants of 1.15 m mean height were observed on intercropped pigeonpea plots compared to 0.80 m for plants from sole pigeonpea plots. Interaction between cropping system and P rates also exhibited a significant effect on the plant height during the 2009/10 season (Table 4). Increasing P rates in both sole and intercrop pigeonpea plots did not significantly influence plant height in 2009/10 (Figure 5) Intercrop pigeonpea plots with 0 kg P ha^{-1} application rate produced the tallest plants while lowest plant height was recorded under sole pigeonpea plots when no P rate was applied. Application rate of 60 kg P ha^{-1} produced the tallest plants in both sole and intercropped plots compared to other P rate by cropping system interactions.

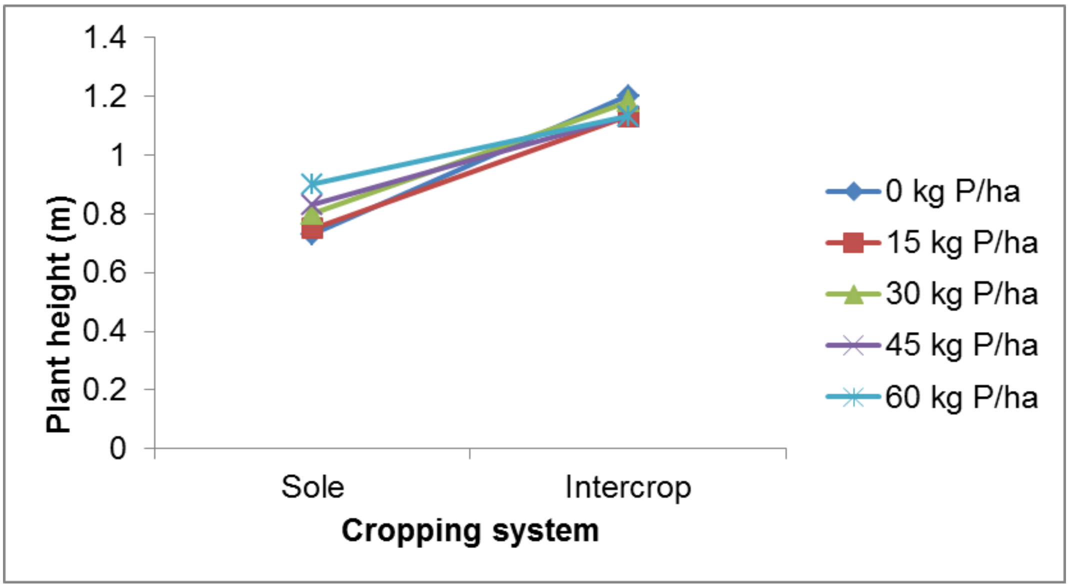

Figure 5: Plant height of pigeonpea as influenced by interaction of P rate and cropping system during the 2009/10 season

4.1.2.4 Chlorophyll content

The interaction between cropping system and P rates exhibited significant effect on the chlorophyll content during both seasons (Table 4). Although there was significant P rate by cropping system interaction effect on leaf chlorophyll content, P application rates exerted no significant effects on the leaf chlorophyll content in both cropping systems during both seasons (Figures 6a and 6b). Sole pigeonpea plots at 0 kg P ha^{-1} achieved highest leaf chlorophyll content during both seasons.

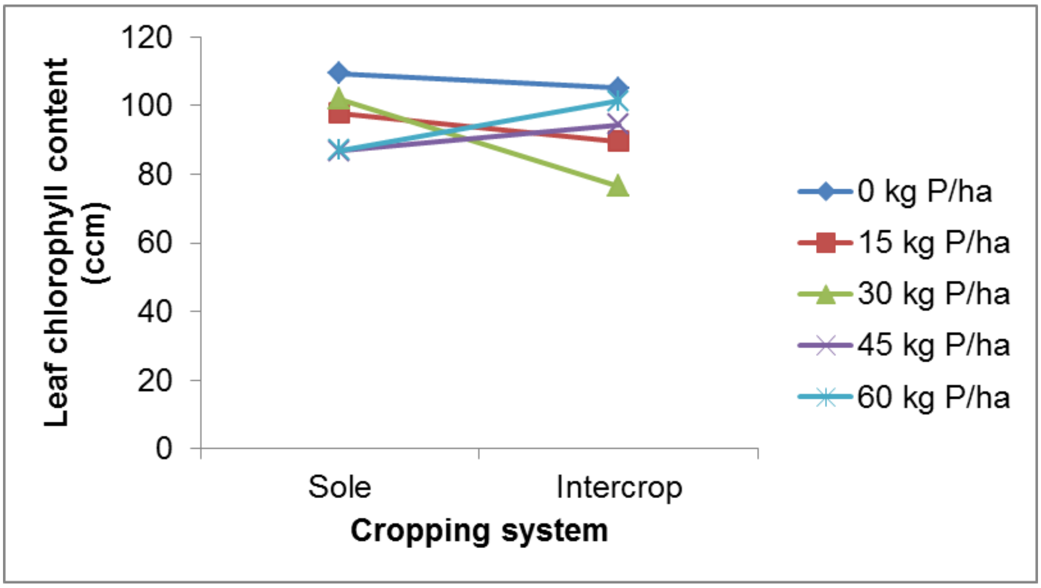

Figure 6a: Leaf chlorophyll content of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10 season

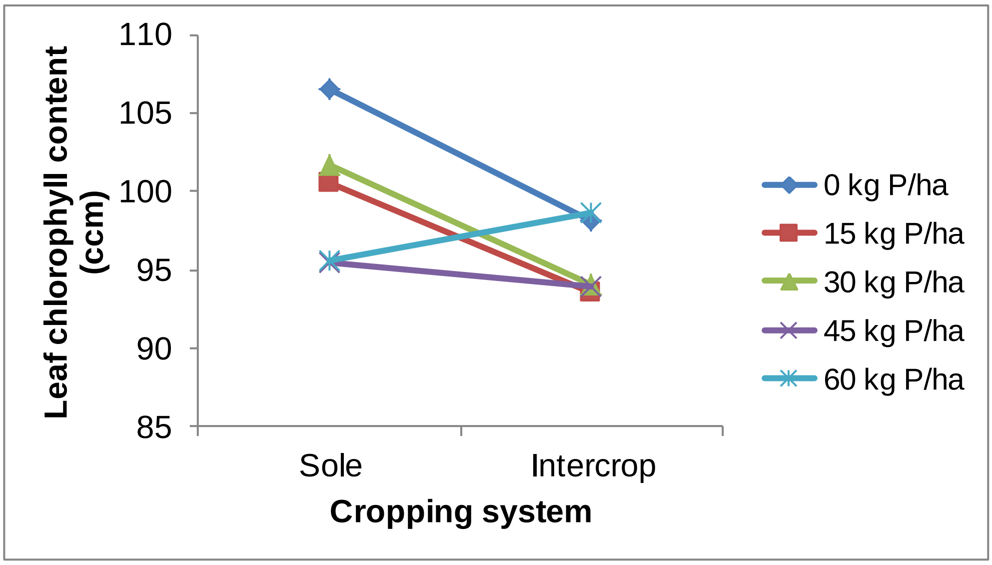

Figure 6b: Leaf chlorophyll content of pigeonpea as influenced by interaction of P rate and cropping system during 2010/11season

4.1.3. Treatment effect on yield and yield attributes of pigeonpea

4.1.3.1 Aboveground biomass

Aboveground biomass had differed significantly due to the influence of P rates during 2010/11 season (Table 7). Highest aboveground biomass of 3348 kg ha^{-1} was recorded at the P rate of 45 kg ha^{-1} compared to 1424 kg ha^{-1} for the control (Table 7). Interaction between cropping systems and P rates had a significant effect on the aboveground biomass during the 2010/11 season. Interaction between P rates and cropping system observed during the 2010/11 indicated that increase in P rate increase a aboveground biomass in both sole and intercrop pigeonpea plots (Figure 7). Intercrop plots with 45 kg P ha^{-1} produced the highest aboveground biomass during the 2010/11 season (Table 8).

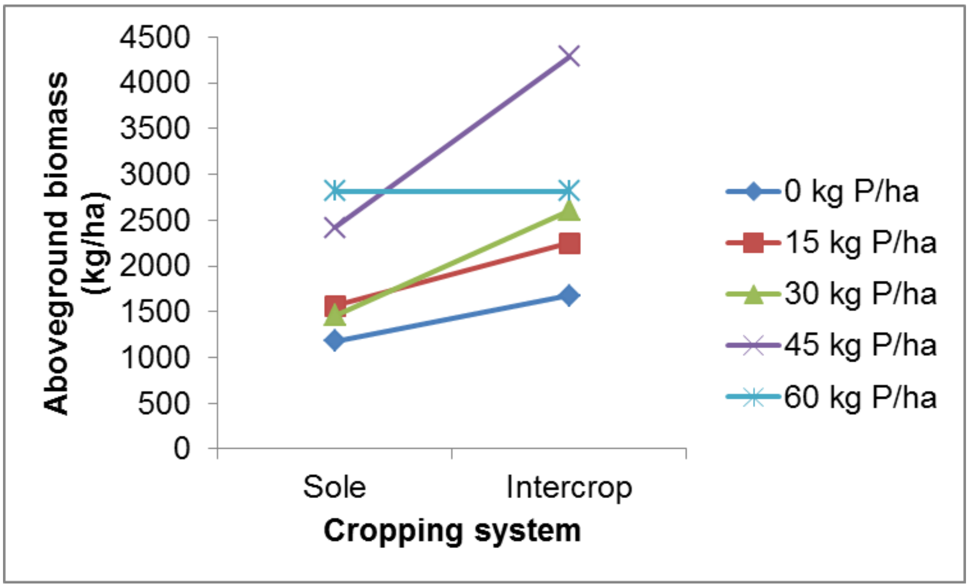

Figure 7: Aboveground biomass of pigeonpea as influenced by interaction of P rate and cropping system during the 2010/11season.

Table 5: Yield and yield components of pigeonpea as influenced by cropping system and P application rates in 2009/10 season

Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	Pods plant^{-1}	Seeds pod^{-1}	Pod length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
0	3493^{a}	19.1^{d}	5.4^{a}	7.1^{a}	57.9^{ab}	9.64^{a}	294^{d}	1360^{d}	9.27^{b}
15	3219^{a}	25.2^{c}	5.8^{a}	6.9^{a}	51.3^{b}	9.64^{a}	392^{c}	1814^{c}	12.70^{b}
30	3491^{a}	32.6^{b}	5.5^{a}	6.9^{a}	63.4^{ab}	10.53^{a}	502^{b}	2322^{b}	15.13^{ab}
45	3693^{a}	39.6^{a}	5.4^{a}	6.6^{a}	74.4^{a}	10.04^{a}	781^{a}	3613^{a}	22.98^{a}
60	3900^{a}	40.1^{a}	5.8^{a}	6.9^{a}	67.9^{ab}	10.56^{a}	733^{a}	3394^{a}	21.43^{a}
P value	ns	0.0000	ns	ns	0.0318	ns	0.000	0.000	0.0003
Tukey HSD	-	2.41	-	-	14.65	-	61.13	282.73	8.58
Cropping system									
Sole	3350.5^{a}	31.5^{a}	5.5^{a}	6.9^{a}	63.9^{a}	10.3^{a}	543^{a}	2512^{a}	16.48^{a}
Intercropping	3768.6^{a}	31.4^{a}	5.6^{a}	6.9^{a}	62.0^{a}	9.9^{a}	538^{a}	2489^{a}	16.13^{a}
P value	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tukey $HSD_{0.05}$	-	-	-	-	-	-	-	-	-
CV%	32.10	7.48	14.63	13.68	22.67	17.77	11.02	11.02	36.03

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, $P<0.001$= highly significant, ns=not significant, CV=coefficient variation

Table 6: Interaction effects of P rate and cropping system on the yield and yield components of pigeonpea in 2009/10 season

Cropping system	Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	Pods $plant^{-1}$	Seeds pod^{-1}	Pod length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
Sole	0	3077^{a}	20.1^{e}	5.5^{a}	7.0^{a}	55.41^{a}	10.63^{a}	249^{f}	1156^{f}	9.80^{b}
	15	2789^{a}	24.8^{d}	5.8^{a}	7.3^{a}	57.65^{a}	9.00^{a}	343^{e}	1587^{e}	13.32^{ab}
	30	3810^{a}	32.7^{c}	5.8^{a}	6.3^{a}	63.67^{a}	10.68^{a}	565^{c}	2615^{c}	15.92^{ab}
	45	3994^{a}	37.8^{b}	5.0^{a}	7.0^{a}	69.43^{a}	10.15^{a}	922^{a}	4264^{a}	25.51^{a}
	60	3083^{a}	42.4^{a}	5.5^{a}	6.8^{a}	73.43^{a}	11.10^{a}	635^{c}	2938^{c}	24.59^{a}
intercropping	0	3909^{a}	19.9^{e}	5.3^{a}	7.3^{a}	60.34^{a}	8.65^{a}	338^{e}	1565^{e}	8.74^{b}
	15	3651^{a}	25.5^{d}	5.8^{a}	6.5^{a}	45.00^{a}	10.28^{a}	441^{d}	2041^{d}	12.09^{ab}
	30	3172^{a}	32.6^{c}	5.3^{a}	7.5^{a}	63.05^{a}	10.38^{a}	439^{d}	2030^{d}	14.35^{ab}
	45	3393^{a}	41.4^{a}	5.8^{a}	6.3^{a}	79.31^{a}	9.93^{a}	641^{c}	2962^{c}	20.36^{ab}
	60	4718^{a}	37.8^{b}	6.0^{a}	7.0^{a}	62.42^{a}	10.03^{a}	832^{b}	3849^{b}	18.27^{ab}
P value		ns	0.0305	ns	ns	ns	ns	0.000	0.000	ns
Tukey HSD		-	3.41	-	-	-	-	86.45	399.85	-
CV%		32.10	7.48	14.63	13.68	22.67	17.77	11.02	11.02	36.03

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, P<0.001= highly significant, ns=not significant, CV=coefficient variation

Table 7: Yield and yield components of pigeonpea as influenced by cropping system and P application rates in 2010/11 season

Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	Pods plant^{-1}	Seeds pod^{-1}	Pod length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
0	1424^{b}	35.5^{a}	5.9^{a}	7.1^{a}	62.1^{b}	9.81^{a}	467^{d}	2328^{d}	33.21^{ab}
15	1906^{b}	30.2^{a}	5.1^{a}	6.5^{a}	72.6^{ab}	10.43^{a}	609^{c}	3037^{c}	32.36^{ab}
30	2033^{b}	30.5^{a}	5.9^{a}	6.5^{a}	80.0^{a}	10.63^{a}	768^{b}	3831^{b}	37.91^{a}
45	3348^{a}	32.8^{a}	5.6^{a}	7.1^{a}	81.9^{a}	10.03^{a}	894^{a}	4461^{a}	28.23^{bc}
60	3221^{a}	31.9^{a}	5.6^{a}	6.9^{a}	75.4^{a}	10.00^{a}	721^{b}	3597^{b}	23.615^{c}
P value	0.0000	ns	ns	ns	0.0002	ns	0.0000	0.0000	0.0001
Tukey HSD	777.40	-	-	-	11.29	-	77.056	270.06	7.43
Cropping system									
Sole	1886^{b}	30.6^{a}	5.6^{a}	6.5^{a}	76.7^{a}	9.20^{b}	534^{b}	2665^{b}	31.34^{a}
Intercropping	2887^{a}	33.8^{a}	5.7^{a}	7.1^{a}	72.1^{a}	11.16^{a}	849^{a}	4236^{a}	30.83^{a}
P value	0.0000	ns	\`ns	ns	ns	0.4482	0.0000	0.0000	ns
Tukey HSD$_{0.05}$	344.73	-	-	-	-	0.63	34.169	170.80	-
CV%	23.89	19.19	15.78	15.02	10.39	9.54	10.39	7.63	16.37

Means followed by same letter in a column do not differ significantly at P≤ 0.05, P<0.001= highly significant, ns=not significant, CV=coefficient variation

4.1.3.2 Pods per plant

The P rate applied caused significant differences in pods per plant during 2009/10 season only. Highest pods per plant were observed at 60 kg P ha^{-1} while the least number of pods per plant was recorded at 0 kg P ha^{-1} (Table 5). The highest number of pods per plant was recorded during 2009/10 season as compared to 2010/11 season at 45 kg P ha^{-1} and 60 kg P ha^{-1}, respectively (Tables 5 and 7). Pods per plant was significantly influenced by P rate x cropping system interaction during 2009/10 season. Increase in P rate up to 60 kg P ha^{-1} resulted in an increase in the number of pods per plant under sole plots while increase a P rate increase up to 45 P kg ha^{-1} also led to an increase in the number of pods per plant in intercrop plots (Figure 8). However, the highest number of pods per plant was observed under sole plots with 60 kg P ha^{-1} during 2009/10 (Table 6).

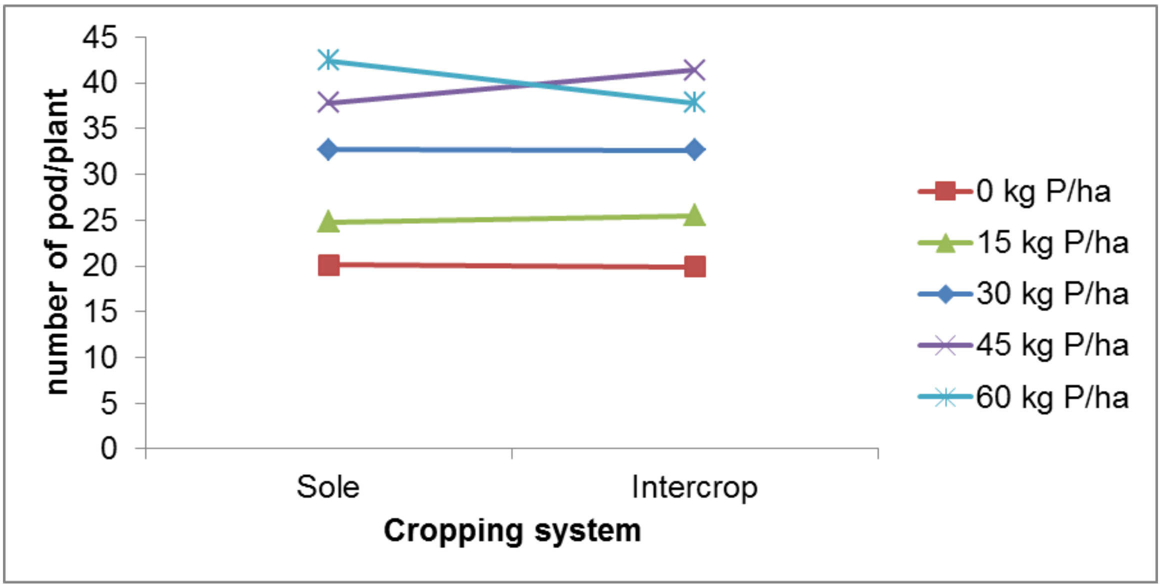

Figure 8: Number of pods per plant of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10 season

4.1.3.3 Seeds per pod

Data pertaining to the number of seeds per pod as influenced by P rate and cropping system for both seasons indicated no significant differences. Similarly, there was no significant cropping system × P interaction effect on the mean number of seeds per pod (Tables 6 and 8).

4.1.3.4 Pod length

The main effects of P rate and cropping system were not significant on the pod length of pigeonpea during both seasons. Cropping system × P interaction effect on pod length was significant during 2010/11. Increased P rate in both sole and intercrop pigeonpea plots did not significantly influence the pod length in that season. Highest pod length was achieved under intercrop plots with 45 kg P ha^{-1} while the lowest was achieved under sole cropping with 15 kg P ha^{-1} (Table 8).

4.1.3.5 Shelling percentage

P rate had significant effect on the shelling percentage of pigeonpea during both seasons. Highest shelling percentage was recorded when 45 kg P ha^{-1} was applied in both seasons. Cropping system had no significant effect on shelling percentage during both seasons. Cropping system × P interaction effect on the shelling percentage was only significant during 2010/11. Increase in P rate from 0 to 30 kg P ha^{-1} resulted in increase in the shelling percentage under sole plots while increase of P rates from 0 to 45 P kg ha^{-1} resulted in increase of shelling percentage in intercrop plots (Figure 9). Intercrop plots with 45 kg P ha^{-1} also achieved the highest shelling percentage (Table 8).

Table 8: Interaction between P rate and cropping system on the yield and yield components of pigeonpea in 2010/11 season

Cropping system	Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	Pods plant^{-1}	Seeds pod^{-1}	Pod length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
Sole	0	1176^{e}	33.7^{a}	5.8^{a}	7.0^{ab}	64.2bc	9.08^{b}	397^{e}	1978^{f}	34.05^{ab}
	15	1565^{cde}	28.1^{a}	6.0^{a}	6.0^{b}	78.4abc	9.05^{b}	529^{d}	2637^{e}	34.07^{ab}
	30	1458^{de}	31.2^{a}	6.3^{a}	6.5^{ab}	81.10ab	9.65^{ab}	549^{d}	2737^{e}	37.92^{a}
	45	2415^{bcde}	30.6^{a}	5.5^{a}	6.8^{ab}	80.5ab	9.68^{ab}	647^{cd}	3226^{d}	28.10^{ab}
	60	2816^{c}	28.5^{a}	5.5^{a}	6.8^{ab}	78.6abc	8.55^{b}	551^{d}	2751^{e}	22.58^{b}
Intercropping	0	1672^{cde}	37.3^{a}	6.0^{a}	7^{ab}	60.1c	10.550^{ab}	537.0^{d}	2679.2^{e}	32.55^{ab}
	15	2248^{cde}	31.4^{a}	5.3^{a}	7^{ab}	66.9abc	11.80^{a}	688.9^{c}	3436.8^{d}	30.66^{ab}
	30	2609^{bcd}	29.9^{a}	5.5^{a}	7^{ab}	78.1abc	11.60^{a}	987.0^{b}	4924.2^{b}	37.93^{a}
	45	4282^{a}	34.1^{a}	5.8^{a}	7.5^{a}	83.2a	10.375^{ab}	1141.7^{a}	5695.7^{a}	28.37^{ab}
	60	2816^{bc}	35.3^{a}	5.8^{a}	7.0^{ab}	72.1abc	11.45^{a}	890.7^{b}	4443.8^{c}	24.65^{b}
P value		0.0449	ns	ns	0.0451	0.0487	0.0000	0.0000	0.0000	0.8576
Tukey $HSD_{0.05}$		1294.6	-	-	1.49	18.81	2.36	128.33	381.93	12.378
CV%		23.89	19.19	15.78	15.02	10.39	9.54	10.39	7.63	16.37

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, $P<0.001$= highly significant, ns=not significant, CV=coefficient variation

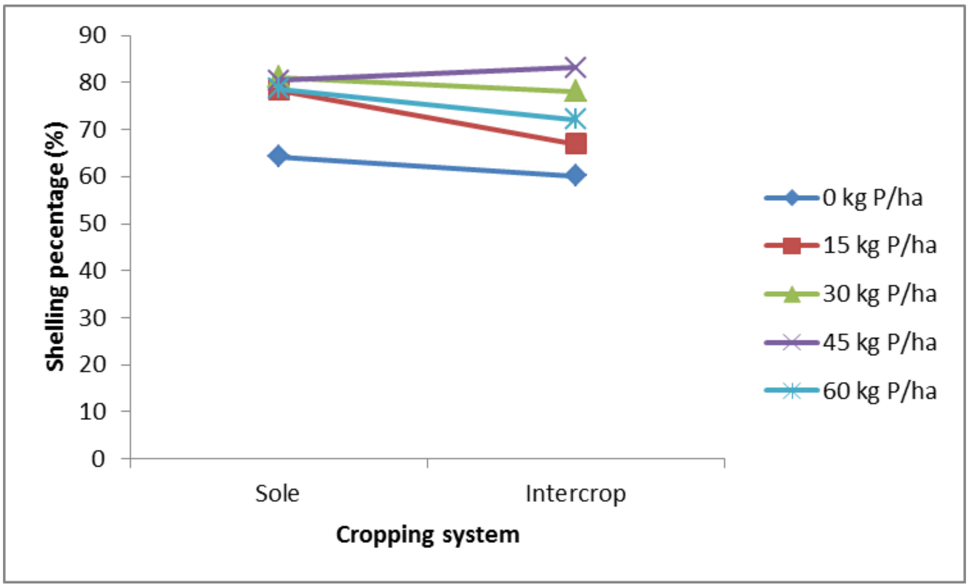

Figure 9: Shelling percentage of pigeonpea under sole and intercrop systems at varying P rates during 2010/11season

4.1.3.6 100 seed weight

Tables 5 and 7 showed that there was no significant effect of P rate on the 100 seed weight of pigeonpea during both seasons. Cropping system showed significant effect during the 2010/11 season. The highest 100 seed weight was recorded under intercrop plots. There were significant interaction effects of cropping system and P rates on the 100 seeds weight during 2010/11 season. In 2010/11, increasing P rate on both sole and intercrop pigeonpea plots did not significantly influence 100 seed weight (Figure 10). Highest 100 seed weight was observed under intercrop plot at 15 kg P ha^{-1} application rate (Table 8).

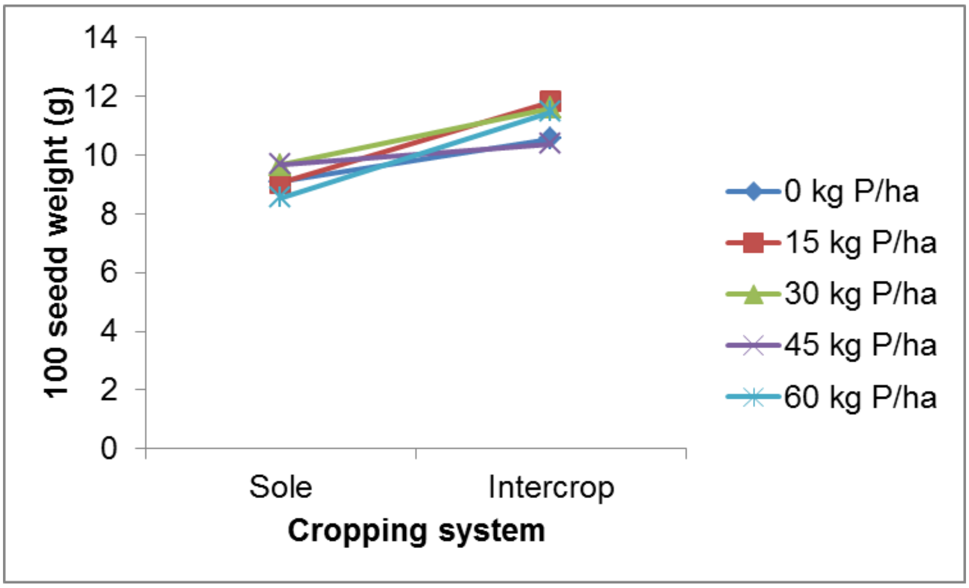

Figure 10: Hundred seed weight of pigeonpea under sole and intercrop systems at varying P rates during 2010/11season

4.1.3.7 Grain yield

Pigeonpea grain yield was considerably higher in 2010/11 than in 2009/10 season (Tables 5 and 7). There were significant differences (P<0.001) in the grain yield of pigeonpea across the different P rates in both seasons. There was a significant difference in pigeonpea grain across the different cropping systems during 2010/11. Highest grain yields were recorded at 45 kg P ha^{-1} while the control recorded lowest yield during the two seasons. There was 21.8% increase in grain yield across two seasons as influenced by P rate relative to the control. Intercrop pigeonpea plots achieved 37.1% higher grain yield than the sole pigeonpea plots during 2010/11 (Table 7). However, highest pigeonpea grain yield of 922 kg ha^{-1} was recorded under sole cropping during 2009/10 (Figure 14). In addition, highest grain yield of 849 kg ha^{-1} was recorded under intercrop plots during 2010/11. The interaction between cropping system and P rate exerted a significant effect on the grain yield during both seasons. Increase in P rate up to 45 kg P ha^{-1} resulted in increase in the grain yield under sole plots while increase in P rate up to 60 P kg ha^{-1} resulted in increase of grain yield in intercrop plots during 2009/10 (Figure 11a). In addition, increase in P rate up to 45 kg P ha^{-1} resulted in increase in the grain yield under both sole and intercrop plots during 2010/11 (Figure11b). Optimum pigeonpea grain yield was achieved at 52.67 and 41.83 kg P ha^{-1} under sole plots in 2009/10 and 2010/11, respectively (Table 9). Moreover, optimum yield under intercrop plots was achieved at 42.84 kg P ha^{-1} in 2010/11 while during 2009/10 it was achieved at -2.68 kg P ha^{-1}.

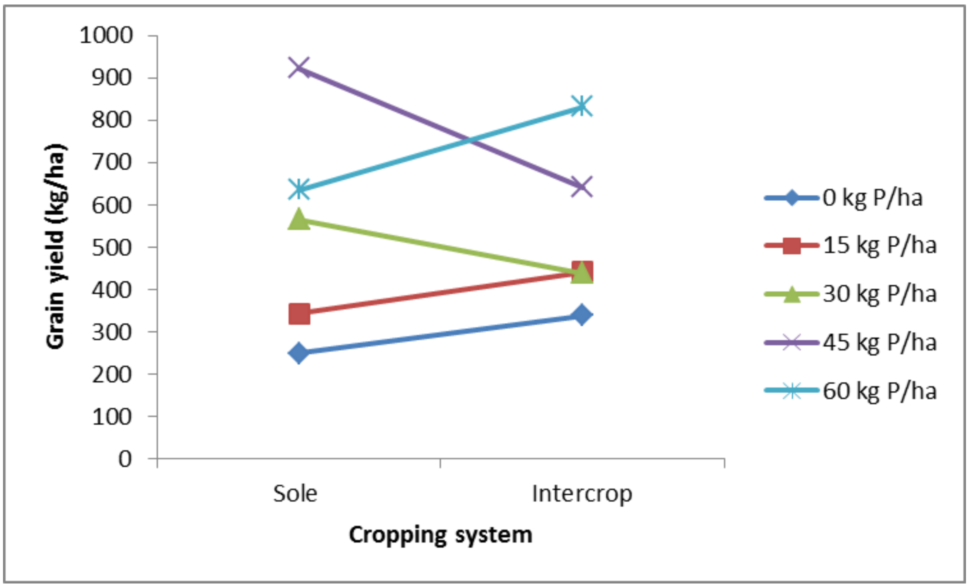

Figure 11a: Grain yield of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10 season

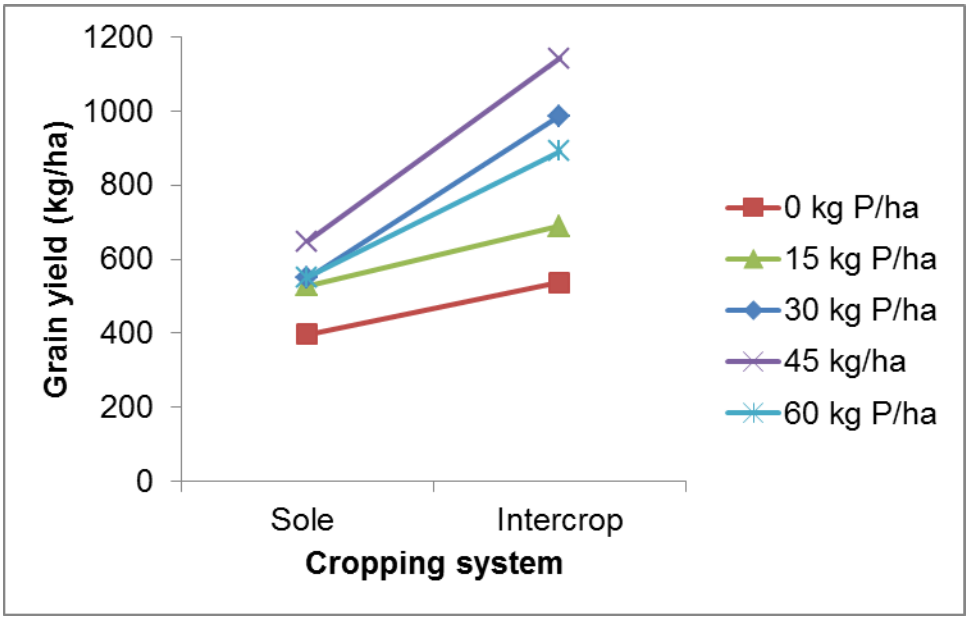

Figure 11b: Grain yield of pigeonpea as influenced by interaction of P rate and cropping system during 2010/11season

Table 9: Quadratic equation of the grain yield parameter with the cropping system as independent variable and the corresponding R^2 values of the equation

Cropping system	Season	Parameters	Regression equation	X	Y-value	R^2 value	P
Sole	2009/10	Grain yield	$-0.1985x^2 + 20.909x + 183.83$	52.67	734.44	0.7543	0.0000
	2010/11		$-0.12x^2 + 10.04x + 395.4$	41.83	605.40	0.884	0.0000
Intercropping	2009/10	Grain yield	$0.1211x^2 + 0.6492x + 355.35$	-2.68	354.48	0.969	0.0000
	2010/11		$-0.3013x^2 + 25.815x + 481.42$	42.84	1034.37	0.8672	0.0000

4.1.3.8 Monetary value

Treatment means of monetary value were significantly different as influenced by P rate and cropping system in both seasons. P rate x cropping system interactions were significant during 2009/10 and 2010/11 seasons. Increase in P rate up to 45 kg P ha^{-1} resulted in increase in the monetary value under sole plots while increase of P rate up to 60 P kg ha^{-1} resulted in increase of monetary value in intercrop plots during 2009/10 (Figure 12a). In addition, increase in P rate from 0 to 45 kg P ha^{-1} resulted in increase in the monetary value under both sole and intercrop plots and in increase of grain yield during 2010/11 (Figure 12b). Highest monetary value was achieved at 60 kg P ha^{-1} during 2009/10 while during 2010/11 it was achieved at 45 kg P ha^{-1}. Higher monetary returns were obtained under intercrop plots in both seasons.

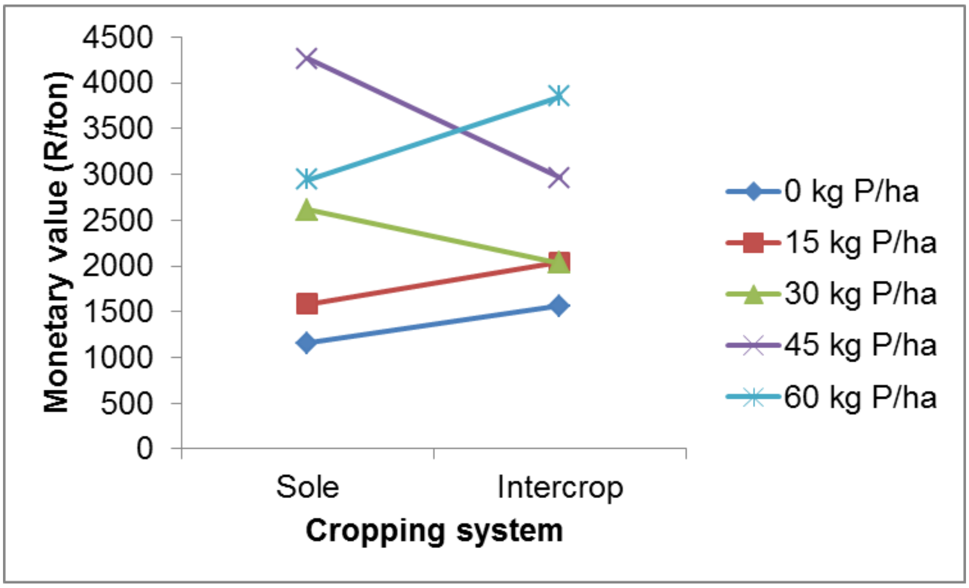

Figure 12a: Monetary value of pigeonpea as influenced by interaction of P rate and cropping system during 2009/10 season

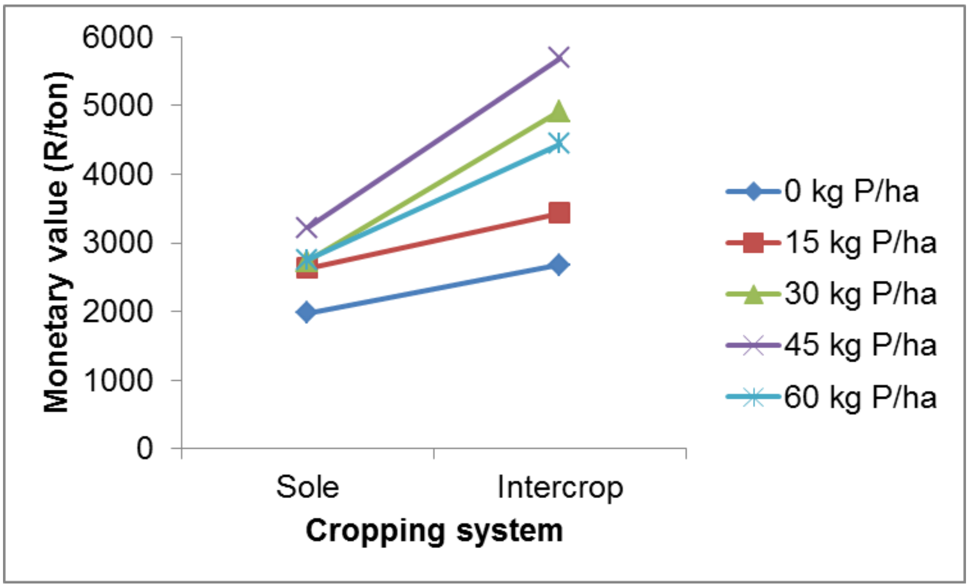

Figure 12b: Monetary value of pigeonpea as influenced by interaction of P rate and cropping system during 2010/11season

4.1.3.9 Harvesting index

The harvest indices (HI) for pigeonpea obtained in this study were low in both seasons.There were significant differences in HI as influenced by cropping system and P rate in both seasons. Cropping system × P rate interaction also had significant effect on the HI of pigeonpea in 2009/10 and 2010/11 seasons. Increasing P rate from 0 to 45 kg ha^{-1} increased HI in both sole and intercrop plots where highest HI values were obtained at 45 kg P ha^{-1} for both sole and intercrop plots (Figure 13a). During 2010/11 season, HI was not significantly influenced by an increase in P rate in both sole and intercrop plots. The maximum HI of 22.98 % was achieved at 45 kg P ha^{-1} during 2009/10 season while in the 2010/11 season HI of 37.91% was achieved at 30 kg P ha^{-1} (Tables 5 and 7). During 2009/10 and 2010/11 seasons, maximum HI was recorded on sole pigeonpea plots.

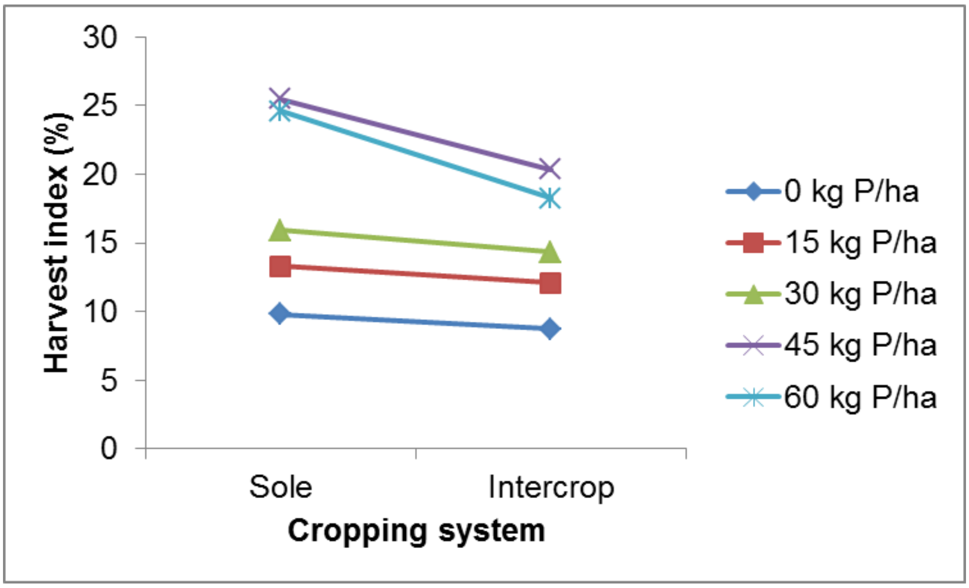

Figure 13a: Harvest index of pigeonpea as influenced by interaction of P rate with cropping system during 2009/10 season

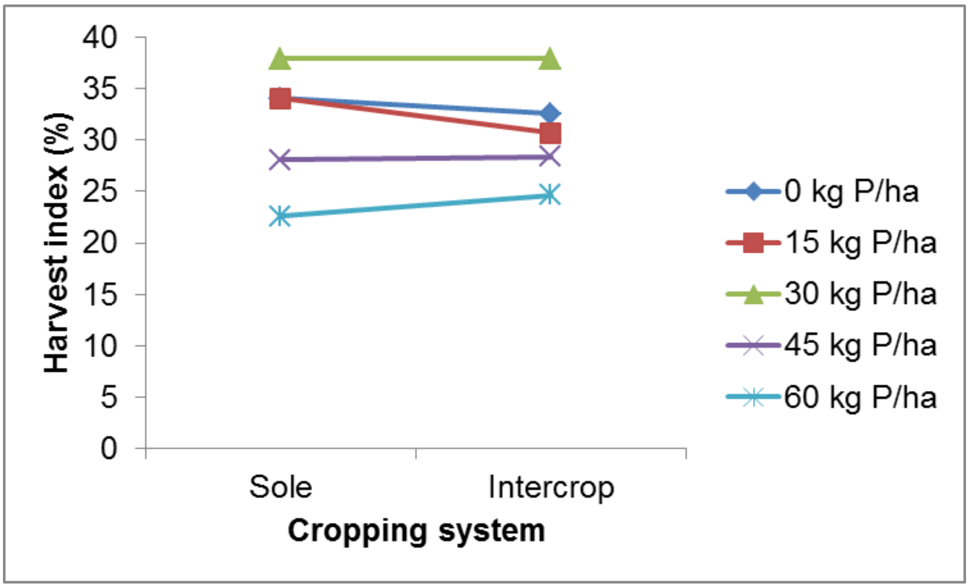

Figure 13b: Harvest index of pigeonpea as influenced by interaction of P rates and cropping system during 2010/11season

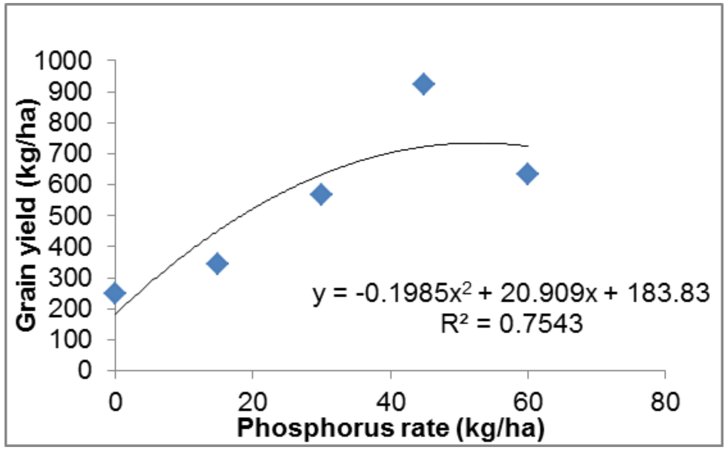

Figure 14: Grain yield of sole pigeonpea under variable P rates (2009/10)

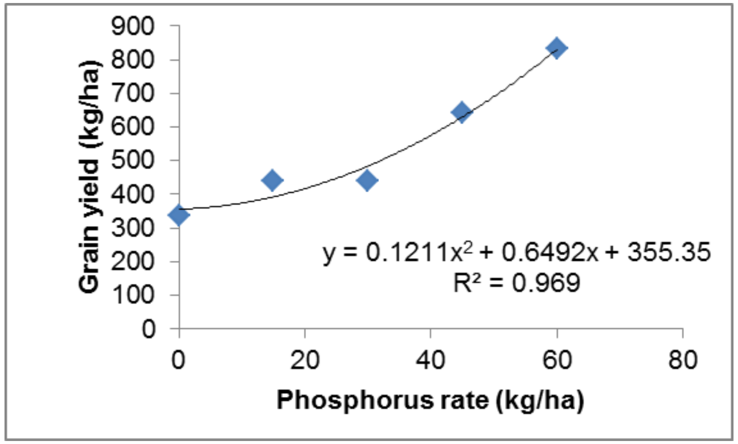

Figure 15: Grain yield of pigeonpea intercropped with maize under variable P rates (2009/10)

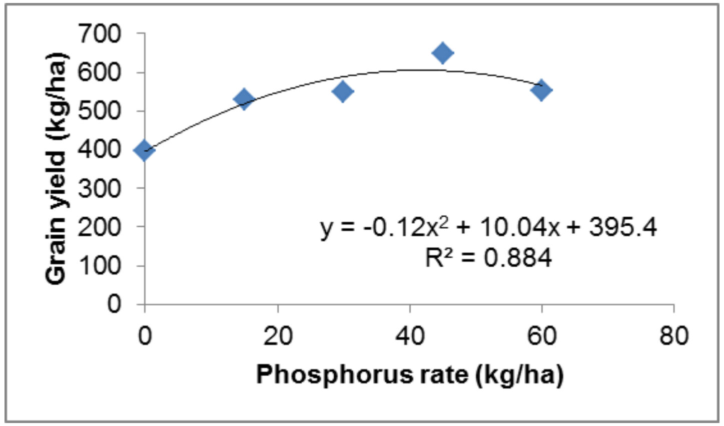

Figure 16: Grain yield of sole pigeonpea under variable P rates (2010/11)

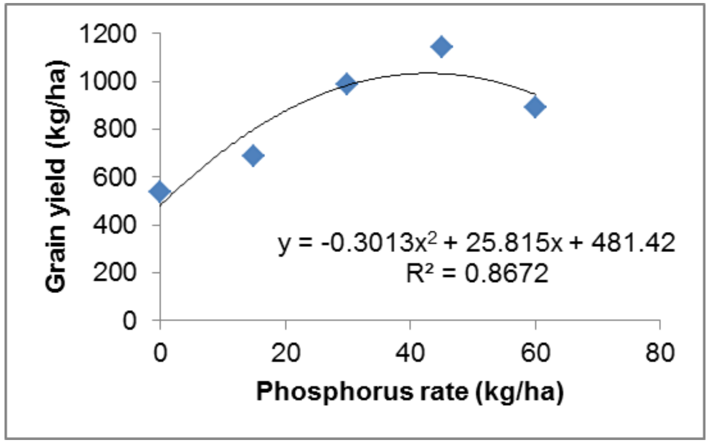

Figure 17: Grain yield of pigeonpea intercropped with maize under variable P rates (2010/11)

4.2 Performance of maize

4.2.1 Treatment effect on phenological development of maize

4.2.1.1 Number of days to 50 % flowering and physiological maturity

The different treatments did not affect the number of days to 50% flowering during both seasons (Tables 10). The number of days to 50% physiological maturity (PM) was not influenced by P rate of application nor cropping system. It took 136 days and 129 days on average for maize to reach 50% PM in 2009/10 and 2010/11 seasons, respectively (Tables 10).

4.2.2 Treatment effect on growth parameters of maize

4.2.2.1 Plant density (plants m^{-2})

Plant density was not significantly influenced by cropping system and P rate during both seasons (Table 11).

4.2.2.2 Cobs per plant

Cropping system and P rates did not affect cobs per plant during 2009/10. During 2010/11 season only cropping system exhibited slight differences in cobs per plant (Table 11). Higher number of cobs per plant was observed under intercrop plots.

4.2.2.3 Chlorophyll content

Cropping system and P rate had no effect on the flagleaf chlorophyll content during both seasons. The highest chlorophyll contents of 43.58 and 45.69 CCI were achieved at 30 kg ha^{-1} and 45 kg ha^{-1} during 2009/10 and 2010/11, respectively (Table 11).

Table 10: Phenological development of maize as influenced by P rate and cropping system in 2009/10 and 2010/11

Treatment effect	2009/10		2010/11	
	50% flowering	50% PM	50% flowering	50% PM
P rates				
0	73[a]	136[a]	73[a]	128[a]
15	76[a]	137[a]	75[a]	129[a]
30	73[a]	137[a]	72[a]	128[a]
45	75[a]	136[a]	73[a]	128[a]
60	73[a]	136[a]	74[a]	127[a]
P value	ns	ns	ns	ns
Tukey HSD	-	-	-	-
Cropping system				
Sole	74[a]	136[a]	73[a]	127[a]
Intercropping	74[a]	137[a]	74[a]	129[a]
P value	ns	ns	ns	ns
Tukey $HSD_{0.05}$	-	-	-	-
CV	3.88	1.28	3.62	1.36

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, ns=not significant, CV=coefficient variation, PM=physiological maturity

Table 11: Plant density, nnumberof cobs per plant and leaf chlorophyll content of maize as influenced by cropping system and P application rate

P rates (kg ha^{-1})	2009/10			2010/11		
	Plants density (plants m^{-2})	Cobs $plant^{-1}$	Leaf chlorophyll content (CCI)	Plants density (plants m^{-2})	Cobs $plant^{-1}$	Leaf chlorophyll content (CCI)
0	1.8^{a}	1^{a}	39.92^{a}	2.4^{a}	0.9^{a}	37.26^{a}
15	1.5^{a}	1^{a}	40.03^{a}	2.5^{a}	0.9^{a}	40.98^{a}
30	1.8^{a}	1^{a}	43.58^{a}	2.6^{a}	0.9^{a}	38.28^{a}
45	1.7^{a}	1^{a}	41.53^{a}	2.5^{a}	0.8^{a}	45.69^{a}
60	1.9^{a}	1^{a}	38.47^{a}	2.5^{a}	0.7^{a}	40.11^{a}
P values	ns	ns	ns	ns	ns	ns
Tukey HSD	-	-	-	-	-	-
Cropping systems						
Sole	1.7^{a}	1^{a}	38.87^{a}	2.6^{a}	0.7^{b}	39.47^{a}
Intercropping	1.8^{a}	1^{a}	42.54^{a}	2.4^{a}	0.9^{a}	41.47^{a}
P value	ns	ns	ns	ns	0.0388	ns
Tukey $HSD_{0.05}$	-	-	-	-	0.3159	-
CV(%)	20.53	-	27.47	9.45	17.69	29.92

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, ns=not significant, CV=coefficient variation.

4.2.3 Treatment effect on yield and yield attributes of maize

4.2.3.1 Aboveground biomass

P rates applied to pigeonpea did not affect aboveground biomass of maize during both seasons. However, highest aboveground biomass was achieved in second season compared to the aboveground biomass from the first season (Tables 12 and 14). Cropping system had significant effect on aboveground biomass during 2010/11 season. The aboveground biomass yield of 9998 kg ha^{-1} recorded under sole maize plots was 23.7% higher than that of intercropped plots (Table 13)..

4.2.3.2 Plant height

Cropping system and P rate had no significant effect on the height of plants of maize during both seasons. However the 2010/11 season produced taller plants as compared to the 2009/10 season (Tables 12 and 13). The plant height of maize ranged from 1.59 m to 1.64 m in the 2009/10 and 2.3 m to 2.4 m in the 2010/11 season.

4.2.3.3 Cob length

No significant differences were observed on the length of cob as influenced by both P rate and cropping system during 2009/10 and 2010/11 seasons (Tables 12 and 12).

4.2.3.4 Shelling percentage

P rate and cropping system had no significant effect on the shelling percentage of maize during both seasons (Tables 12 and 13).

4.2.3.5 100 seed weight

There were significant differences in the weight of 100 seeds as influenced by P rate during 2009/10 season. The highest 100 seed weight of 35.63 g was achieved at 60 kg P ha^{-1} compared to 20.63 g from 30 kg P ha^{-1}. Hundred seed weight was not significantly influenced by cropping system in both seasons. Highest 100 seed weight was achieved at P rate of 60 kg P ha^{-1} (Table 12).

Table 12: Yield and yield components of maize as influenced by cropping system and P application rate in 2009/10season

Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	Plant height (m)	Cob length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
0	5350^{a}	1.59^{a}	15.1^{a}	39.1^{a}	24.63^{ab}	1650^{b}	1845^{b}	32.69^{a}
15	5568^{a}	1.61^{a}	14.1^{a}	77.4^{a}	27.88^{ab}	3128^{a}	3497^{a}	60.44^{a}
30	5979^{a}	1.59^{a}	16.4^{a}	63.6^{a}	20.63^{b}	2484^{ab}	2777^{ab}	43.06^{a}
45	5533^{a}	1.64^{a}	16.4^{a}	71.3^{a}	22.13^{b}	1948^{ab}	2178^{ab}	36.74^{a}
60	5549^{a}	1.64^{a}	15.4^{a}	74.1^{a}	35.63^{a}	1699^{ab}	1900 ^{ab}	30.98^{a}
P value	ns	ns	ns	ns	0.0183	0.0402	0.0402	ns
Tukey HSD	-	-	-	-	12.744	1301.8	1455.4	-
Cropping system								
Sole	5956^{a}	1.63^{a}	15.9^{a}	73.5^{a}	26.30^{a}	1973^{a}	2206^{a}	34.853^{a}
Intercropping	5235^{a}	1.60^{a}	15.1^{a}	56.7^{a}	26.05^{a}	2391^{a}	2673^{a}	46.707^{a}
P value	ns	ns	ns	ns	ns	ns	ns	ns
Tukey $HSD_{0.05}$	-	-	-	-	-	-	-	-
CV%	14.00	5.31	10.92	32.59	22.29	31.55	31.55	39.81

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, ns=not significant, CV=coefficient variation

Table 13: Yield and yield components of maize as influenced by cropping system and P application rate in 2010/11season

Phosphorus rates (kg ha^{-1})	Aboveground biomass (kg ha^{-1})	Plant height (m)	Cob length (cm)	Shelling percentage (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
0	8420^{a}	2.3^{a}	18.8^{a}	68.7^{a}	37.16^{a}	3420.4^{a}	6331^{a}	41.28^{a}
15	8270^{a}	2.4^{a}	19.8^{a}	68.2^{a}	36.83^{a}	3518.1^{a}	6512^{a}	43.39^{a}
30	9008^{a}	2.4^{a}	20.0^{a}	67.3^{a}	37.11^{a}	3784.7^{a}	7006^{a}	42.410^{a}
45	8878^{a}	2.3^{a}	19.0^{a}	70.7^{a}	38.84^{a}	3844.0^{a}	7115^{a}	44.54^{a}
60	9497^{a}	2.3^{a}	19.3^{a}	78.4^{a}	37.94^{a}	4044.2^{a}	7486^{a}	43.34^{a}
P value	ns	ns	ns	ns	ns	ns	ns	ns
Tukey HSD	-	-	-	-	-	-	-	-
Cropping system								
Sole	9998^{a}	2.31^{a}	19.35^{a}	71.4^{a}	37.865^{a}	4148^{a}	7677^{a}	42.59^{a}
Intercropping	7631^{b}	2.25^{a}	19.35^{a}	69.9^{a}	37.290^{a}	3297^{b}	6102^{b}	43.43^{a}
P value	0.0442	ns	ns	ns	ns	0.0414	0.0414	ns
Tukey $HSD_{0.05}$	2298.1	-	-	-	-	813.43	1505.7	-
CV%	17.29	10.09	7.88	16.48	4.62	14.49	14.49	11.97

Means followed by same letter in a column do not differ significantly at $P \leq 0.05$, ns=not significant, CV=coefficient variation

4.2.3.6 Grain yield

Data pertaining to grain yield revealed significant differences due to P rate during 2009/10 season and 15 kg P ha^{-1} produced highest grain yield of 3128 kg ha^{-1}. The highest grain yield of 4044 kg ha^{-1} was recorded at P rate of 60 kg P ha^{-1} during 2010/11 season. There was 58.6% increase in grain yield from intercrop plots as influenced by P rate from 2009/10 to 2010/11. Cropping system had not significant influence on grain yield during 2010/11 season. Intercropped plots achieved 20.5% more grain yield than sole maize plots during 2010/11 (Table 12).

4.2.3.7 Monetary value

Monetary return of maize was not influenced by cropping system in the first season but sole maize plots achieved higher monetary values in the 2010/11 season (Tables 11 and 12). Phosphorus rate only affected maize monetary value in the 2009/10 season. In that season the highest value of R3497.0 was achieved at 15 kg P ha^{-1} while the lowest was R1844.9 for the control.

4.2.3.8 Harvest index (HI)

The HI values obtained in this study ranged from 30.98 to 60.44 and 41.28 to 44.54 percent in 2009/10 and 2010/11 seasons, respectively. Phosphorus rate did not affect HI significantly during both seasons. However, highest HI were recorded at 15 kg ha^{-1} and 45 kg ha^{-1} during 2009/10 and 2010/11, respectively (Tables 11 and 12).

4.3 INTERCROP PRODUCTIVITY

4.3.1 Land equivalent ratio (LER)

The calculated land equivalent ratios (LER) for the two crops over two seasons ranged from 1.686 to 3.702. Partial LER values for maize greater than one were recorded during the 2009/10 season. Partial LER was maximum in maize crop under P rate of 15 kg ha^{-1}. Among the P rate treatments, 30kg P ha^{-1} and 45kg P ha^{-1}

indicated significantly higher pigeonpea LER over other treatments. The mean for LER_T was 2.37 in both seasons. Thus intercropping had 137% yield advantage over sole cropping system.

Table 14: Partial and total LER for the component crops in the intercrop at different phosphorus rates

P rates	PLER $_{(maize)}$	PLER$_{(pigeonpea)}$	LER_T
2009/2010 season			
0	0.863	0.823	1.686
15	1.686	0.784	2.47
30	1.656	2.046	3.702
45	1.671	1.675	3.346
60	1.324	1.103	2.427
Mean	1.44^{a}	1.286^{a}	2.726^{a}
2010/2011 season			
0	0.779	0.977	1.756
15	0.804	1.0247	1.8287
30	0.874	1.145	2.019
45	0.889	1.438	2.327
60	0.941	1.231	2.172
Mean	0.857^{a}	1.1647^{a}	2.02^{b}
SEM across seasons	0.1145	0.1169	0.1191
Prob.(0.05) across seasons	0.0042	ns	0.0176

P = phosphorus, PLER=partial land equivalent ratio, LERT=total land equivalent ratio,SEM= standard error of mean

CHAPTER 5

DISCUSSION

The results drawn from the experiments conducted during 2009/10 and 2010/11 under rainfed conditions to study the performance of maize and pigeonpea under two cropping systems and variable P application rates are discussed in this chapter.

5.1 Growing conditions at Syferkuil experimental farm during two growing seasons

First growing season was very short compared to the second season since the planting was delayed causing the frost damage on the final product or yield of maize and pigeonpea. In the first season, during the month of February, temperatures were very high with little rainfall of about 10.16 mm while during the following season during the same month temperatures were a bit lower with rainfall of about 28.7 mm. Rainfall, especially during February during 2009/10 season, was considerably lower coupled with high temperatures compared to the average conditions at Syferkuil where it normally receives 50-60 mm. High evaporation due to high temperature during early stage of growth of the two crops, particularly maize, could have resulted in poor maize stand and ultimately affected yield. Status of the soil in terms of fertility for maize was adequate as medium amount of P was present in the soil during both seasons. Furthermore, there was frost that occured during the first season just before all pigeonpea pods reached physiological maturity. The occurrence of frost towards the end of the season in 2010 suggests the need for early planting of pigeonpea at Syferkuil.

5.1.1 Soil condition at Syferkuil

The soil pH (H_20) ranged from 6.61 to 6.67 in both seasons whereas in pH (KCl) was ranging from 5.57 to 5.85. This pH range is within the range for normal growth of pigeonpea (Singh and Oswalt, 1992). Soil results from laboratory indicated that P level from both seasons was ranging from 28 to 34 parts per million (ppm) (Table 1). According to Marx *et al*. (1999) soil P of between 20 to 40 ppm is regarded as medium. Responses to P may therefore be reduced by this relatively high soil P.

Total N of about 343 to 421 ppm during 2009/10 and 2010/11 was recorded. Medium level of potassium was recorded at 0-15 cm depth during both seasons suggesting that crops with shallow roots such as cereal crops would do better compared to crops with deep root systems such as legumes. Zinc level was sufficient for both crops since it was above 1.0 ppm during both seasons for example according to Hossain *et al.* (2011) critical level for maize is 0.78 mg kg^{-1}. The soil texture of both trial sites was silt loam (Table1).

5. 2 Performance of pigeonpea

5.2.1 Phenology of crop development and crop weather interaction

Pigeonpea growth and yield response to P rates and cropping system was not influenced by phenological development. However, pigeonpea took longer period to flower during both seasons. Probably, low temperatures during early growth stage might have lowered crop growth rate. Patel and Mehta (2001) stated that seed yield of pigeonpea can be diminished as a consequence of slower growth rate in response to cooler temperature. However, grain yield from the second season was 21.83% higher than first season grain yield. The difference could have been due to difference in rainfall and also frost damage that prevailed just before 100% physiological maturity during 2009/10. During 2009/10 there was decrease in rainfall coupled with long period of high day temperatures thus resulting in high evapotranspiration. Gwata and Siambi (2009) reported widespread leaf shedding, flower abortion and poor pod development of pigeonpea under similar conditions. For example, the first trial was planted on the 8 January 2009 during the period when about 90 mm of rain was received with the minimum and maximum temperatures of 16 and 30^{o}C, respectively.The second trial was planted on the 1st December 2010 during which period 106.3 mm rainfall was received with the minimum and maximum temperatures of 16 and 28^{o}C, respectively. The plant reached 50% flowering around March with the rainfall of about 26 mm during the first season whereas second season 50% flowering was noticed around February with the rainfall of 29 mm.

5.2.2 Effect of P rates on the performance of pigeonpea

Higher grain yields of 781 and 894 kg ha^{-1} were achieved at 45 kg p ha^{-1} during 2009/10 and 2010/11 seasons, respectively. Grain yield of pigeonpea varied significantly due to different P application rates. Grain yield of pigeonpea increased with the increased P rates of application until 45 kg P ha^{-1}. Increase in grain yield may be due to the increase in nitrogen fixation by pigeonpea as in influenced by P rate of application. Adu-Gyamfi *et al*., (1989) revealed significant increment of dinitrogen fixation in the pigeonpea cultivars due to the increase of P application rate. Srinivasan and Ahlawat (1990) also noticed increases in grain yield of 29.5, 45.1 and 47.9%, respectively, of pigeonpea over the control following application of 30, 60 and 90 kg P ha^{-1}. Grain yields of pigeonpea increased with P (37, 56 and 75 kg ha^{-1}) applications from 1.56 t ha^{-1} up to 1.83 t ha^{-1} (Janboonme., *et al*., 2007). There is likelihood that more sensitive response to P application is possible at rates lower than 45 kg P ha^{-1} in soils of lower P status. The P levels in most Limpopo soils are extremely low, for example, Kgonyane *et al*., (2013) reported P levels ranging from 1 to 6 mg kg^{-1} P at six sites in smallholder farming areas of Limpopo. However, in the present study, 2009/10 grain yields of pigeonpea were considerably lower than those achieved during the 2010/11growing season. The quality of data generated in this study, particularly in the first season, seems to have been compromised by late planting and considerable gap filling as a result of bird damage.

Grain yield of second season was 21.83% higher than the grain yield obtained during the first season. The grain yield variation between two seasons might be due to the late planting that resulted into flower abortion and poor pod filling during the first season trial, inadequate rainfall and also low soil fertility. Mathews and Saxena (2005) reported that late planting of the long to medium duration varieties after December could result in smaller canopy and lower yields. However, medium level of phosphorus was only noticed at 0-15 cm depth compared to 15-30 cm during both seasons at our experimental site. This could have negatively impacted on potassium uptake by the pigeonpea crop since it has a deep root system. There was strong relationship between number of pods per plant and the grain yield during 2009/2010 season. Plant density, branches per plant, plant height, and seeds per pod, pod length, hundred seed weight and chlorophyll content did not show any response to P application during both seasons. Pods per plant and aboveground biomass were not consistent in response to P rates of application during the seasons. Lingaraju *et al*. (2008) reported reduction in yield of pigeonpea attributed to the decreased dry matter production, pods per plant and grain weight per plant. Low pods per plant at 0 kg P ha^{-1} during first season might be ascribed by reduction of leaf initiation due to P deficiency hence reduction of its photosynthesis. The findings from this study agree with those of Fujita *et al*. (2004) who reported the reduction of photosynthetic rate in low P among three cultivars of pigeonpea where two non-hybrid cultivars ICPL 87 and UPAS 120 were grown in pots at two levels of phosphorus, i.e. control P (100 kg P ha^{-1}) and low P (10 kg P ha^{-1}). The results of their study indicated that the whole plant weight of pigeonpea was adversely affected by the low P treatment. The decrease was smallest in cultivar ICPH 8 and largest in UPAS 120 and this is indicative of tolerance of P deficiency in the improved hybrid cultivar compared with the non-hybrids.

In the current study, 30 kg P ha^{-1} produced higher PLER for pigeonpea in the first season and during the second season, 45 kg P ha^{-1} recorded higher PLER. The means for LER_T was 2.37 in both seasons. Thus intercropping had 137% yield advantage over sole cropping system. Thus, the yield advantage was obtained due to increased P rates application to pigeonpea. Abnormally high LER_T obtained in this study may be due to P applied to pigeonpea that benefitted maize crop in intercrop plots compared to sole maize with 0 kg P ha^{-1}. In addition, partial LER value greater than one of pigeonpea intercropped with maize suggest positive interactions between pigeonpea and maize in the use of available resources. Marer (2005) stated that large yield advantage in intercropping system is due to the component crops that differed in their use of natural resources and utilized them more efficiently resulting in higher yields per unit area than that produced by their sole crops. In addition Pigeonpea crop in terms of grain yield showed favorable response up to 52.67 and 42.84 kg P ha^{-1} during 2009/10 and 2010/11, respectively.

5.2.3 Effect of cropping system on the performance of pigeonpea

Yields of pigeonpea in intercropping systems were generally higher than in monocropping systems in both seasons. The inconsistency in grain yield of pigeonpea in both sole and intercrop plots may be due to erratic rainfall patterns. However, grain yield of pigeonpea in intercropping plots during the first season were superior to sole plots may be due to more soil moisture conservation in intercrop plots. The results obtained from the study contradict the findings by Ansari *et al*. (2012) who reported lower productivity (0.61 t/ha) under intercropped stand of pigeonpea when compared to sole stand (1.52 t/ha). The decreases observed in plant height in sole plots during 2009/10 season might be ascribed to intensification of interplant competition for growth factors (light, water and soil nutrients) whereas the increase in plant height that was observed in intercrop plots during 2009/10 season may be due to the low plant height of maize. The results contradict the findings of Tejpal and Mahendra (2003) who reported that intercropping with maize significantly declined the growth parameters of pigeonpea viz., plant height, dry matter production and leaf area index. Intercrop and sole pigeonpea plots showed a similar trend towards the response to P rate. The superior performance of intercrop plots in 2009/10 season suggests that there was low competition for resources both above-ground and below-ground. The decline in the number of pods per plant, dry pod weight and grain yield of intercropped pigeonpea as compared to its sole cropping might also have resulted from inter- and intra- specific competition for plant growth resources. Sole pigeonpea had a greater monetary value than intercropped pigeonpea plots during the first season while during the second season intercrop pigeonpea plots outperformed sole pigeonpea plots and this may be due to replanting of maize during 2009/2010 which was damaged by birds thus it took some time to establish and shade the pigeonpea from sunlight. Anon, (1982) reported higher yield and net return of pigeonpea when intercropped with maize than sole pigeonpea.

5.2.4 P rate interaction with cropping system on growth and yield parameters of pigeonpea

The increase of some of the parameters of pigeonpea such as number of pods per plant and grain yield with increasing P rates in both cropping systems during 2009/10 could have been attributed to the low biomass thus plant channel more nutrients to yield components. For example, the plant might have influenced nodule development as P rates application increased thus fixing more nitrogen for crop yield parameters such as number of pods per plant. Phosphorus (P) enhances the symbiotic nitrogen (N) fixation process in legume crops (Anonymous, 1999). Tauer, (1989) reported that legumes fix more nitrogen with an increase in legume yields of 10 percent. Grain yield of 2010/11 followed the same trend of 2009/10 but it was higher possibly due to the variation in rainfall distribution pattern between two seasons, and earlier planting. The decrease in plant parameters under low phosphorus in both cropping systems may be due to the negative effect of low phosphorus on the nodule capacity to fix nitrogen. Tsvetkova and Georgiev (2003) revealed that phosphorus deficiency decreased the whole plant fresh and dry mass, nodule weight, number and functioning of a soybean plant.

In the present study, the P rate x cropping system that achieved the highest yield was sole plots with 45 P kg ha^{-1} during 2009/10 while during 2010/11 season, it was intercropped plots with 45 kg P ha^{-1}. This was probably because of P rate that improved the performance of pigeonpea. Yakubu *et al*, (2010) observed increment in the nodule number of cowpea by 153%, N content in the plant tissue by 288%, and amount of N fixed by 378% when 40 kg P ha^{-1} was applied compared to control. The lowest yield was achieved under sole plots with 0 kg P ha^{-1} during both seasons. This could have been caused by low nitrogen fixation by pigeonpea crop since there was no P applied. Yakubu *et al*. (2010) also stated that low phosphorus content of the soil may restrict rhizobia population and legumes root development, which in turn, can affect their N_2 fixing potential.

5. 3 Performance of maize

5.3.1 Phenology of crop development and crop weather interaction

Phenological development was not ideal to the maize growth and yield response to P rates and cropping system. Maize tasselled at the begin of March during 2009/2010 while low rainfall of 10 to 26 mm was received and also tasselled around February during the second season with rainfall of about 29 mm. The difference in grain yield across the season could be due to the difference in rainfall and temperature across the seasons.

5.3.2 Effect of P rates on the performance of maize

Maize grain yield showed little response to P rate only during the first season. Though there was no response to P rates during the second growing season, the grain yields were higher compared to the first season and this may be due to late planting of the first season trial. Beiragi *et al*, (2011) reported that delayed planting reduced cob percentage (-1.73%), physiologic maturity (-2.96%), total leaf number (-6.79%), 300 kernel weight (-18.94%), kernel no. per row (-1.63%), kernel depth (-15.21%) and ear length (-0.12%). In addition, there was noticeable difference between figures obtained in 2009/10 and 2010/11 in all parameters measured probably due to late planting of the 2009/10 trial and also unequal amount of rainfall received during the two growing seasons. About 41.38 % increase in yield was recorded in the second season. Aboveground biomass, plant height, cob length shelling percentage, HI, plant density, cobs/ plant, chlorophyll content did not show any response to P rate of application during both seasons. Though plant height did not respond to P rate, 2010/11 season produced considerably higher plant height compared to 2009/10 season and that might be due to the late planting of the first season trial. Only hundred seed weight showed response to P rates during 2009/10 season, suggesting that P rates can affect seed size in maize. Poor response to P may also be due to the fact that the P was applied to pigeonpea which was planted 45 cm away from the maize row.

5.3.3 Effect of cropping system on the performance of maize

Almost all the parameters on maize did not show any response to cropping system during both seasons except grain yield during 2010/11 season. Sole maize plots achieved higher yield of 4148 kg ha^{-1} than 3297 kg ha^{-1} under intercrop plots during 2010/11 and the results contradict with the findings of Mathews *et al*, (2001a) who reported lower maize yield under monocropping system compared to intercropping system. Molatudi and Mariga (2012) recorded higher grain yield of 3674 kg ha^{-1} under sole plots than 3416 kg ha^{-1} under intercropped plots at Syferkuil during 2007/8. Makumba *et al*. (2009) noticed higher maize grain yields and stover biomass in plots intercropped with Gliricidia than in sole maize plots. In this study, reduction of about 25.81% from sole to intercrop maize plot was observed during 2010/11 season. Waddington (1997) reported that intercropping resulted in minimal yield reduction of the maize associated with pigeonpea genotypes. However, he reported aboveground biomass and plant height which were generally higher in sole than intercrop maize plots over two seasons. Egbe and Adeyemo (2006) observed reduction in plant height, dry cob weight, and inconsistent number of cobs per plant of maize at harvest as compared to sole maize.

CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

6.1.1 Performance of pigeonpea

Phosphorus rate of 45 kg ha^{-1} achieved highest grain yield during both seasons. Intercropping also resulted in significant increase in pigeonpea yield. Optimum grain yield of 1034.37 kg ha^{-1} under intercrop plots was obtained at 42.84 kg P ha^{-1} during 2010/11. Yields were lower in first season due to late planting. Overally results suggest low potential for pigeonpea at Syferkuil.

6.1.2 Performance of maize

Maize had less response to P rates application especially on grain yield. Maize intercropped with pigeonpea produced higher grain yield when 15 kg P ha^{-1} was applied to pigeonpea.

6.2 Conclusion and recommendations

Overall, the yields obtained in this study suggest low yield potential for pigeonpea at Syferkuil. Intercrop and sole pigeonpea gave higher income at 45 kg P ha^{-1} application rate. However 45 kg P ha^{-1} can be a challenge to small-holder farmers since most of Limpopo province soils are characterized with low P. Future studies should include basic economic analysis. The possible threat of low temperatures towards the later part of the growing season implies the need for early planting of pigeonpea at Syferkuil. It is also recommended that other pigeonpea varieties, preferably of shorter growth duration, be tested to check their response to lower phosphorus application levels since the current study used only one pigeonpea variety. It may also be beneficial to intercrop pigeonpea with shorter duration maize so as to reduce competition for growth factors during grain filling in pigeonpea. The LER values obtained in this study are abnormally high and support the notion that poor maize and pigeonpea growth due to late planting produced somewhat a typical results. Future trials should therefore be established with the very first planting rains around mid-November and more testing sites should be used. Lastly, further studies should also focus on the effect of P application on biological nitrogen fixation by pigeonpea.

7. REFERENCES

ADHIKARY, S. AND SARKAR, B.K. 2000. Pigeonpea (*Cajanus cajan*) intercropping with legumes in Bihar plateau at different levels of phosphate and cropping patterns. Indian Journal of Agronomy, 45: 279-283.

ADU-GYAMFI, J.J., MYAKA, F.M., SAKALA, W.D., ODGAARD, R. AND HØGH-JENSEN, H. 2007. Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize-pigeonpea in semi-arid Southern and Eastern Africa. Plant Soil, 295:127-136.

ADU-GYAMFI, J. J., FUJITA K. AND OGATA, S. 1989. Phosphorus absorption and utilization efficiency of pigeon pea (*Cajanus cajan (L) Millsp*.) in relation to dry matter production and dinitrogen fixation. Plant and Soil, 119: 315-324.

AE, N., ARIHARA, J., OKADA, K., YOSHIHARA, T. AND JOHANSEN, C. 1990. Phosphorous uptake by pigeonpea and its role in cropping systems of the Indian subcontinent. Science, 248: 477-480.

AGRA COMMUNICATIONS, 2012. AGRA-soil –health- bulletin- 3rd edition. Available online at http://www.agra-alliance.org/resources/. Accessed on 20 June 2012.

AKHTAR, N., AMJAD, M AND ANJUM, M.A. 2003. Growth and yield response of pea (*Pisum sativum* l.) crop to phosphorus and potassium application. Pakistan Journal of Agriculture Science, 40:3-4.

ALHAJI, I. H. 2008. Yield performance of some cowpea varieties under sole and intercropping with maize at Bauchi, Nigeria. African Research Review, 2 (3): 278-291.

ANONYMOUS. 1999. Effect of phosphorus on nitrogen fixation. Better Crops, International Plant Nutrition Institute, USA, Vol. 83, pp. 30–31.

ANONYMOUS. 1982. Annual Progress Report. AICRP on Dryland Agriculture, Udaipur.

ANONYMOUS. 1970. National sample survey of agriculture. National Statistics Office, Zomba, Malawi, National Statistics Office.

ANSARI, M.A., RANA, K.S., RANA, D.S., KUMAR, A. AND HARIOM, P.H.D. 2012. Effect of anti-transpirant and nutrient management on pearlmillet (*Pennisetum glaucum*)-pigeonpea (*Cajanus cajan*) intercropping system under rainfed conditions. Indian Journal of Agronomy, 57(4): 343-348.

AWE, G.O AND ABEGUNRIN, T.P. 2009. Effects of low input tillage and amaranth intercropping system on growth and yield of maize (*Zea mays*). African Journal of Agricultural Research, 4 (7): 578-583.

BEIRAGI, M.A., KHORASANI,S.K., NABAVI,M.S., NIKZAD, F. AND ZANDIPOUR,E. 2011. Study of yield stability of commercial corn hybrids (*Zea mays L*.) evaluated in two planting dates in Iran. African Journal of Agricultural Research, 6 (13): 3161-3166.

BHEEMASENRAO, K. 2007. Studies on planting geometry and nutrient management in companion cropping of pigeonpea [*Cajanus cajan(l.) millsp*.] and *ashwagandha (Withania somnifera Dunal*.) PhD thesis, Department of Agronomy, College of Agriculture, University of Agricultural Science. Dharwad.

BIRADAR, S. A. 2008. In situ green manuring of intercropped legumes on the performance of maize – chickpea / safflower cropping system under rainfed conditions. PhD thesis. University of Agricultural Sciences, Dharwad. Available online at http://etd.uasd.edu/. Accessed on 6 June 2012

BREMNER, J. M. 1955. Nitrogen Distribution and Amino-Acid Composition of Fractions of a Humic Acid from a Chernozem Soil (“Hildesheimer Schwarzerde”). Z. Pflanzenernaehr. Dueng. Bodenk., 71: 63–66. doi: 10.1002/jpln.19550710107

BUSMAN, L., LAMB, J., RANDALL, G., REHM., G. AND SCHIMITT, M. 2009. Nature of phosphorus in soil. St. Paul, Minnesota: University of Minnesota Extension FO-6795-B.

CARLSON, J.D. 2008. Intercropping with Maize in Sub – arid Regions. In: Community Planning and Analysis, Technical Brief. April 16th. 4pp.

CARRUTHERS, K., FE, Q., CLOUTIER, D. AND SMITH, D.L. 1998. Intercropping corn with soybean, lupin and forages: weed control by intercrops combined with inter row cultivation. European Journal of Agronomy, 8: 225–238.

CHAPMAN, H.D. 1965. Cation exchange capacity. In: Black, C. A. (Ed.). Methods of soil analysis. American Society of Agronomy, Madison WI., 9, 891-901.

DEPARTMENT OF AGRICULTURE. 2010. Maize market value profile 2010-2011. National Department of Agriculture, Private Bag X144, Pretoria, South Africa. Available online at URL. http://www.nda.agric.za/. Accessed on 15 May 2011.

DEPARTMENT OF AGRICULTURE. 2009. Pigeonpea production. National Department of Agriculture, Private Bag X144, Pretoria, South Africa. Available online at http://www.nda.agric.za/. Accessed on 10 March 2011.

DUBINSKY, E.A., SILVER, W.L. AND FIRESTONE, M.K. 2010. Tropical forest soil microbial communities couple iron and carbon bio-geochemistry. Ecology, 91:2604–2612.

DUKE, J.A. 1983. Handbook of Energy Crops. Unpublished.

ECKERT, D.J. 1988. Recommended pH and Lime Requirement Tests. P.68. In: WC. Dahne (ed.). Recommended chemical soil test procedures for the North Central Region. North Dakota Agr. Expt. Sta. Bulletin No. 499 (revised).

EDJE, O.T. 1980. Comparative development and yield and other agronomic characteristics of maize and groundnut in monoculture and in association. Pp17-26. In: Symposium on Intercropping in Semi-Arid Areas, held at Morogoro, Tanzania.

EGBE, O.M. 2005. Evaluation of some agronomic potential of pigeonpea genotypes for intercropping with maize and sorghum in Southern Guinea Savanna. Ph.D. Thesis, University of Agriculture, Makurdi, Nigeria.

EGBE, O.M. AND ADEYEMO, M.O, 2006. Estimation of the Effect of Intercropped Pigeon Pea on the Yield and Yield Components of Maize in Southern Guinea Savannah of Nigeria. Journal of Sustainable Development in Agriculture and Environment, 2(1): 107-119.

EGBE, O. M. AND KALU, B. A. 2009. Evaluation of pigeonpea [*Cajanus cajan (*l.) Millsp.] genotypes for intercropping with tall sorghum (*Sorghum bicolor* (l.) Moench) in Southern Guinea Savanna of Nigeria. Journal of Agricultural and Biological Science, 4 (4): 54-65.

EGBE, O.M., IDOGA, S. AND IDOKO, J.A. 2007. Preliminary investigation of residual benefits of pigeonpea genotypes intercropped with maize in Southern Guinea Savanna of Nigeria. Journal of Sustainable Development in Agriculture and Environment, 3:58-75.

EGBE, O.M. AND IDOKO, J.A. 2012. Evaluation of Pigeonpea Genotypes for Intercropping with Maize and Sorghum in Southern Guinea Savanna: Economic Benefits. International Journal of Agriculture and Forestry, 2(1): 108-114.

ELLIOTT, M.B. 1991. An economic analysis of the market for carbohydrates in South Africa with specific reference to white maize. Unpublished D.Sc Thesis, University of Pretoria.

ESKANDARI, H. 2011. Intercropping of wheat (*Triticum aestivum*) and bean (*Vicia faba*): Effects of complementarity and competition of intercrop components in resource consumption on dry matter production and weed growth. African Journal of Biotechnology, 10(77):17755-17762.

FARIS, D.G. AND SINGH, U. 1990. Pigeonpea: Nutrition and products. In: Nene, Y.L., Nene, Y.L., Hall, S.D. and Sheila, V.K. Eds., The Pigeonpea, CAB International, Wallingford, 401-434.

FARMER'S WEEKLY, 2013. Improving your soil. Available from: http://www.farmersweekly.co.za/article.aspx?id=47354&h=Improving-your-soil. Accessed on 19 September 2014.

FARIS, D.G., SAXENA, K.B., MAZUMDAR, S. AND SINGH, U. 1987. Vegetable pigeonpea: a promising crop in India. Patancheru, A.P. 502 324, India: ICRISAT.

FOOD AND FERTILIZER TECHNOLOGY CENTRE, FFTC. 2000. Cropping systems and their mechanisms of nutrient uptake. FFTC. Taiwan.

FRANKLIN, S., SHIFERAW, B., KASSIE, M., MONYO, E., SILIM, S.AND MURICHO, G. 2009: Assessment of the Current Situation and Future Outlooks for the pigeonpea sub-sector in Malawi- ICRISAT-Nairobi.

FUJITA, K,. KAI, Y., TAKAYANAGI, M., EL-SHEMY. H., ADU-GYAMFI, J.J. AND MOHAPATRA, P. K. 2004. Genotypic variability of pigeonpea in distribution of photosynthetic carbon at low phosphorus level. Plant Science, 166: 641–649.

GBANGUBA, A. U., ISMAILA, U., KOLO, M. G. M. AND UMAR, A. 2011. Effect of cassava/legumes intercrop before rice on weed dynamics and rice grain yield at Badeggi, Nigeria. African Journal of Plant Science, 5(4): 264-267.

GICHANGI, E. M. 2007. Enhancing phosphorus availability in some phosphate fixing soils of the Transkei region, South Africa using goat manure. PhD thesis, University of Fort Hare, Department of Agronomy. Available online at http://ufh.netd.ac.za/bitstream/10353/80/1/THESIS%20_Jan%202008_%20-%20_Gichangi_.pdf. Accessed on 19 September 2014.

GOVINDAN, A. India: Grain and Feed Annual. 2010. GAIN Report Number: IN101.U.S. Department of Agriculture, Foreign Agriculture Service, February 17, 2010.

GRAHAM, P. H. AND ROSAS, J .C. 1979. Phosphorus fertilization and symbiotic nitrogen fixation in common bean. Agronomy Journal, 71: 925-926.

GREEN HARVEST, 2013. Pigeon Pea Growing Information. http://greenharvest.com.au/PoultrySupplies/PigeonPeaGrowingInformation.html. Accessed on 2 December 2013.

GWATA, E.T. and SIAMBI, M. 2009. Genetic enhancement of pigeonpea for high latitude areas in Southern Africa. African Journal of Biotechnology, 8(18):4413-4417.

HASNURI M. H., PETRA, M., ANN, M. AND CAIXIAN, C. 2011. Growth, P uptake in grain legumes and changes in rhizosphere soil P pools. Biology and Fertility of Soils, 48:151–159.

HOSSAIN, M. A., JAHIRUDDIN, M. AND KHATUN, F. 2011. Response of maize varieties to zinc fertilization. Bangladesh Journal of. Agriculture, 36(3): 437-447.

HØGH-JENSEN, H., MYAKA, F. A., SAKALA, W. D., KAMALONGO, D., NGWIRA, A., VESTERAGER, J.M., ODGAARD, R. AND ADU-GYAMFI, J. J. 2007. Yields and qualities of pigeonpea varieties grown under smallholder farmers' conditions in Eastern and Southern Africa. African Journal of Agricultural Research, 2(6): 269-278.

HUGAR, H. Y. 2006. Studies on maize-based vegetable intercropping systems in vertisols of northern transition zone of Karnataka. MSc. Dissertation. Available online at http://etd.uasd.edu/. Accessed on 12 May 2012.

ICRISAT (International Crops Research Institute for the Semi-Arid tropics), 2008. Annual report - Improving Access and Utilization of Fertilizers by Smallholder Farmers in the Limpopo Province of South Africa. Zimbabwe, Bulawayo: ICRISAT. 43 pp.

IGWE, CA, ZAREI, M. AND STAHR, K. 2010. Fe and Al oxides distribution in some ultisols and inceptisols of south-eastern Nigeria in relation to soil total phosphorus. Environmental Earth Science, 60:1103–1111.

IJOYAH, O.M. 2011. Yield effects of intercropping white guinea yam (*Dioscorea rotundata P*.) minisetts and maize (*Zea mays L*.) in the southern Guinea savanna of Nigeria. African Journal of Agricultural Research, 6(23): 5227-5231.

IRRI, 2008. Maize intercropping systems in Africa. Available online at http://www.knowledgebank.irri.org/. Accessed on 29 May 2012.

JACKSON, M. L. 1967. Soil Chemical Analysis. Prentice-Hall of India Pvt. Ltd., New Delhi. 498pp.

JANBOONME, S., TIPPAYARUK, J., DHUMMARANGSI, P., AND BANTILAN M.C.S. 2007. Impact of pigeonpea research in enhancing sugarcane production in Thailand. Journal of SAT Agricultural Research, 3 (1): 1-19.

KAMH, M., HORST. W.J., AMER, F., MOSTAFA, H. AND MAIER, P. 1999. Mobilisation of soil and fertilizer phosphate by cover crops. Plant and Soil, 211: 19- 27.

KGONYANE, M.C., MARIGA, I.K AND DIMES, J.P. 2013. Low rates of nitrogen and phosphorus as fertilizer options for maize production by smallholding farmers in drier regions of South Africa. Journal of Research on Crops, 14 (2): 444-454.

KOMBIOK, J.M. AND ELEMO, K.M. 2005. The Influence of N and P on Maize Yield and Yield Components in Maize/Rice Mixture in the Northern Savanna Zone of Nigeria. West African Journal of Applied Ecology, 8 (1):8.

KUMAR RAO, J.V D.K., AND DART, P.J. 1987. Nodulation, nitrogen fixation and nitrogen uptake in pigeonpea (*Cajanus cajan (L.) Millsp*) of different maturity groups. Plant and Soil, 99: 255-266.

KUMAR RAO, J.V.D.K., DART, P.J. AND. SASTRY, P.V.S.S. 1983. Residual effect of pigeonpea (*Cajanus Cajan*) on yield and nitrogen response of maize. Experimental Agriculture, 19: 131-141.

KUO, S. 1996. Phosphorus. p. 869-919. In D.L. Sparks (ed.) Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America Book Ser. 5. SSSA and ASA, Madison, Wisconsin.

KUTU, F.R. AND ASIWE, J.A.N. 2010. Assessment of maize and dry bean productivity under different intercrop systems and fertilization regimes. African Journal of Agricultural Research 5 (13), pp. 1627-1631. Available online at http://www.academicjournals.org/AJAR .Accessed on 16 December 2013.

LINGARAJU, B.S., MARER, S. B. AND CHANDRASHEKAR, S. S. 2008. Studies on Intercropping of Maize and Pigeonpea Under Rainfed Conditions in Northern Transitional Zone of Karnataka. Journal of Agricultural Science, 21(1):1-3.

MABAPA, M.P., OGOLA, J.B.O., ODHIAMBO,J.J.O WHITBREAD, A. AND HARGREAVES, J. 2010. Effect of phosphorus fertilizer rates on growth and yield of three soybean (Glycine max) cultivars in Limpopo Province. African Journal of Agricultural Research, 5(19):2653-2660.

MACCOLL, D. 1989. Studies on maize at Bunda, Malawi. II. Yield in Short rotations with legumes. Experimental Agriculture, 25:367-374.

MAINA, J.M. AND DRENNAN, D.S.H. 1997. Suppression of weeds in maize intercrops in Kenya. The 1997 Brighton Crop Protection Conference – Weeds, pp. 655-656.

MAKUMBA, W., AKINNIFESI, F.K. AND JANSSEN, B.H. 2009. Spatial rooting patterns of gliricidia, pigeon pea and maize intercrops and effect on profile soil N and P distribution in southern Malawi. African Journal of Agricultural Research, 4 (4): 278-288.

MARER, S.B. 2005. Studies on intercropping of maize/pigeonpea under rainfed condition in northern transitional zone of Karnataka. Unpublished MSc. Dissertation, University of Agriculture, Dharwad. Available online at http://etd.uasd.edu/. Accessed on 6 June 2012.

MARX, E., HART, J. AND STEVENS, R. 1999. Soil Test Interpretation Guide. Oregon State University Extension Service Publication EC 1478.

MATHEWS, C., DAKORA, F.D., AND VAN AVERBEKE, W. 2011. Maize/pigeonpea intercropping systems in Mpumalanga: residual effect of pigeonpea. Poster paper presented at the South African Society of Crop Production, Soil Science Society of South Africa, Southern African Society for Horticultural Science, Southern African Weed Science Society, Combined congress held during 17 to 20 January 2011 at University of Pretoria, Pretoria, South Africa.

MATHEWS, C. AND SAXENA, K.B. 2005. Prospects for pigeonpea cultivation in drought-prone areas of South Africa. In: Proceedings of the First International Edible Legume Conference in conjunction with the IVth World Cowpea Congress, 17–21 April 2005, Durban, South Africa.

MATHEWS C., SAXENA, K.B. AND SILIM SN. 2001a. Evaluation of short, medium and long- duration pigeonpea cultivars in Mpumalanga, South Africa. International Chickpea and Pigeonpea Newsletter (ICPN), 8: 37-38.

MATHEWS, C., JONES, R.B. AND SAXENA, K. B. 2001b. Maize and Pigeonpea Intercropping Systems in Mpumalanga, South Africa. International Chickpea and Pigeonpea Newsletter, 8:52-53.

MCLAUGHLIN, M.J., MALIK, K.A., MEMON, K.S. AND IDRIS, M. 1990. The role of phosphorus in nitrogen fixation in upland crops, Page 295-305. In: Phosphorus requirements for sustainable agriculture in Asia and Oceania. IRRI, Los Banos.

MEYER, N.G. 1998 The agricultural potential of South Africa: A provincial perspective on food security and land reform. Unpublished Ph.D. Thesis, University of Pretoria, Pretoria.

MOLATUDI, R. L. AND MARIGA, I. K. 2012**.** Grain yield and biomass response of a maize/dry bean intercrop to maize density and dry bean variety. African Journal of Agricultural Research, 7(20):3139-3146.

MYAKA, F.M., SAKALA, W.D., ADU-GYAMFI, J.J., KAMALONGO, D., NGWIRA, N., ODGAARD, R., NIELSEN, N.E. and HØGH-JENSEN, H. 2006. Yields and accumulation of N and P in farmer managed intercrops of maize and pigeon pea in semi-arid Africa. Plant Soil, 285: 207–220.

NADEEM, M. 1995. Effect of different doses of fertilizer and inoculation on the growth and the yield performance of chickpea (*Cicer arietinum L*.). MSc. ‘ Agric. Dissertation. Dept. of Agronomy. Univ. Agric., Faisalabad.

NEMUTSHILI, VZ AND OGOLA, JBO. 2010 The effect of nitrogen fertilizer, planting density, and variety on maize yield at Lwamondo, limpopo province. Poster paper presented at the South African Society of Crop Production, Soil Science Society of South Africa, Southern African Society for Horticultural science, Southern African Weed Science Society, Combined congress held between 18 and 21 January 2010 at University of Free State, Bloemfontein, South Africa

NORFLEET, M.L. (ed.). 1998. Phosphorus in agriculture. Soil Quality Institute Technical Pamphlet No. 2. Soil Quality Institute.

NURUZZAMAN, M., LAMBERS, H., BOLLAND M.D.A. AND VENEKLAAS, E.J. 2005. Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertiliser. Australia Journal of Agricultural Research, 56:1041-1047.

NWOKE, O.C., DIELS, J., ABAIDOO, R, NZIGUHEBA, G. AND MERCKX, R. 2008. Organic acids in the rhizosphere and root characteristics of soybean (Glycine max) and cowpea (Vigna unguiculata) in relation to phosphorus uptake in poor savanna soils. African Journal of Biotechnology, 7 (20):3620-3627.

NWOKOLO, E. 1987. Nutritional evaluation of pigeon pea meal. Plant Foods for Human Nutrition, 37:283-290.

ODENY, D.A. 2007. The potential of pigeonpea (*Cajanus cajan (L.) Millsp*.) in Africa. Natural Resources Forum, 31:297–305.

OFORI, F. AND STERN, W.R. 1987. Cereal–legume intercropping systems. Advances in Agronomy, 41: 41–90.

OGOKE, I.J., TOGUN, A.O., CARSKY, R.J. AND DASHIELL, K. 2004. Effect of phosphorus fertilizer on soyabean pod yield in Guinea Savanna. Nigeria Agriculture Journal, 35:40-50.

OKUDA, A. AND YAMAGUCHI, M. 1955. Nitrogen-fixing microorganisms in paddy soils. I. Characteristics of the nitrogen fixation in paddy soils. Soil Plant Food, 1:102-104.

ONIM, J.F.M. 1987. Multiple uses of pigeonpea, Pp. 115-120. In: Research on grain legumes in eastern and central Africa. International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

OTANI, T., AE, N. AND TANAKA, H. 1996. Phosphorus Uptake Mechanisms of Crops Grown in Soils with Low P Status. Soil Science and Plant Nutrition, 42 (3): 553-560.

PATEL, N.R. AND MEHTA, A.N. 2001. Phenological Development and Yield of Two Diverse Pigeonpea [*Cajanus cajan (L.) Millsp*.] Genotypes in Relation to Weather. Journal of Agricultural Physics, 1 (1): 52-57.

PATHAK, K.N. 1970. Pulse crops of India. Redgram. New Delhi, India: Indian Council of Agriculture. Pp 14-53.

PEOPLES, M.B., HERRIDGE, D.F. and LADHA, J.K. 1995. Biological nitrogen fixation: An efficient source of Nitrogen for sustainable agricultural production? Plant and Soil, 174: 3–28.

PIRI, I., ABRAHIMPOUR, F., TAVASSOLI, A., AMIRI, E. AND RASTEGARIPOUR, F. 2011. Effect of fertilizer in controlling weeds under intercropping of pearl millet and red bean in Sistan region, Iran. African Journal of Biotechnology, 10(38):7397-7403.

PRAMANIK, M. Y. A., SARKAR, M. A. R., UDDIN, M. S. AND FARUK, G. M. 2009. Effect of phosphorus rate on growth, nodulation and biomass yield of green manure crop. Journal of Bangladesh Agricultural University, 7(1): 23–28.

RANI, B.P. AND REDDY, D.R. 2010. Performance of pigeonpea in sole and inter cropping system in vertisols of Krishna - Godavari zone in Andhra Pradesh. Indian Journal of Agricultural Research, 44(3): 225-228.

REDDY, M.S., FLOYD, C.N. AND WILLEY, R.W. 1980. Groundnut in intercropping systems. In: Proceedings of the International Workshop on Groundnuts, 13-17 October 1980, ICRISAT Center Patancheru, India.

REDDY, S.J. and VIRMANI, S.M. 1981. Pigeonpea and its climatic environment. Pp. 259-270. In: Patancheru, A.P. (ed.) Proceedings of the international workshop on pigeonpeas held on 15-19 Dec 1980 at India International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Vol. 1.

RYAN, J., IBRIKCI, H., SINGH, M., MATAR, A., MASRI, S., RASHID, A. AND PALAA, M. 2008. Response to residual and currently applied phosphorus in dryland cereal/legume rotations in three Syrian Mediterranean agroecosystems. Europian Journal of Agronomy 28: 126–137.

SAKTHIVEL, N., RADHAMANI, S., BALASUBRAMANIAN, A. AND SUBBIAN, P. 2003. Comparative performance of different maize-based intercropping systems and planting patterns under rainfed situations.

SOUTH AFRICAN GRAIN INFORMATION SERVICE, SAGIS. 2012. Monthly report. http://www.sagis.org.za/. Accessed on 6 June 2012.

SARIKA, A, V., IQUEBAL, M. A., RAI, A. AND KUMAR, D. 2013. PIPEMicroDB: microsatellite database and primer generation tool for pigeonpea genome. The Journal of Biological Databases and Curation, 2013. Article ID bas054, doi:10.1093/database/bas054.

SAXENA, K.B., MATHEWS, C. AND SILIM, S.N. 2001. Evaluation of short-, medium-, and long- duration ICRISAT pigeonpea cultivars in Mpumalanga, South Africa. International Chickpea and Pigeonpea Newsletter (8), 37-38.

SHAMIM, P.B. AND NAIMAT, S. 1987. Effect of seed inoculation with rhizobium and NP fertilizer levels on yield of gram. Pakistan Journal of Agricultural Research, 8(4):383-386.

SHARMA, A. 2009. Performance of pigeonpea based cropping systems under set-furrow cultivation in vertisols. PhD Thesis. University of Agricultural Science., Dharwad (India).Available online at http://etd.uasd.edu/. Accessed on 6 June 2012.

SINCLAIR, T.R. 2004. Increasing yield potential of legume crops – similarities and contrasts with cereals. New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia.

SINGH, F. and OSWALT, D.L. 1992. Pigeonpea botany and production practices. Skill Development Series no. 9. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, 41Pp.

SINGH, P. (2006). Leaping Over the Legume Yield Gap. South Africa Trends ICRISAT Monthly Newsletter, 63.

SINGH, T. AND PAL, M. 2003, Growth parameters, yield attributes and yield of pigeonpea as influenced by cropping systems and nitrogen + phosphorus levels. Annals of Agricultural Research, 24: 755-759.

SINGH, R. AND PATEL, C.S., 1991, Weed management in maize based intercropping system. Indian Journal of Weed Science, 23(1&2): 61-63.

SINGH, U. 1993. Protein quality of pigeon pea (*Cajanus cajan (L.) Millsp*) as influenced by seed polyphenols and cooking process. Plant Foods for Human Nutrition, 43: 171-179.

SINGH, U. 1991. The Role of Pigeonpea in Human Nutrition. In: Patancheru, A.P. (ed.) Use of Tropical Grain Legumes: Proceedings of a Consultants' Meeting held during 27-30 March 1989, ICRI SAT Center, Hyderabad.

SINGH, U., AND EGGUM, B.O. 1984. Factors affecting the protein quality of pigeonpea (*Cajanus cajan L*.). Qualitas Plantarum Plant Foods for Human Nutrition, 34:273-283.

SINHA, S.K. 1977. Food legumes: distribution, adaptability and biology of yield, Pp. 117-124. In: FAO Plant Production and Protection paper 3. FAO, Rome.

SIVAKUMAR, M. V. K. AND VIRMANI, S. M. 1980. Growth and Resource Use of Maize, Pigeonpea and Maize/Pigeonpea Intercrop in an Operational Research Watershed. Experimental Agriculture, 16:377-386.

SMARTT, J. 1976. Tropical pulses. Longman Group Limited, London. 348Pp.

SOIL ASSOCIATION OF UK, 2010. A rock and a hard place: peak phosphorus and the threat to our food security. Soil Association, (Bristol :). Pp 23.

SRINIVASAN, A. AND AHLAWAT, I. P. S. 1990. Growth and yield responses of short duration pigeonpea to Intercropping with mungbean and sorghum, and to phosphate fertilization. Journal of Agronomy and Crop Science, 165(5): 329-339.

STATISTIX 9. Analytical Software. Tallahassee FL. 2008.

STOCKDALE, L. AND ATKINSON, D. 2010. Managing phosphorus dynamics in organic rotations. Results of Organic Research: Technical Leaflet 8. Institute of Organic Training and Advice, Newcastle University. Available online at http://www.organicadvice.org.uk/. Accessed on 20 June 2012.

SUMATHI, S., AND PATABHIRAMAN, T.N. 1976. Natural plant enzyme inhibitors. Part I I. Protease inhibitors of seeds. Indian Journal of Biochemistry and Biophysics, 13:52-56.

SUNDARAJ, D.D. AND THULASIDAS, G. 1980. Botany of field crops. New Delhi. The Macmillan company of India LTD. 496Pp.

SYNGENTA. 2012. Maize (corn) and related products Available online at http://www.syngenta.com/country/za/en/cropsandproducts/keycrops/Pages/Maize.ax .Accessed on 11 July 2013.

SZUMIGALSKI, A. 2005. Weed suppression and crop production in annual intercrops. Weed Science, 53: 813-825.

TAUER, L. W. (1989). Economic impact of future biological nitrogen fixation technologies on United States agriculture. Plant and Soil, 119:261-270.

TEJPAL, S. AND MAHENDRA, P. 2003. Growth parameters, yield attributes and yield of pigeonpea as influenced by cropping systems and nitrogen + phosphorus levels. Annals of Agricultural Research, 24: 755-759.

THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing methods for advisory purposes. Soil Sci. Soc. South Africa, P.O. Box 30030, Sunnyside, Pretoria.

THIYAGARAJAN, T.M., BACKIYAVATHY, M.R. AND SAVITHRI, P. 2003. Nutrient management for pulses - a review. Agricultural Reviews, 24(1):40-48.

TSVETKOVA, G.E. AND GEORGIEV, G.I. 2003. Effect of phosphorus nutrition on the nodulation, nitrogen fixation and nutrient use efficiency of *Bradyrhizobuim japonicum*-soybean (*Glycine max L. merr*) symbiosis. Bulgarian Journal of Plant Physiology. 331- 335.

VALENZUELA, H. and SMITH, J. 2002. Pigeonpea. Honolulu (HI): University of Hawaii. Sustainable Agriculture; SA-GM-8. Pp 3.

VAVILOV, N.I. 1951. The origin, variation, immunity and breeding of cultivated plants. Chronic Botanical, 13 (1-6):1-36.

VERMA, K.P. AND WARSI, A.S. 1997. Production potential of pigeonpea (*Cajanus cajan*) based intercropping systems under rainfed conditions. Indian Journal of Agronomy, 42 (3): 419-421.

VITTAL, K.P.R., ALI, M., CHARY, G. R., SANKAR, G.R.M., RAMAKRISHNA, Y.S. SRIJAYA, T., SAMRA J.S AND SINGH, G. 2004. District-wise Promising Technologies for Rainfed Pigeonpea based Production System in India. All India Co-ordinated Research Project for Dryland Agriculture, Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad 500 059. 132Pp.

WADDINGTON, S. 1997. Some promising soil fertility technologies being developed within Soil Fertility Net. Being paper presented at Soil Fertility Results and Planning Workshop held at Africa University, July 1997.

WANI, S.P., MCGILL, W.B. AND ROBERTSON, J.A. 1991. Soil N dynamics and N-yield of barley grown on Breton loam using N from biological fixation or fertilizer. Biology and Fertility of Soils, 12: 10-18.

WANI, S.P., MCGILL, W.B., HAUGEN-KOZYRA, K.L. AND JUMA, N.G. 1994. Increased proportion of active soil N in Breton loam under cropping systems with forages and green manures. Canadian Journal of Soil Science, 76: 67-74.

WILLEY, R.W. and REDDY, S. 1981 A field technique for separating above and below ground interaction for intercropping experiments with pearl millet/groundnut. Experimental Agriculture, 17: 257-264.

WILLEY, R. W., NATARAJAN, M., REDDY, M. S., AND RAO, M.R. 1986. Cropping Systems with Groundnut: Resource Use and Productivity. In: Agrometeorology of groundnut. Proceedings of an international symposium, 21-26 August 1985, ICRISAT, Niger.

WILLEY, R.W., RAO. M.R. AND NATARAJN, M. 1980, Traditional cropping systems with pigeonpea and their improvement. In : Proc. Inte. Workshop Pigeonpea, December 15-19, 1980, ICRISAT, Patancheru, pp. 11-25.

WOLFSWINKEL, M.V. 2012. Intercropping of annual crops. in : Agro mica . Available online athttp://www.allindiary.org/pool/resources/intercropping.pdf.Accessed on 29 May 2012.

YAKUBU, H.,. KWARI J. D. AND SANDABE, M.K. 2010. Effect of Phosphorus Fertilizer on Nitrogen Fixation by Some Grain Legume Varieties in Sudano – Sahelian Zone of North Eastern Nigeria. Nigerian Journal of Basic and Applied Science), 18(1):19-26.

YEBOAH, E., FENING J.O. AND AMPONTUAH, E.O. 2004. The use of pigeon pea (*Cajanus cajan*) for amelioration of Ultisols in Ghana, In Bationo, A (ed.). Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. Pp 401-410.

8. APPENDICES

1. Analysis of variance for pigeon pea parameters

Mean square value for the phonological data for pigeonpea in both seasons

	2009/2010			2010/11	
Source of variation	Degrees of Freedom	Days to fifty percent flowering	days to fifty percent physiological maturity	Days to fifty percent flowering	days to fifty percent physiological maturity
Cropping system	1	5.21137ns	2.88202ns	0.33402ns	12.3906ns
P rate	4	1.08633ns	1.63612ns	0.31699ns	6.3454ns
Cropping system X P rate	4	3.82611ns	9.33379ns	0.58808ns	8.1984ns

ns=not significant, *=significant, ***=highly significant

Mean square value for the selected growth parameter for pigeonpea in both seasons

Source of variation	Degrees of Freedom	Plant density (plants/m^2)#	Number of branches per plant	Plant height (m)	Leaf Chlorophyll content (CCI)	Plant density (plants/m^2)	Number of branches per plant	Plant height (m)	Leaf Chlorophyll content (CCI)
Cropping system	1	59.753ns	5.202ns	1.225*	159.20ns	2.884ns	81.225*	0.025ns	187.438ns
P rate	4	2.335ns	0.786ns	0.006ns	869.81ns	0.248ns	0.163ns	0.0013ns	63.866ns
Cropping system X P rate	4	1.435*	1.438ns	0.018ns	1089.58ns	1.4469ns	9.788*	0.003ns	48.890ns

ns=not significant, *=significant, ***=highly significant

Mean square value for the selected yield parameter for pigeonpea in 2009/10 season

Source of variation	Degrees of Freedom	Aboveground biomass (kg ha^{-1})	Pods per plant	Seeds per pod	Pod length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI%
Cropping system	1	8345161ns	0.081ns	0.100ns	0.025ns	35.847ns	2.116ns	250634***	5361220***	1.259*
P rate	4	516610ns	625.268***	0.288ns	0.250ns	632.427ns	1.649ns	358987***	7678973***	269.431ns
Cropping system X P rate	4	351835ns	17.384*	0.538ns	1.400ns	192.859ns	2.882ns	13087**	279945**	35.876ns

ns=not significant, *=significant, ***=highly significant

Mean square value for the selected yield parameter for pigeonpea in 2010/11 season

Source of variation	Degrees of Freedom	Aboveground biomass (kg ha^{-1})	Pods per plant	Seeds per pod	Pod length (cm)	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI%
Cropping system	1	1.002***	101.761ns	0.025ns	2.025ns	35.847*	38.22***	355.87***	355.87***	2.621ns
P rate	4	5808347***	36.263ns	0.750ns	0.788ns	632.427ns	0.90ns	75.50***	75.50***	234.595ns
Cropping system X P rate	4	582152ns	17.663ns	0.400ns	0.338ns	192.859ns	1.67ns	18.43***	18.43***	8.461ns

ns=not significant, *=significant, ***=highly significant

2. Analysis of variance for maize parameters

Mean square value for the phonological data for pigeonpea in both seasons

		2009/2010		2010/11	
Source of variation	Degrees of Freedom	Days to fifty percent tasselling	days to fifty percent physiological maturity	Days to fifty percent tasselling	days to fifty percent physiological maturity
Cropping system	1	0.482ns	6.020ns	1.524ns	0.095ns
P rate	4	10.464ns	3.250ns	5.931ns	5.324ns

ns=not significant, *=significant, ***=highly significant

Mean square value for the selected growth parameter for maize in both seasons

		2009/10				2010/11			
Source of variation	Degrees of Freedom	Plants density (plants/m^2)	Cobs per plant	Leaf chlorophyll content (CCI)	Plant height (m)	Plants density (plants/m^2)	Cobs per plant	Plant height (m)	Leaf chlorophyll content (CCI)
Cropping system	1	0.017ns	0.000ns	27.195ns	0.00125ns	0.014ns	0.000ns	0.045ns	8.000ns
P rate	4	0.091ns	0.000ns	15.890ns	0.00250ns	0.078ns	0.000ns	0.007ns	42.687ns

ns=not significant, *=significant, ***=highly significant

Mean square value for the selected yield parameter for maize in 2009/10 season

Source of variation	Degrees of Freedom	Aboveground biomass (kg ha^{-1})	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
Cropping system	1	1040537ns	0.814ns	0.125ns	348996ns	436219ns	281.049ns
P rate	4	213946ns	664.574*	141.800ns	1626316ns	1945249*	548.231ns

ns=not significant, *=significant, ***=highly significant

Mean square value for the selected yield parameter for maize in 2010/11 season

Source of variation	Degrees of Freedom	Aboveground biomass (kg ha^{-1})	Shelling (%)	100 seed weight (g)	Grain yield (kg ha^{-1})	Monetary value (R ha^{-1})	HI (%)
Cropping system	1	1448150ns	752.999ns	0.66ns	149585ns	54771ns	8.037ns
P rate	4	255178*	92.552ns	2.653ns	118613ns	53855ns	33.718ns

ns=not significant, *=significant, ***=highly significant