EFFECT OF PHOSPHORUS APPLICATION ON THE PERFORMANCE OF FOUR COWPEA VARIETIES AND TWO MAIZE VARIETIES UNDER STRIP INTERCROPPING IN LIMPOPO PROVINCE

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MINI-DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY, DEPARTMENT OF PLANT PRODUCTION, SOIL SCIENCE AND AGRICULTURAL ENGINEERING, SCHOOL OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES, FACULTY OF SCIENCE AND AGRICULTURE, UNIVERSITY OF LIMPOPO, SOUTH AFRICA

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DECLARATION

I, Mzamani Knowledge Nkuna, declare that this mini-dissertation hereby submitted to University of Limpopo, for the degree of Master of Science in Agronomy 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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Supervisor: Prof J.A.N Asiwe

DEDICATION

This study is affectionately dedicated to my beloved mother; the late Tsatsawani Maria Mabasa, and to my three beloved sisters; Nkhesani, Tirhani and Eaglet.

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ABSTRACT

Limpopo Province is a semi-arid region prone to drought. Crop yields continue to decline due to low soil fertility and poor cropping systems. Cowpea is nutritionally rich in proteins essential for human consumption and livestock feeding. It fixes N_2 which becomes available for the succeeding crop in rotation. For this reason, it is used as a companion crop in cereal-legume intercropping systems. Maize is one of the most important grain crops in South Africa, it serves as the major staple food for many households. Phosphorus is one of the macro-nutrient elements required by crops to produce satisfactory yields. The interactions between different rates of P fertilisation and cowpea-maize strip intercropping have not been studied in detail under rain-fed maize-cowpea strip intercropping in Limpopo Province. Many smallholder farmers in Limpopo Province obtain low yields due to the practice of mixed intercropping.

Two season (2014/15 and 2015/16) experiments were laid out in a split-split plot design at Syferkuil farm to determine the performance of cowpea and maize varieties in cowpea-maize strip intercropping at varying P application rates. Treatments consisted of factors namely, P levels (0, 15, 30, 45 kg/ha), cropping system (monocropping and intercropping), maize varieties (WE3127 and ZM1423) and cowpea varieties (PAN311, TVu13464, IT86D-1010 and IT82D-889). Data were collected from growth and yield parameters that included (number of days to flowering, plant height, number of days to physiological maturity, root weight, number of pods per plant, unshelled net pod weight, number of cobs per plant, unshelled net cob weight and grain yield) in order to determine their performance.

Results obtained revealed that P application levels significantly influenced most of the measured growth and yield parameters of both crops. PAN311 flowered earliest (49 days) across P levels. Increasing P application hastened the maturity of the varieties of PAN 311 and TVu13464 in both seasons. The P levels of 30 and 45 kg/ha reduced the number of days to maturity as compared to 0 and 15 kg/ha. TVu13464 variety produced more pods per plant (30) than other varieties. PAN311 yielded more grains (2491 kg/ha) than other varieties. Maize varieties performed well between P applications of 30 and 45 kg/ha. WE3127 yielded 3462 kg/ha whereas ZM1423 yielded 3306 kg/ha. Intercropping system performed better than monocropping system based on the measured growth and yield parameters. Two promising cowpea varieties (PAN311 and TVu13464) performed well and were selected based on their early maturity, drought tolerance and high yielding. Increasing P application levels increased crop yield. Optimum P levels for cowpea-maize strip intercropping were between 30 and 45 kg/ha. The calculated LER values were greater than one which indicates that intercropping was advantageous in land utilisation. The study showed the importance of P application in improving cowpea yield in cowpea-maize strip intercropping.

Keywords: *Growing season*, *Cropping system, Phosphorus, Cowpea, Maize, Grain yield*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background information

South Africa, particularly Limpopo Province is mostly semi-arid region prone to drought (Mpandeli *et al*., 2015). According to Ramaru *et al*. (2000), crop yields continue to decline due to low soil fertility and monoculture cropping systems of crops such as maize (*Zea mays*), sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*). Sandy soil with inadequate nutrients, particularly nitrogen and phosphorus occurs in most areas of Limpopo Province (Ramaru *et al*., 2000). Maize is one of the important grain crops in South Africa serving as the major staple food for many households (DAFF, 2008; Govereh *et al*., 2003). According to Minde *et al*. (2008), maize is the most dominant dryland crop for smallholder farmers in Limpopo Province. Cowpea is a nutritionally rich crop in protein which is important for both human consumption and livestock feeding (Asiwe, 2009a; Sheahan, 2012). It is mainly grown as grain legume crop, though, the young leaves and immature pods are used as vegetable (DAFF, 2011). Inclusion of cowpea in cropping systems has the potential of increasing crop yields due to residual fixed N (Belane *et al.,* 2011; Smith, 2006).

Phosphorus is one of the important nutrient elements required by crops to produce satisfactory yields (Syers *et al*., 2008); however, it is the least accessible nutrient element due to its immobility. It plays a major role in numerous plant processes including photosynthesis, respiration, cell division and energy transformation (Balemi and Negisho, 2012). It is also known for improving early root formation and development, therefore enhances drought tolerance of crops. However, the application of P in strip intercropping situation have not been intensively studied.

Intercropping is a cropping practice that permits the growing of two or more component crops in the same field in one season (Parker, 2004). Row intercropping, mixed intercropping, relay intercropping and strip intercropping form the basis of intercropping. Most farmers in Limpopo province practice mixed planting (bad cultural practice) which therefore compromises crop yields in many ways due to the fact that it does not permit mechanisation and application of farm inputs (Asiwe, 2009b). The use of strip intercropping (growing two or more component crops together in wider strips to facilitate individual crop production but close enough to have some crop interaction) will improve farmer's yield and also evenly distribute the labour requirements throughout the growing season, maximize complementary interactions, improve pest management, control soil erosion, build-up soil fertility and reduce the requirement of N-fertilisation (Dahmardeh *et al*., 2010).

1.2 Problem statement

Threats from climate change, water scarcity, environmental degradation and competition for scarce energy resources have been challenging agricultural production in Africa (Feed the Future, 2014). According to Msangi (2014), agriculture supports over 70% of the rural population; primarily concentrated in smallholder farming in South Africa. Although South Africa is believed to be self-sufficient in food production, 43% of households were classified as vulnerable to food insecurity (Minde *et al.,* 2008). Approximately 13% of South African land is arable, this is due to low erratic rainfall and poor soils (ARC-GCI, 2015). In Limpopo Province, smallholder rainfed agriculture has been particularly vulnerable to erratic soil moisture, low soil fertility and over dependence on monocultural systems, which has a negative impact on crop production for family consumption and generation of income (Minde *et al*., 2008).

Several plant nutrients have a well-established role in improving drought tolerance including potassium with its effects on osmotic adjustment in plant cells (Farooq *et al*., 2009). Phosphorus nutrition also have important effects on drought tolerance of crops possibly through its effect on root growth and other plant physiological processes (Eghball and Maranville, 1993; Ragothama, 2005). Furthermore, P application enhances water-use efficiency and improve drought tolerance as a result of decreased stomatal conductance, maintaining leaf water potential, increasing root hydraulic conductivity and root access to more soil water in deep soil layers (Jin *et al*., 2015). Despite the importance of P, the interactions between different rates of P-fertilisation have not been intensively studied under rainfed cowpea-maize strip intercropping in Limpopo Province.

1.3 Rationale of the study

Maize is one of the important grain crops in South African region serving as staple food crop for many people (Govereh *et al*., 2003). Cowpea is not yet a staple food crop in South Africa, however, it is an important leguminous crop which is a source of proteins (Asiwe, 2009a; DAFF, 2011). South Africa, particularly Limpopo Province is an arid to semi-arid region, characterised by low soil fertility and low erratic rainfall, which result in reduced crop yields (Mpandeli *et al*., 2015). Mixed intercropping is the common cropping system for many smallholder farmers in Limpopo Province. This kind of cropping system tends to compromise crop yields in many ways due to the fact that without definite row arrangements it is difficult to apply farm inputs needed for good crop growth and development. Therefore, strip intercropping seem to have a potential to cover the flaws of mixed intercropping because it will evenly distribute labour requirements throughout the growing season, maximise complementary interactions, improves pest management, control soil erosion, build-up soil fertility, allow mechanisation and application of farm inputs (Dahmardeh *et al*., 2010).

Phosphorus is one of the most limiting nutrient elements for crops, therefore, adequate supply is necessary for successful crop production (Syers *et al*., 2008). Phosphorus is critical for good crop growth and development; it is involved in numerous physiological and biochemical processes such as photosynthesis, respiration, energy transformations, nucleic acid biosynthesis, cell division and enlargement (Mullins, 2009). Apart from this, it also improves early root formation and growth, thereby enhancing crop drought tolerance. Adequate P application helps crops to better withstand drought under future climate scenarios. Normally, smallholder farmers are not precise when they apply fertilisers, instead they use bottle cap to top dress or free hand to broadcast the fertiliser (Minde *et al*., 2008). This procedure is likely to result in nutrient imbalance situation whereby the crop does not get the adequate amount of the nutrient element, therefore compromise the output.

The contribution of P in maize-cowpea strip intercropping has not been studied in detail in South Africa. If P application in strip intercropping situation is proved to enhance drought tolerance of the crops, this means that smallholder farmers of Limpopo Province and South Africa would benefit from optimum P-fertilisation, improved crop yields, income and food security. Furthermore, this project will play an important role for advisory services and production guide for South African smallholder farmers. It is expected that the findings of this research project will be published and provide the basis for a larger scale proposal related to this topic.

1.4 Purpose of the study

1.4.1 Aim

The aim of the study was to improve traditional mixed intercropping system through cowpea-maize strip intercropping.

1.4.2 Objectives

The objectives of the study were to:

i) Determine the performance of four cowpea varieties and two varieties of maize in cowpea-maize strip intercropping.

ii) Determine the performance of four cowpea varieties strip-intercropped with two maize varieties under four P application levels.

iii) Determine the land equivalent ratio (LER) of the component crops

1.5 Hypotheses

i) The performance of four cowpea varieties and two varieties of maize in cowpea-maize strip intercropping do not differ.

ii) The performance of four cowpea varieties strip intercropped with two maize varieties under P application do not differ.

iii) The LER of the component crops will not differ

CHAPTER 2: LITERATURE REVIEW

2.1 Maize production

Maize (*Zea mays*) is one of the important grain crops in South Africa together with of wheat, soybeans and sunflower seed (Smith, 2006). According to SAMT (2016), the crop is used as a staple food crop especially for the poor population. It originated from Mexico (Govereh *et al*., 2003). In South Africa, it grows under diverse environments (du Plessis, 2003), but the production is primarily based in North West, Free State, Mpumalanga, Limpopo and KwaZulu-Natal provinces (SAMT, 2016).

Weather and market conditions are key factors in determining the expansion of maize production in South Africa; maize hectares vary from year to year, but on average approximately 2.5-2.75 million hectares of hybrid maize are planted in each year yielding approximately 10-12 million tons of grain (SAMT, 2016). In addition, about 350 000-500 000 hectares are planted by smallholder farmers using a mix of saved seed, open-pollinated varieties and hybrids. The total crop planted comprises of about 85% genetically modified maize. Smallholder farmers normally obtain low yields of about 1 ton/ha because of little or no fertiliser application, and also crop failure due to moisture stress during drought periods (ARC-GCI, 2015).

2.2 Importance of maize

Maize is the staple food crop for more than 70% of the South African population (ARC-GCI, 2015). According to DAFF (2008), the crop has various end-uses; grain such as meal and green mealies, and processed maize such as snacks and cereals. Maize is the largest contributor to gross value of field crops in South Africa (DAFF, 2013). For the past five seasons (2008-2012), the total gross value percentage of maize was 46.1% followed by sugarcane at 14.2%, this is clear evidence that maize is the major source of revenue and employment in agricultural sector (DAFF, 2013). Maize crop has a strong linkage for South African economy through wet milling (maize starch and syrup dextrose), dry milling (maize meal, flour and grits) and animal feed industries (SAMT, 2016). Normally, white maize is mainly for human consumption, whereas, yellow maize is for livestock feeding. Feed production in South Africa is estimated at more than 11 million tons per annum (SAMT, 2016).

2.3 Production requirements of maize

According to du Plessis (2003), it is important to sustain the environment and agricultural production through correct application of production inputs such as adapted cultivars, plant population, soil tillage, fertilisation, weeding, insect and disease control because successful maize production depends on them. Maize is the summer cereal crop which grows well on a variety of soils though optimum production requires soils with favourable physical properties, good drainage, optimal moisture regime, sufficient and balanced quantities of plant nutrients and other chemical properties (DAFF, 2008). As with other crops, maize also depend on optimal climate for good growth and development. According to du Plessis (2003), a temperature above 32˚C is detrimental to maize crop, it requires between 19-25˚C for flowering. Frost free period is also essential during the crop cycle because frost can damage maize at all growth stages.

The crop requires annual rainfall of 500-750 mm for adequate soil moisture (du Plessis, 2003). Moisture stress limits maize yield where efficient maize cultivation practices are applied (DAFF, 2008). Cultivar selection is of utmost importance for maize production because it affects seasonal planning for the producers (ARC-GCI, 2015). In South Africa, there are many registered varieties for various producing areas (DAFF, 2008). It is important to choose cultivars which are best suited for each area and also to evaluate some of their characteristics (yield potential, length of growing season, lodging, tillering, disease resistance, prolificacy and percentage grain moisture) based on grower's preference (ARC-GCI, 2015). Maize is a heavy feeder and it requires large adequate amount of macronutrients (NPK) to guarantee high yield production (Olusegun, 2015). Therefore, optimum fertilisation is important and should be bet achieved through soil testing and target yield.

2.4 Limitations to maize production in South Africa

Bio-physical constraints for maize production can be grouped into biotic (insect pests, diseases and weeds) and abiotic (drought stress and low soil fertility) stresses.

2.4.1 Biotic stresses

a) Insect pests

According to M'mboyi *et al*. (2010), insect pests in sub-Saharan Africa cause significant yield losses and grain quality degradation. Major insects that attack maize are stem and ear borers, chilo borer, pink stem borer, Africa bollworm, false bollworm, common cutworm, armyworm, black beetle and false wire worm (ARC-GCI, 2015). Tropical areas are more infested with insect pests than temperate environments because of more favourable climatic conditions for accelerated insect development with multiple and overlapping generations leading to high infestation levels and yield losses (M'mboyi *et al*., 2010).

b) Diseases

Maize is susceptible to various fungal, bacterial and viral diseases (ARC-GCI, 2015). These diseases spread very quickly and can cause terrible damage in all different parts of the plant including the roots, stems, leaves and the cobs when sound control measures are not followed (du Plessis, 2003). Major maize diseases in Africa include downy mildew, common leaf rust, leaf blight ear rots, gray leaf spot, head smut, and maize streak virus (M'mboyi *et al*., 2010). Bacterial whorl, bacterial leaf streak and stalk rot are common throughout the maize production areas in South Africa and periodically cause severe localised outbreaks (ARC-GCI, 2015).

c) Weeds

Weeds compete vigorously with maize crop for nutrients, soil moisture and light during the first 6-8 weeks after planting (du Plessis, 2003). Efficient weed control is important for successful production of maize. In South Africa, controlling weeds such as *Cyperus esculentus, C. rotundus, Digitaria nuda, Eleusine coracona, Sorghum halepense, Urochloa panacoides* and *Commelina benghalensis* it may be difficult due to their long season of germination (ARC-GCI, 2015). Weed infestations results in annual yield losses. Weeds are not only the problem during maize growth cycle, but also during harvesting because they may slow the harvesting process, contaminate grain with seeds and odour, therefore reduce grain quality and incur additional costs for removal of foreign material (du Plessis, 2003).

2.4.2 Abiotic stresses

a) Drought

According to AGRISA (2016), 83% of South African maize production is under dryland, which therefore makes the country to be most vulnerable in times of drought. Inadequate rainfall is a major constraint to agricultural growth. Drought is ranked among the most important constraints to maize productivity in Africa, contributing to production losses (M'mboyi *et al*., 2010). Maize production depends on climatic conditions, with temperature and precipitation being the main drivers (Van Rensberg, 2015). Farmers in North West, Free State and Limpopo Provinces are believed to have experienced hot dry weather because of the cyclones in the Indian Ocean which absorb the moisture from the subcontinent's interior, and this has contributed a lot in maize yield losses during 2015/16 growing season (AGRISA, 2016).

Under drought stress, stomata in the leaves of maize plants close to reduce transpiration (Van Rensberg, 2015). However, this can have a negative effect on flowering, pollination and grain fill. A moisture stress for only four days is enough to reduce maize yield by up to 50% (du Plessis, 2003). Air temperature higher than 36°C reduces the viability of pollen, damages maize leaves, reducing the area of chlorophyll production needed for growth and grain fill (AGRISA, 2016). Furthermore, drought also favours insect pests such as spider mites and stalk borers, which can act as vectors of pathogens (M'mboyi *et al*., 2010).

b) Low and declining soil fertility

Successful maize production is affected by low fertility status of most tropical soils (Olusegun, 2015). In sub-Saharan Africa, there is a rapid decline in soil fertility due to intensified land use and the rapid decline in fallow periods, coupled with the extension of agriculture into marginal lands (M'mboyi *et al*., 2010). Much of the arable land in Limpopo province is inherently infertile and subjected to low erratic rainfall (Minde *et al*., 2008). There are diverse soils which vary in productivity. Communal fields are mostly sandy soils coupled with inadequate nutrients, particularly nitrogen and phosphorus (Odhiambo and Nemadodzi, 2007). Most of the smallholder farmers are constrained to produce satisfactory maize yields because of the lack of capital to purchase inorganic fertilisers, or even the lack of knowledge in the application methods and rates (Minde *et al*., 2008).

c) Soil acidity

Soil acidity relates to soil nutrient availability which therefore influences biological nitrogen fixation of leguminous crops. According to Dudenhoeffer (2012) there are reactions within the soil that happens with P as the result of the soil pH, and this usually result in low P availability. Optimum soil pH range for P availability in the soil is 6-7 (Beegle and Durst, 2002). Under acidic soil conditions, P forms insoluble complexes with cations such aluminium and iron, but with calcium and magnesium under alkalinity soil conditions (Pierre and Norman, 1953). These reactions result in the formation of insoluble phosphate compounds which then inhibits P availability.

2.5 Cowpea production

Cowpea (*Vigna unguiculata*) commonly known as tinyawa or dinawa in South Africa, is an indigenous tropical leguminous crop that produce highly nutritious, valuable pods and grain (Asiwe, 2009a; DAFF, 2011). According to Sheahan (2012), Africa is the leading continent in cowpea production, it constitutes almost 68% of the world total production. In South Africa, it is produced in North West, Limpopo, Mpumalanga and KwaZulu-Natal Provinces (DAFF, 2011), however, it is still underutilised by smallholder and commercial farmers (Whitbread *et al*., 2009). According to DAFF (2011), underutilisation of the crop resulted in no records with regard to the size of the area under production and the quantities produced. Cowpea research and production in South Africa has been neglected because of inadequate funding capacity for researchers to improve the crop (Asiwe, 2009b).

2.6 Importance of cowpea

Cowpea is an important crop that can benefit farmers in numerous ways. Cowpea is a leguminous crop, it develops nodules on the roots through the help of *Rhizobia* bacteria (Sheahan, 2012). It biologically fixes atmospheric nitrogen when provided with favourable soil environment in terms of physical, chemical and biological properties (Belane *et al*., 2011). In areas with poor soil fertility such as Limpopo Province, cowpea has the potential to increase fertility of the soil because the fixed N will be available for the succeeding crop from the decay of its leaf litter, roots and nodules. The fixed N reduces nitrogen fertiliser demand and cost for producing cowpea (Asiwe, 2009a).It is also used as a break crop in rotation with cereals, excellent cover crop and soil improver because it has the potential to increase soil productivity and improve soil health (Whitbread *et al*., 2009).

Cowpea is largely consumed in sub-Saharan Africa particularly in West Africa (Dugje *et al*., 2009). It is important for both human and livestock feeding. It is used as a vegetable crop (leaves and pods), grain crop (seeds) and source of fodder (Dugje *et al*., 2009). Cowpea seeds are an inexpensive source of proteins, vitamins and minerals essential for healthy living (Sheahan, 2012). In South Africa, cowpea leaves are harvested fresh, cooked and preserved for future use (DAFF, 2011). Furthermore, the crop is important in rural communities of Limpopo Province because it serves as a source of income generation to support household livelihoods and also the cowpea meal is served with maize meal as a vegetable (Asiwe, 2009b).

2.7 Production requirements of cowpea

Cowpea is tolerant to drought and poor soil conditions, well adapted to both rainfed and irrigated farming systems in Limpopo Province (Whitbread *et al*., 2009). In Limpopo Province, it can be planted from December to late January. It is adapted to wide variety of soils though it prefers well drained sandy loams (Sheahan, 2012), grows well in summer rainfall areas (400-700 mm per annum), require warm temperatures (25-30˚C) for good crop growth and development (Asiwe, 2009). Fertiliser programme of cowpea largely depends on the expected yield and soil fertility results. Phosphorus is an essential nutrient element for legumes, so adequate amount have to be applied where soil P is low (DAFF, 2011). As a legume, it fixes nitrogen, therefore, there is no need for N fertiliser or is needed in small quantities.The application of *Bradyrhizobium* strain to cowpea seeds at planting is required to improve nodulation and N fixation, although cowpea is likely to nodulate with native soil rhizobia (Whitbread *et al*., 2009).

2.8 Limitations to cowpea production in South Africa

The study of Asiwe (2009b), showed many constraints to cowpea production in South Africa including; unimproved varieties, lack of knowledge of good agronomic practices, non-availability of good seeds for planting, lack of market for the produce, discouraging poor marginal returns to farmers, lack of storage facilities, insect pests and diseases, and also funding.

2.8.1 Biotic stresses

a) Insect pests

Insect pests pose a major limitation to cowpea production because each growth stage attract a number of insect pests (Dugje *et al*., 2009). DAFF (2011), reported a number of insect pests that attack cowpea during the growing season including pod sucking bugs (*Riptortus spp., Nezara viridula* and *Acantomia spp.*), aphis (*Aphis fabae, Aphis craccivora*), blister beetle (*Mylabris spp.*) and pod borer (*Maruca vitrata*). Major important cowpea insect pests reported in Limpopo and KwaZulu-Natal Provinces are aphids, thrips, pod sucking bugs and cowpea weevil (Asiwe, 2009b). Lack of control to these insect pests can cause a serious decline in yield production.

b) Diseases

Various fungal, bacterial and viral diseases affect cowpea at different stages of crop growth (Dugje *et al*., 2009). In Limpopo and KwaZulu-Natal provinces, viral diseases ranked first as common cowpea diseases (Asiwe, 2009b). The major common cowpea diseases in South Africa are anthracnose, *Sclerotium* stem, root and crown rot, damping off, *Cercospora* leaf spot, *Septoria* leaf spot, *Fusarium wilt*, aphid-borne mosaic virus (CabMV) and scab (DAFF, 2011). Stem rot frequently occurs in the wetter coastal and subcoastal areas, and on heavier soils which may become waterlogged (Sheahan, 2012). Bacterial blight (*Xanthomonas vignicola*) causes severe damage to cowpeas, therefore reduce yield to a great extent. Cowpea is susceptible to nematodes and should therefore not be planted consecutively on the same land (Dugje *et al*., 2009).

c) Weeds

According to Dugje *et al*. (2009), weeds compete seriously with cowpea for resources, when they are not well managed. They suppress cowpea growth and development or become a habitat for pests, therefore reduce the yield and the quality of the grain. Both annual and broadleaf weeds affect cowpea production in South Africa (DAFF, 2011). The survey done in Limpopo and KwaZulu-Natal provinces showed grasses as the common weeds than broadleaves, however, minor Striga and Alectra species were also mentioned as important parasitic weeds affecting their production (Asiwe, 2009b).

2.8.2 Abiotic stresses

a) Drought

Drought is one of the major abiotic stresses limiting cowpea production in South Africa (Asiwe, 2009b). Prolonged drought periods results in cowpea moisture stress, affects flowering, pod and seed development (DAFF, 2011). Cowpea is a drought tolerant crop and usually adapted to dryland cultivation (Whitbread *et al*., 2009), however prolonged periods of moisture stress more especially during critical growth periods limits cowpea productivity (Uarrota, 2010).

b) Low soil fertility

Southern Africa is not considered to be a fertile land due to its topography and low erratic and poorly distributed rainfall (Hall, 1940). In South Africa particularly Vhembe district of Limpopo province, inadequate soil fertility is one of the most important limiting constraints to crop production (Odhiambo and Nemadodzi, 2007). Most of the soils in Limpopo province are sandy with inadequate nutrients such as N and P (Minde *et al*., 2008; Ramaru *et al*., 2000). Phosphorus is an essential nutrient required by legumes for root and plant growth stimulation, initiate nodule formation (Mullins, 2009), as well as to influence the efficiency of the rhizobium-legume symbiosis (Whitbread *et al*., 2009). Low soil fertility greatly limit the adequate production of cowpeas in South Africa.

c) Storage facilities

Cool and protected places for storage is a necessity to prevent seed damage by the major cowpea storage pest such as weevil (*Callosobruchus maculatus*). Most farmers are constrained by the access to good storage facilities and chemicals to fumigate their stored seed (Dugje *et al*., 2009). Insecticides are somehow expensive and prohibitively for most smallholder farmers, furthermore, they often lack the necessary equipment and training for their safe use (Uarrota, 2010). Severe infestation by cowpea weevil can lead to total grain loss in storage (DAFF, 2011). Generally, the storage life of cowpea grain depends on its moisture content before storage; the lower the moisture content, the better the quality of seeds in storage (Uarrota, 2010).

2.9 Cropping systems

Cropping system refers to the crop sequences or patterns and the management techniques used on a particular field over a period of years (Seran and Brintha, 2010). Currently, human population is more than 7 billion worldwide (Feed the Future, 2014). There is a need to increase crop productivity and labour utilization per unit of available arable land through intensifying the land use in order to feed the growing population. This can be met by adoption of cropping systems that will grow more than one crops simultaneously in the same piece of land (Seran and Brintha, 2010). Factors such as water balance, sunlight, temperature and soil conditions determine the physical ability of crops to grow and for a cropping system to exist, therefore, cropping system varies from place to place worldwide.

2.9.1 Type of cropping systems

Multiple cropping has been practiced in many areas throughout the world with an idea of maximising land productivity of a specific area in one growing season (Gliessman, 1980). The dimensions of time and space are important in multiple cropping situation (Gliessman, 2000). Seran and Brintha (2010) defined intercropping as a type of multiple cropping practice whereby two or more crops are grown in the same space at the same time. Various intercropping systems (mixed intercropping, row intercropping, strip intercropping and relay intercropping) are used in agriculture depending on the farmer’s goals (Francis, 1986). In a mixed intercropping system, a variety of crops are planted without distinct row arrangements (Asiwe, 2009b).

Row intercropping is the practice of growing more than one crop simultaneously with one or more crops planted in rows (Altieri, 1999). In strip intercropping, multiple crops are grown in narrow adjacent strips, that allow interaction between the different species (ISU, 1999), but also allows management of individual crops with modern equipment (Gliessman, 2000). Relay cropping is a type of intercropping that grows two or more crops simultaneously during part of each crop’s life cycle (Amador and Gliessman, 1990), but a second crop is planted after the first crop has reached its reproductive stage of growth and before it is ready for harvest (Francis, 1986).

2.9.2 Benefits of intercropping

a) Better utilisation of natural resources

Generally, component crops in intercrops use natural resources differently than when grown separately, therefore, they end up using these natural resources much better (Seran and Brintha, 2010). However, it should be noted that inherent efficiency of individual crops that make up intercropping system and complimentary effects between the crops determines the efficient use of these resources. Different crop species in intercropping system tends to use more soil moisture and nutrients than in monocropping situation (Francis, 1986), this is due to the fact that roots of one species in monocrop compete with each other since they are all similar in their orientation (Seran and Brintha, 2010).

When aspects of intercropping system (planting time, crop maturity, crop compatibility, crop and density) are well considered, there are numerous benefits coupled with more efficiency in using natural resources (Seran and Brintha, 2010). Generally, crop species and varieties differ on the amount of resources they require and how they will obtain them. Differences in root and shoot geometry may result in more exploitation of natural resources than in monocropping system (Francis, 1986). Higher leaf area index and high leaf area of crops in intercropping system conserve soil moisture. Furthermore, various root systems in the soil reduces water loss, thereby increasing water uptake and transpiration, which therefore is important to create a cooler microclimate than the surroundings (Seran and Brintha, 2010).

b) Improves reduction of insect pests and diseases

Component crops in intercropping system suffer less insect and diseases loss than in monocropping due to high crop diversity (Amador and Gliessman, 1990). Pest populations are lower and inflict less damage in diversified cropping system because the environment tends to provide habitat and food sources for predators and parasites for the pest insects (Andrews, 1967). The less pest damage to crop species is also due to the fact that crops are attacked by pests differently, so insect pests and diseases surviving in one crop are likely not to survive in the next crop. According to Seran and Brintha (2010), one component crop in intercropping system may act as a barrier against the spread of pests. In case of weeds, intercropping provides a more competitive effect against weeds in time and space, however, it is important to consider crop’s growth habit because it determines crop to weed competition (Seran and Brintha, 2010). High diversity of crop species improves leaf cover or canopy and plays a major role to suppress weed populations once the crops are well established (Beets, 1990).

c) Reduction of erosion and runoff

Soils with less cover are prone to erosion and runoff because the raindrops directly hit the bare soil, therefore seal surface pores, reduce water infiltration and increase surface erosion (Gliessman, 2000). With improved soil cover in intercropping system, rain drops will be prevented from hitting the bare soil, therefore reduce soil erosion and runoff. In western Sudan where sesame is grown with sorghum or millet under sandy soil environment, the cereals are large enough to protect sesame seedlings from abrasion by wind induced sand erosion (Andrews, 1967).

d) Increases economic returns

Intercropping spread labour requirements evenly because farm activities such as planting, weeding and harvesting schedules are different for each crop grown (Francis, 1986). According to Andrews (1967), one of the important advantages of intercropping is that it reduces labour bottlenecks and gives higher return on the amount of labour invested. Generally, growing two or more crops provides higher cash return than monocropping due to greater land usage (Seran and Brintha, 2010).

e) Reduces risk of total crop failure

According to Andrews (1967), intercropping system is adopted by the farmers because in reduces risks, thereby increasing production stability. Millet differ with sorghum in susceptibility to drought, diseases, pests and weeds (Francis, 1986). When these crops are included in intercropping system, it increases the chances of harvest regardless of pests and unfavourable weather conditions. When one crop fails, the other crop will compensate the loss by using some of the available resources such as soil moisture, nutrients and light. Furthermore, some component crops in intercropping systems are not planted at the same time, so if the first crop fails, the farmer can still decide to increase the planting density of the subsequent crops in order to compensate the loss of the first crop, thus, intercropping reduces the risk of total crop failure.

f) Improve yield

Crop yield is a primary consideration in assessing the potential of intercropping system (Dariush *et al*., 2006). Diversified cropping system have a yield advantage because of better and more efficiency of using natural resources differently (Gliessman, 2000). Inclusion of legumes in cropping systems help to restore soil nitrogen thereby improving soil fertility and total yield. Diversity of crop species coupled with different lifecycles and critical growth stages reduces competition among crops and therefore increase yield (Gliessman, 2000). In West African Sahel, pearl millet is commonly intercropped with traditional cowpea variety, whereby, the cereal is planted with early rains and cowpea follows after establishment of the pearl millet, so cowpea tends to put little competition to the millet crop (Andrews, 1967).

2.10 Cowpea-maize intercropping systems in South Africa

Cereal-legume intercropping is a common practice in the tropics (Seran and Brintha, 2010). It is important to include cowpea as a companion crop in cereal-legume intercropping to reduce risk of total crop failure and distribution of farm labour (Asiwe, 2009b). Cowpea-maize intercropping has the potential to increase the amount of N and reduce the amount of nutrients taken from the soil as compared to maize monocrop (Dahmardeh *et al*., 2010; Seran and Brintha, 2010). Legumes biologically fix atmospheric N, which is made available by the decay of the nodules and can be used by other crops growing in succession (Belane *et al*., 2011). In cowpea-maize intercropping, the legume will not compete with the maize for N resources. Cereal-legume based intercropping improves availability of N to the subsequent crops (Thobatsi, 2009), reduces the requirement of N-fertilisation and therefore save costs to be incurred for purchasing N based fertilisers (Dugje *et al*., 2009).

Cereal-legume cropping system tends to use soil moisture more efficiently (Thobatsi, 2009). Water use efficiency under cowpea-maize intercropping was higher than cowpea or maize monocropping when soil moisture was not limiting, but under limiting soil moisture conditions, intercropping system had higher water use efficiency coupled with retarded growth and reduced yield (Hulugalle and Lal, 1986). Intercropping maize with cowpea provides more competitive effect against weeds in both the time and space aspects (Seran and Brintha, 2010). According to ARC-GCI (2015), maize is susceptible to many insect pests and diseases such as maize stem borer (*Busseola fusca*), chilo borer (*Chilo partellus*), pink stem borer (*Sesamia calamistis*), bacterial leaf streak, bacterial whorl and stalk rot of maize. Generally, intercropping act as a barrier against the spread of pests because of high crop diversity. Maize-cowpea strip intercropping reduced the effect of stem borer (Henrick and Peeter, 1997).

2.11 Effect of phosphorus fertilisation on crops

Phosphorus is one of the major important nutrient element for plants, no other element can replace its important role in physiological and biochemical processes (Syers *et al*., 2008). It is absorbed by plants roots as phosphate ions (H_2PO^{4-} or HPO_4^{2-}) to produce high crop yields (Kuun *et al*., 2006). According to Mullins (2009), physiological and biochemical processes that P enhances include photosynthesis, respiration, energy transformations, nucleic acid biosynthesis, cell division and enlargement, and it also improves early root formation and growth, it is used as integral component of several plant structures such as phospholipids, seed formation and crop quality (Balemi and Negisho, 2012).

According to Pierre and Norman (1953), the symptoms that are associated with P deficiency are not very specific as compared to other mineral nutrients. However, the common deficiency symptoms of P in crops are reduced shoots and roots growth, spindly upright growth, premature defoliation particularly with older leaves, reduced blossoming resulting in poor grain yield, purplish bronze colour leaves and leaf margins often show brown scorching.

Leguminous crops such as cowpea require an adequate supply of P in the soil to improve nodulation and crop yield (Singh *et al*., 2011; Smith, 2006). The study of Singh *et al*. (2011) revealed that P application at the rate of 40 and 60 kg/ha increased the number of pods per plant, grain yield and 100 seed weight than at the plots with 0 and 20 kg P/ha, this was attributed to the fact that P fertiliser on cowpea improves photosynthesis, nodulation, N-fixation intensity, seed formation and seed quality. Ayodele and Oso (2014) also reported similar results to Singh *et al*. (2011), in terms of assessed agronomic parameters; P application on cowpea enhanced number of nodules, number of leaves, plant height, number of branches, leaf area, number of flowers, pod length, number of seeds per pod and grain yield as compared to the plots with no P application.

Olusegun (2015) regarded maize as a heavy feeder crop that requires adequate P supply. Phosphorus enhances the growth and development of the crop through it's crucial role as an important component of nucleic acid, phosphorylated sugar, lipids and proteins, enhance grain production, forms a high energy phosphate bonds with adenine, guanine and uridine which are energy carriers in various biological reactions within the crop, enhance seed and fruit formation and also hasten crop maturation. Phosphorus application at the rate of 45 kg/ha positively influenced the cob length and diameter over the control, but it was not the same with grain yield, which was only influenced from 0-30 kg/ha with an increasing trend, however, beyond that it reduced the grain yield (Olusegun, 2015). Jin *et al*. (2015) found that increasing P application enhanced synthesis of the osmotically active carbohydrates in the leaf cells which have a critical role responsible in the maintenance of leaf water potential under drought conditions.

According to Jones *et al*. (2003), when P is increased in the soil it also increases water use by the crop, efficiency for drought tolerance and shoot dry matter under water stress conditions. The study of Ragothama (2005) revealed that P may increase drought tolerance of the crop due to the fact that P-fertilisation may partially overcome the direct and indirect effects of water stress on P uptake and diffusion to roots, increases root growth and the potential of root hydraulic conductance and therefore lead to greater volume of soil explored, hence, greater potential reservoir of soil moisture. Normally, the root architecture changes, resulting in root elongation and high root to shoot biomass ratio (Gyaneshwar *et al*., 2002), root branching, root angle and formation of root hairs increases in order to adapt to moisture stress conditions (Eghball and Maranville, 1993). One of the functions of P in the crop is to store energy and protein formation, which in turn helps the crop to withstand moisture stress conditions (Kuun *et al*., 2006).

2.12 Crop response to phosphorus application

Phosphorus is an important macronutrient element for crop production (Beegle and Durst, 2002; Parker, 2004). Phosphate ion is immobile in soil as compared to the nitrate which readily moves in soil solution towards the roots section through mass flow and diffusion (Balemi and Negisho, 2012). According to Beegle and Durst (2002), only limited quantity of phosphate ions is transported towards the roots through mass flow, whereas the large quantity reach the root surface through diffusion. However, this tends to disadvantage the crop since the diffusion degree coefficient for phosphate ion is very low as compared to other nutrient elements in the soil solution (Lambers *et al*., 2006).

Low availability of P in the soil is attributed to the reactions happening with P within the soil as the result of the soil pH (Dudenhoeffer, 2012). According to Beegle and Durst (2002), optimum soil pH range for P availability in the soil is 6-7. Under acidic soil conditions, P forms insoluble complexes with cations such aluminium and iron, but with calcium and magnesium under alkalinity soil conditions (Pierre and Norman, 1953). These reactions result in the formation of insoluble phosphate compounds which then inhibits P availability. Most of the P applied in the form of inorganic fertilisers in the soil results in adsorption by soil particles and therefore inhibit P availability for crops with limited specific adaptations (Balemi and Negisho, 2012).

Crops absorb P from the soil solution (Parker, 2004). Replenishment of soil solution with phosphate from other forms that are in the soil is important in order to maintain the available P (Pierre and Norman, 1953). Factors such as soil pH, soil P level, fixation by soil and placement of added P determines the rate at which the soil solution is replenished with phosphate (Beegle and Durst, 2002). Soil chemical and physical properties are known to influence P availability to crops (Fernandez and Hoeft, 2012).

According to Mullins (2009), when the phosphate fertiliser is applied in the soil, only a small quantity of the P is immediately absorbed by the plant roots and the rest is adsorbed by the soil particles due to very complex chemistry within soil solution. Reactions within the soil solution lead to P absorption only after the initial adsorption (Dudenhoeffer, 2012), this will tend to result in strong bonds and makes P to be less readily available. According to Fernandez and Hoeft (2012), aluminium, calcium, iron, soil acidity, organic matter and mineral particle size greatly influence the speed of P absorption and adsorption within the soil solution. In South Africa, many soils are inherently low in P, so the target yield, extractable P and clay plus silt content plays a major role in P application recommendations (SAMT, 2016).

2.13 Measurement of productivity of intercropping systems

Intercropping system enables interaction between component crop species and this improve diversity of an agroecosystem (Dariush *et al*., 2006). According to Thobatsi (2009), increased and diversity of productivity per unit area is amongst major benefits of intercropping system. Seran and Brintha (2010), referred yield as the primary consideration when assessing the potential of intercropping system. The common index adopted in intercropping systems to measure land productivity is land equivalent ratio (LER). LER is used as an important tool to study, evaluate and assess the efficiency of an intercropping system. By definition, LER is the relative land required under monocultural system to match the yields obtained from intercropping system or the magnitude of monocropping needed to produce the same yield on the unit area of land in intercropping system (Federer and Schwager, 1982).

Advantageous intercropping system is attained with the LER of greater than one, whereas disadvantageous intercropping system is attained with LER of less than one (Dariush *et al*., 2006). This means that LER value of greater than one indicates greater efficiency of land utilisation in intercropping system. When computing LER value, intercropping yields are divided by the monocropping yields for each crop in the intercropping system and then the two figures are added together (Federer and Schwager, 1982). The formula used to estimate LER is given by $LER=\sum(Ypi/Ymi)$, whereby Yp represent the yield of individual crops in the intercropping system, and Ym is the yield of the crop in monocultural system. In the case of maize-cowpea strip intercropping it will be given as LER= (intercrop maize/sole maize) + (intercrop cowpea/sole cowpea).

Masvaya *et al*. (2017) reported that the intercropping yield was higher than cowpea or maize sole in semi-arid southern Africa. So most intercrop treatments both on-station and on-farm had LER>1 pointing to the greater land use efficiency of the maize-cowpea intercrop system compared to sole cropping. Furthermore, LER of on-station relay intercrop ranged from 1.8–2.5 as compared with the same planting date intercrop which ranged from 0.5–2.4 in all three seasons.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Study site description

The study was conducted at the School of Agricultural and Environmental Sciences experimental farm (Syferkuil) of University of Limpopo during 2014/15 and 2015/16 growing seasons. The farm is located in Mankweng, Capricorn District, Limpopo Province (23°53′ 9.6″ S and 29°43′ 4.8″ E). The study area is characterised by low erratic summer rainfall ranging between 400-650 mm, average minimum and maximum temperatures of 18°C and 31°C and sandy loam soils.

3.2 Research design, treatments and procedures

3.2.1 The first season experiment (2014/15)

The trial was planted on the 11/02/2015 using a split-split plot design. Two maize varieties (WE3127 and ZM1423) and four cowpea varieties (PAN311, IT86D-1010, TVu 13464, and IT82D-889) were used in a strip intercropping. Four levels of P-fertiliser (0, 15, 30, 45 kg P/ha) were applied at planting in the field. The main-plot factor was a fertiliser (four P levels), subplot factors were four cowpea varieties and two maize varieties, whereas the sub-subplot factor was two cropping system (monocropping and strip intercropping). Each plot was 2 m x 3 m with an alley way of 1 m. Maize lines were spaced at 90 cm x 30 cm, whereas cowpea at 75 cm x 10 cm where both crops had 4 rows. The trial was replicated three times.

Initial soil samples were collected at a depth of 0-15 cm and analysed using different recommended laboratory methods. Soil pH (H_2O) was determined using 1:2.5 soil water ratio suspensions on mass based methods. Plant available P was determined using the Bray-1 procedure. Four cowpea varieties were planted in strip intercropping with two maize varieties. Four different levels of P were applied at planting (P_0= 0 kg P/ha, P_1= 15 kg P/ha, P_2= 30 kg P/ha and P_3= 45 kg P/ha). P was band-placed at 50 mm below the seed.

Herbicide recommendations by Dugje *et al*. (2008) of Round-up with active ingredient of Glyphosate, N-(phosphonomethyl) glycine, in the form of its isopropylamine salt (240 ml/15 L water knapsack = 3 L/ha) and Dual gold with active ingredient of S-metolachlor (chloro-acetanilide) (30 ml/15 L water knapsack = 0.5 L/ha) were used to control weeds before planting. Manual weeding was done on growing weeds in the field as a supplementary procedure. Several sprayings of insecticide in cowpea plants is recommended for good yield depending on the period of maturity of the cowpea variety used (Dugje *et al*., 2008). Different insecticides were used as recommended by Dugje *et al*. (2008); Karate 2.5 EC with active ingredient of lambda-cyhalothrin (pyrethroid) (60 ml/15 L water knapsack = 1 L/ha) and Aphox with active ingredient of pirimicarb (carbamate) (4 g/15 L water knapsack = 500 g/ha).

3.2.2 The second season experiment (2015/16)

The trial was planted on 19/02/2016 using a split-split plot design. Selection was made among the best performing varieties in the first growing season. Two cowpea varieties (PAN311 and TVu 13464) were selected and strip intercropped with maize variety (PAN 6479). Four levels of P-fertiliser (0, 15, 30, 45 kg P/ha) were applied at planting in the field. The main-plot factor was P fertiliser (four P levels), subplot factor were two cowpea varieties and one maize variety, whereas the sub-subplot factor was two cropping systems (monocropping and strip intercropping). Each plot was 2 m x 3 m with an alley way of 1 m. Maize lines were spaced at 90 cm x 30 cm, whereas cowpea at 75 cm x 10 cm. The trial was replicated three times.

Initial soil samples were collected at a depth of 0-15 cm and analysed using different recommended laboratory methods. Soil pH (H_2O) was determined using 1:2.5 soil water ratio suspensions on mass based methods. Plant available P was determined using the Bray-1 procedure. Four cowpea varieties were planted in strip intercropping with two maize varieties. Four different levels of P were applied at planting (P_0= 0 kg P/ha, P_1= 15 kg P/ha, P_2= 30 kg P/ha and P_3= 45 kg P/ha). P was band-placed at 50 mm below the seed.

Herbicide recommendations by Dugje *et al*. (2008) of Round-up with active ingredient of Glyphosate, N-(phosphonomethyl) glycine,in the form of its isopropylamine salt (240 ml/15 L water knapsack = 3 L/ha) and Dual gold with active ingredient of S-metolachlor (chloro-acetanilide) (30 ml/15 L water knapsack = 0.5 L/ha) were used to control weeds before planting. Manual weeding was done on growing weeds in the field as a supplementary procedure. Several sprayings of insecticide in cowpea plants is recommended for good yield depending on the period of maturity of the cowpea variety used (Dugje *et al*., 2008). Different insecticides were used as recommended by Dugje *et al*. (2008); Karate 2.5 EC with active ingredient of lambda-cyhalothrin (pyrethroid) (60 ml/15 L water knapsack = 1 L/ha) and Aphox with active ingredient of pirimicarb (carbamate) (4 g/15 L water knapsack = 500 g/ha).

Table 1: Chemical properties of the fields during 2015 and 2016 growing seasons

Soil properties	Season	
	(2014/2015)	(2015/2016)
pH (H_2O)	7.80	8.04
pH (KCl)	6.71	6.53
P (Bray1) (mg/kg)	25.70	23.28
pH (H_2O)	7.80	8.04

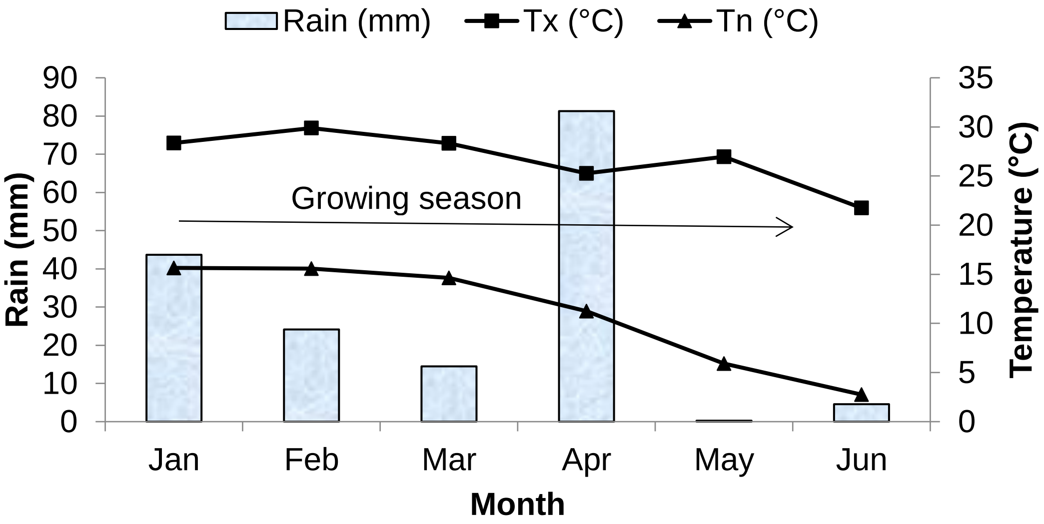

Figure 1: The average monthly rainfall, minimum and maximum temperature during 2014/15 growing season at Syferkuil

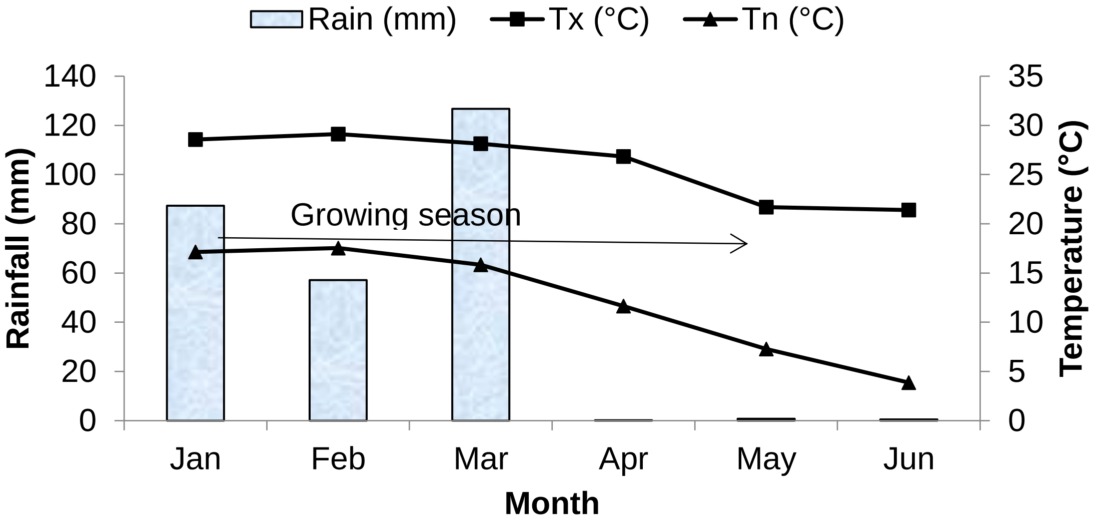

Figure 2: The average monthly rainfall, minimum and maximum temperature during 2015/16 growing season at Syferkuil

3.3 Data collection

3.3.1 Cowpea data

a) Number of days to first and 50% flowering

Date of first flowering and 50% flowering in cowpea were recorded by counting the number of days from date of 50% emergence to the date of first flowering and when 50% of the population has flowered.

b) Number of days to 50 and 90% maturity

Date of maturity was recorded by counting the number of days from date of 50% emergence to date at which 50% and 90% maturity was attained.

c) Canopy height

At maturity, three plants were randomly selected per plot, then the plant height was measured using a meter ruler.

d) Peduncle length

Three representative plants were randomly selected from each plot to measure peduncle length. It was measured from three peduncles to determine the average length using a meter ruler.

e) Pod length

Three plants were randomly selected from each plot to measure pod length. The pod length was measured from three pods sampled from three plants to determine the average length using a 30 cm ruler.

f) Biomass

For biomass determination, the above ground shoots which were randomly selected at physiological maturity from three plants were weighed using a weighing scale.

g) Root mass

At podding stage, three plants were dug and cut at the soil surface level. The roots from the three plants were separately shaken off the clogging soil particles and weighed using a weighing scale and the average weight was obtained to represent the randomly selected roots.

h) Root length

The roots that were used to determine the root weight was then used to measure the length of the roots using a 30 cm ruler. The root length was measured from the cutting point below the soil surface level to the end tip of the root.

i) Number of pods

Number of pods per plant were counted from three randomly selected plants.

j) Net pod weight

Two rows from each plot were harvested, the pods were weighed using a weighing scale in order to get the net unshelled cowpea weight.

k) Seed weight

After threshing the cowpea, the seeds were weighed using a weighing scale in order to get net shelled cowpea weight.

l) 100 seed weight

Hundred normal seeds were randomly picked from the net plot and used to determine the hundred seed weight using a weighing scale. Three lots per plot ere used.

3.3.2 Maize data

a) Number of days to first and 50% tasseling

It was recorded by counting the number of days from emergence to first date of tasseling and 50% of tasseling per each plot.

b) Number of days to first and 50% silking

Silking stage was monitored by counting the number of days from emergence to first date of silking and 50% silking.

c) Root mass

At tasseling stage, three plants were dug using a fork and cut at the soil surface level. The roots from the three plants were separately shaken off the clogging soil particles and weighed using a weighing scale and the average weight was obtained to represent the randomly selected roots.

d) Plant height

At maturity, three plants were randomly selected per plot, then the plant height was measured using a meter ruler. It was measure from a soil surface level to the end tip of the tassel.

e) Biomass

For biomass determination, the above ground shoots which were randomly selected from three plants were weighed using a weighing scale.

f) Number of cobs per plant

The number of ears per plant from each plot were counted from three randomly selected plants.

g) Net cob weight

Two rows from each plot were harvested, the cobs were weighed using a weighing scale in order to get the net unshelled maize cob weight.

h) Grain weight

After shelling the maize, the grain was weighed using a weighing scale in order to obtain net shelled maize weight.

3.4 Data analysis

The generated data were subjected to analysis of variance (ANOVA) to determine variation among treatment means using SAS 9.3 software. Least Significance Difference (LSD) was used to separate the means that showed significant differences at an alpha level of 0.05. Correlation among variables was done to determine relationships between variables, while regression analysis was used to determine the optimum level of P.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 First season experiment (2014/15)

4.1.1 Cowpea performance

4.1.1.1 Number of days to 50% flowering

Phosphorus application significantly ($P<0.05$) influenced the number of days to 50% flowering of cowpea varieties (Table 2). Increasing P applications (30-45 kg/ha) reduced the number of days to 50% flowering (Figure 3). PAN311 flowered earliest (49 days), whereas IT82D-889 took an average of 53 days to flower across P levels. This could be attributed to the importance of phosphorus fertilisation in crops for flower setting (Mullins, 2009). Mawo *et al*. (2016) reported that varieties in pots with high P application flowered earlier than pots with no application of P. This was due due to the fact that application of P fertiliser shortens the time from planting of cowpea to harvesting and therefore hastens maturity.

The interactions of variety*P and variety*cropping system were significant, whereas cropping system*P and variety*cropping system*P were not significant. Figure 4 shows that the number of days to 50% flowering of IT82D-1010 and TVu13464 did not differ under intercropping or monocropping system, but PAN311 under monocropping system flowered earlier than under intercropping system. The results conform to the study of Ssebuliba *et al*. (2014) who found that there was no significance difference between sole and intercropped cowpea in terms of required days to reach flowering.

Table 2: Analysis of variance of number of days to 50% flowering for cowpea in 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	261.4761905	130.7380952	149.41	<.0001
P	3	13.1887302	4.3962434	5.02	0.0076
P*rep	6	65.4285714	10.9047619	12.46	<.0001
Variety	3	391.8777778	97.9694444	111.97	<.0001
Variety*P	9	187.7888889	15.6490741	17.88	<.0001
Variety*P*rep	18	507.1666667	15.8489583	18.11	<.0001
Cropping system	1	8.6805556	8.6805556	9.92	0.0043
Cropping system*P	3	4.1527778	1.3842593	1.58	0.2197
Variety*cropping system	3	7.1111111	3.5555556	4.06	0.0302
Variety*cropping system*P	9	10.5555556	1.7592593	2.01	0.1037

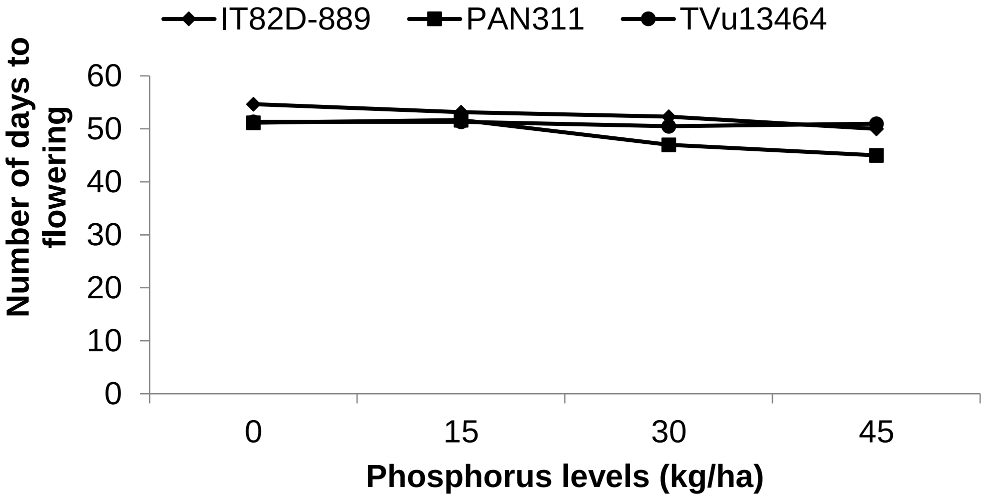

Figure 3: Interaction plot of P levels and cowpea varieties on number of days to 50% flowering for 2014/15 trial

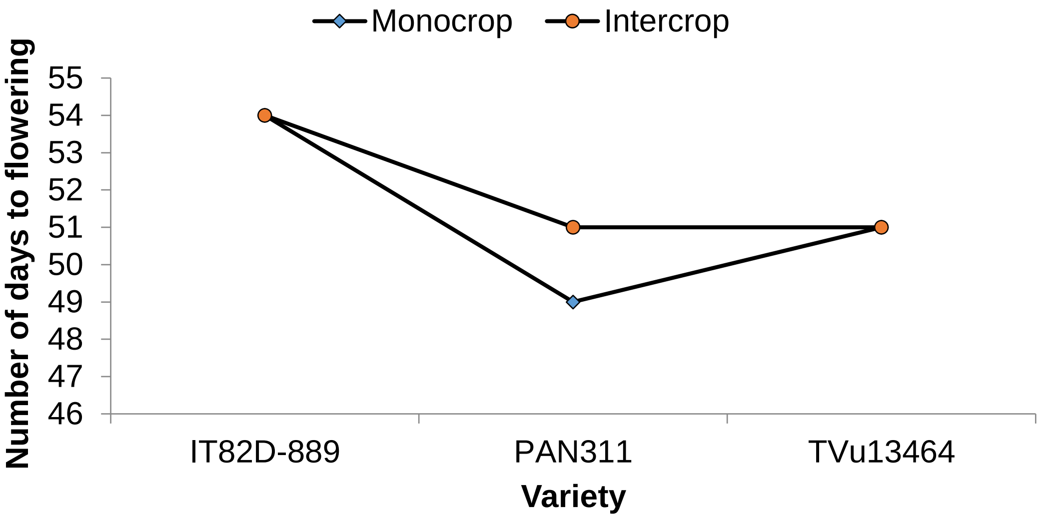

Figure 4: Interaction plot of cowpea varieties and cropping system on number of days to 50% flowering for 2014/15 trial

Table 3: Influence of cropping system on growth and yield parameters of cowpea varieties for 2014/15 trial

Cropping system	Days to 50% flowering	Days to 90% maturity	Plant height (cm)	Root weight (g)	Pod number
Monocrop	51.30^{a}	98.75^{a}	48.61^{a}	22.52^{a}	23.14^{a}
Intercrop	52.05^{b}	97.16^{b}	48.65^{a}	23.47^{b}	23.16^{a}
P value	0.0043**	0.0346*	ns	0.0289*	ns
LSD	0.40	0.57	2.40	0.38	0.61

Means followed by same letter in a column do not differ significantly at P≤ 0.05, **= highly significant at P≤ 0.05

4.1.1.2 Number of days to maturity

The rates of P showed a significant (P<0.05) effect on number of days to 90% maturity (Table 4). There were significant differences (P<0.05) on number of days to attain 90% maturity due to cropping system (Table 4). Across P levels, PAN311 matured earlier with an average of 93 days followed by IT82D-889 (95 days), whereas, TVu13464 matured at 101 days. Increasing P application hastened the number of days to maturity of all cowpea varieties. P levels of 30 and 45 kg/ha reduced the number of days to maturity as compared to 0 and 15 kg P/ha. Similar results were reported by Nkaa *et al*. (2015). This could be attributed to the fact that phosphorus is an important nutrient for growth, utilisation of sugar and starch, photosynthesis, nucleus formation and cell division of crops. This phosphorus is then readily translocated within plants, moving from older to younger tissues as the plant forms cells and develops roots, stems and leaves. Therefore, adequate P results in rapid growth and early maturity.

IT82D-889 and TVu13464 did not show differences in number of days to maturity under cropping system (Figure 5). There was a significant difference in maturity for PAN311 due to cropping system. Monocropping system influenced PAN311 to mature earlier with 90 days as compared to 94 days under intercropping system (Figure 5). Contrary to this findings, Ssebuliba *et al*. (2014) reported non-significant difference between sole and intercropped cowpea in terms of number of days to attain physiological maturity. The reduction in number of days to physiological maturity under monocropping system might be attributed to less competition effects for natural resources especially soil moisture which when deficient can result in lower metabolic process in plants thus reducing maturity date (Lemlem, 2013).

Table 4: Analysis of variance for number of days to 90% cowpea maturity for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	2188.440476	1094.220238	630.27	<.0001
P	3	125.997427	41.999142	24.19	<.0001
P*rep	6	945.607143	157.601190	90.78	<.0001
Variety	3	1397.638889	349.409722	201.26	<.0001
Variety*P	9	817.405556	68.117130	39.24	<.0001
variety*P*rep	18	1792.250000	56.007812	32.26	<.0001
Cropping system	1	8.680556	8.680556	5.00	0.0349
Cropping system*P	3	2.930556	0.976852	0.56	0.6449
Variety*cropping system	3	13.527778	6.763889	3.90	0.0343
Variety*cropping system*P	9	5.694444	0.949074	0.55	0.7676

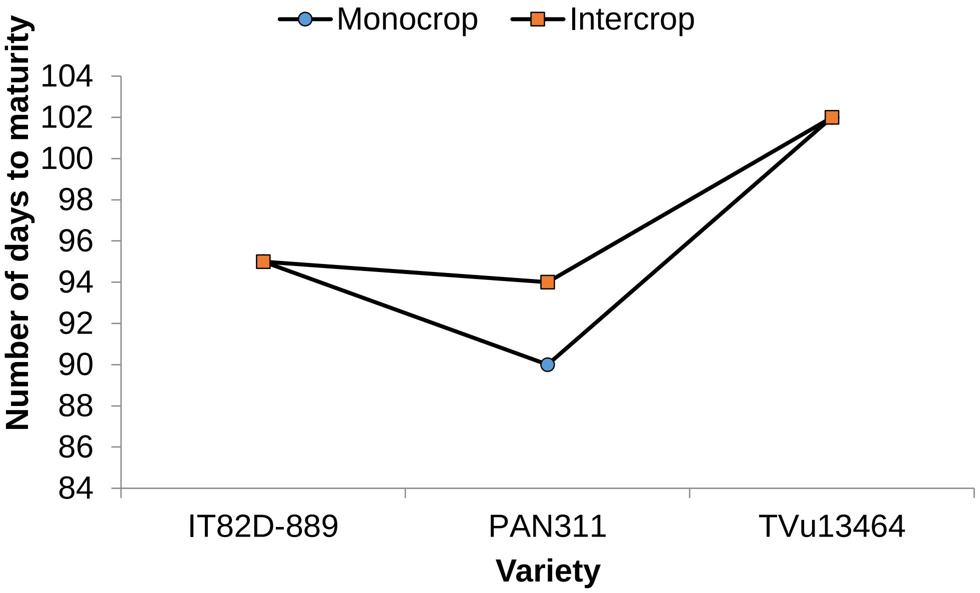

Figure 5: Interaction plot of cowpea varieties and cropping system on number of days to physiological maturity for 2014/15 trial

4.1.1.3 Plant height

Various P application levels showed no significant difference among the varieties for plant height (Table 5). This may probably due to over saturation of P fertiliser in the soil making the soil nutrients immobile because of inadequate soil moisture. This, is however contrary to the observation made by Nkaa *et al*. (2014) who reported that phosphorus fertiliser had a significant effect on plant height. There was also no significant (P>0.05) difference on plant height of cowpea due to cropping system (Table 5). Contrary to this finding, Hamd Alla *et al*. (2014) reported that intercropping had a significant effect on cowpea height. Varieties differed significantly (P<0.05) in plant height. IT82D-889 was significantly taller than PAN311 and TVu13464 (Figures 6 and 7). This could be attributed to the differences in genetic makeup of the test materials. The results are in conformity with the findings of Ssebuliba *et al*. (2014) who reported that IT82D-889 was significantly taller (51.78 cm) than all other cowpea varieties. There were no significant differences among the interactions of variety*P and variety*cropping system*P (Table 5).

Table 5: Analysis of variance for cowpea height for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	1182.142857	591.071429	19.34	<.0001
P	3	79.390197	26.463399	0.87	0.4722
P*rep	6	961.904762	160.317460	5.25	0.0014
Variety	3	7501.805556	1875.451389	61.38	<.0001
Variety*P	9	298.194444	24.849537	0.81	0.6355
variety*P*rep	18	1629.166667	50.911458	1.67	0.0995
Cropping system	1	3.125000	3.125000	0.10	0.7519
Cropping system*P	3	242.708333	80.902778	2.65	0.0719
Variety*cropping system	3	27.083333	13.541667	0.44	0.6471
Variety*cropping system*P	9	106.250000	17.708333	0.58	0.7429

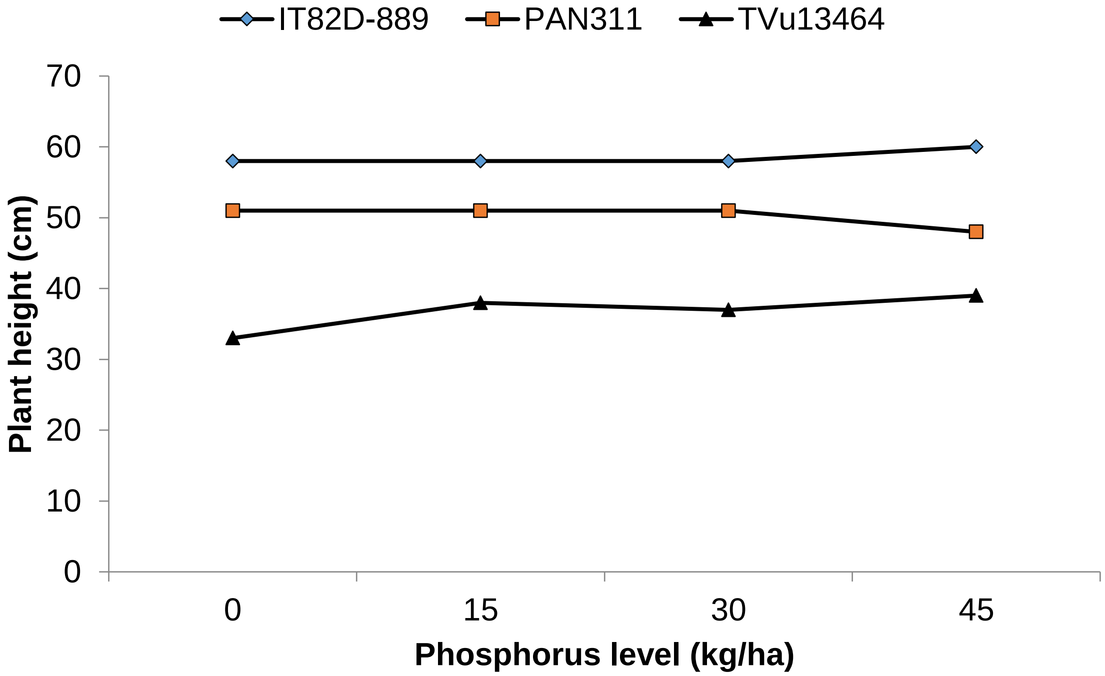

Figure 6: Interaction plot of P levels and varieties on plant height for 2014/15 trial

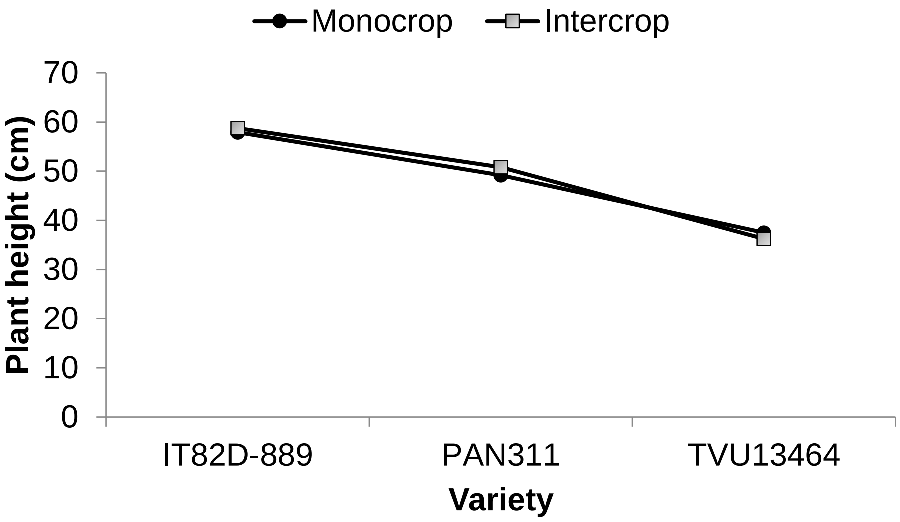

Figure 7: Interaction plot of cowpea varieties and cropping system on plant height for 2014/15 trial

4.1.1.4 Root weight

Phosphorus application rate significantly ($P<0.05$) influenced the root weight of cowpea (Table 6). Increasing P (30-45 kg/ha) resulted in increasing root weight of all varieties (Figure 8). This could be explained on the basis that P fertilisation stimulates the growth of the root and then allows the plant to explore more nutrients and soil moisture to distant areas of metabolic activity (Suryawanshi *et al*., 2017). Furthermore, increasing P application improves root growth and potential of hydraulic conductance (Gyaneshwar *et al*., 2002). Similar results were reported by Nkaa *et al*. (2014), indicating that adequate P is required in root tips where there is high metabolism and rapid cell division.

The varieties also showed significant ($P<0.05$) differences on their root weight. High root mass of IT82D-889 compared to other varieties could be attributed to differences in genetic constitution of varieties (Singh *et al*., 2011). IT82D-889 is a dual-purpose cowpea with greater biomass which must have led to direct increase in its root mass than PAN 311 and TVu13464. There were significant difference on the root weight of cowpea varieties as influenced by the cropping system ($P<0.05$). This could probably be due to the fact that component crops use natural resources for growth and development better and efficiently (Seran and Brintha, 2010). The interaction between variety*P was significant which means that the varieties did not behave the same across various P levels, but no interaction between cropping system*P and variety*cropping system (Table 6).

Table 6: Analysis of variance for weight of cowpea roots for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	2.400833	1.200417	1.56	0.2307
P	3	150.366878	50.122293	65.13	<.0001
P*rep	6	27.684405	4.614067	6.00	0.0006
Variety	3	1939.877611	484.969403	630.17	<.0001
Variety*P	9	154.833278	12.902773	16.77	<.0001
Variety*P*rep	18	123.659167	3.864349	5.02	<.0001
Cropping system	1	4.156806	4.156806	5.40	0.0289
Cropping system*P	3	1.707083	0.569028	0.74	0.5389
Variety*cropping system	3	2.253611	1.126806	1.46	0.2512
Variety*cropping system*P	9	6.787500	1.131250	1.47	0.2305

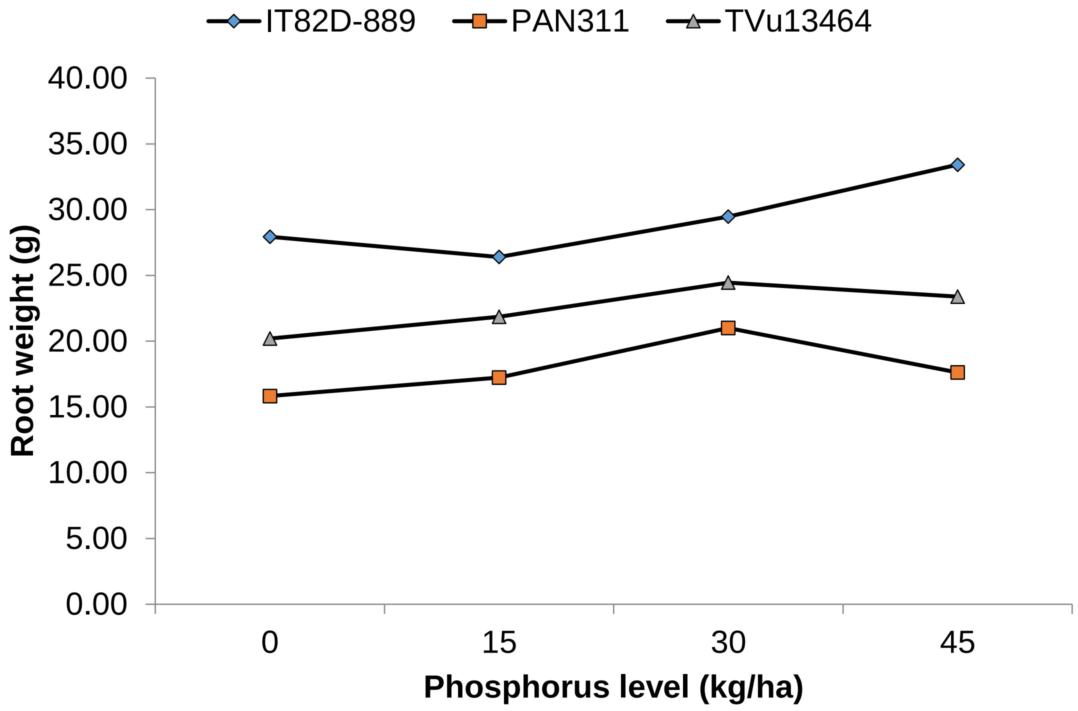

Figure 8: Interaction plot of P levels and cowpea varieties on root weight for 2014/15 trial

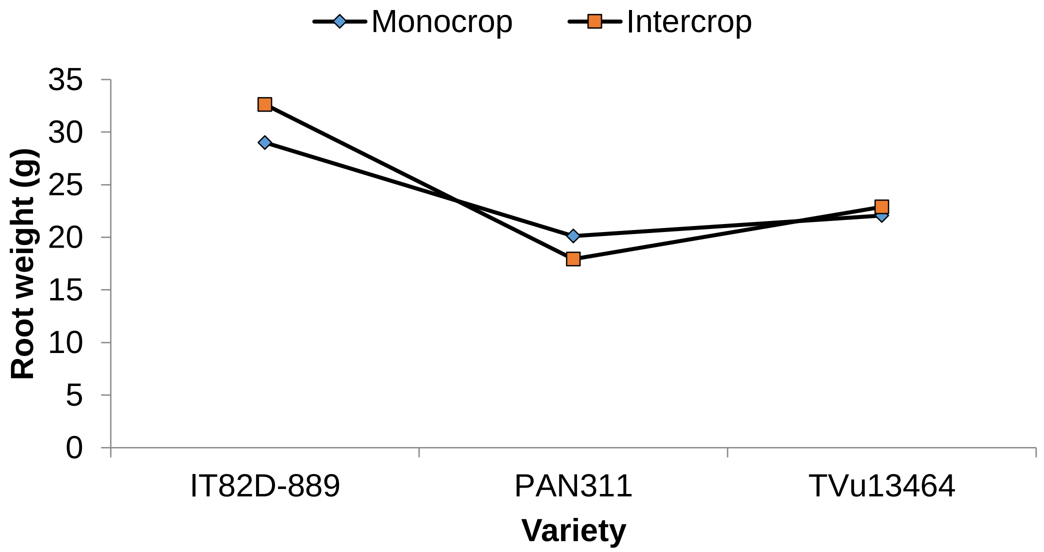

Figure 9: Interaction plot of cowpea varieties and cropping system on root weight for 2014/15 trial

4.1.1.5 Number of pods per plant

Phosphorus application rate showed a significant ($P<0.05$) effect on the number of pods per plant (Table 7). Significantly higher pods per plant were recorded in plots applied with 30 and 45 kg P/ha than 0 and 15 kg P/ha (Figure 10). This could be attributed to the fact that P enhanced cowpea nodulation, probably resulting in higher nitrogen fixation and eventually the number of pods per plant. Singh *et al*. (2011), found similar results, where P had a significant effect on the number of pods per plant.

Varieties showed significant differences on the number of pods per plant (Table 7). TVu13464 variety had more number of pods per plant as compared to IT82D-889 and PAN311 (Figure 10). TVu13464 performed better than other varieties, it had an increasing trend from 0-45 kg P/ha. Different varieties have different genetic constitution. The interaction between the variety and P was significant, the varieties behaved differently across the P levels (Table 7). Figure 10 shows interaction plot of P levels and cowpea varieties whereby TVu13464 and IT82D-889 had increasing trends from low to high P rates, however, PAN311 increased between 0 and 15 kg P/ha but decreased a bit between 15 and 30 kg P/ha and then stared increasing gradually. Cropping system did not show any significant difference in the number of pods per plant (Table 7). Similar results were reported by Legwaila *et al*. (2012) whereby there was no significance difference in the number of cowpea pods between intercropping and monocropping. High number of pods per plant could be good genetic background of the varieties as well as adequate soil moisture available which could have played a major role in pod setting and pod filling stages (Hussein *et al*., 2014).

Table 7: Analysis of variance for number of cowpea pods per plant for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	407.689048	203.844524	100.61	<.0001
P	3	146.667463	48.889154	24.13	<.0001
P*rep	6	338.876667	56.479444	27.88	<.0001
Variety	3	1240.567222	310.141806	153.07	<.0001
Variety*P	9	488.559444	40.713287	20.09	<.0001
variety*P*rep	18	1759.493333	54.984167	27.14	<.0001
Cropping system	1	5.227222	5.227222	2.58	0.1213
Cropping system*P	3	4.655000	1.551667	0.77	0.5244
Variety*cropping system	3	0.734444	0.367222	0.18	0.8354
Variety*cropping system*P	9	3.416667	0.569444	0.28	0.9403

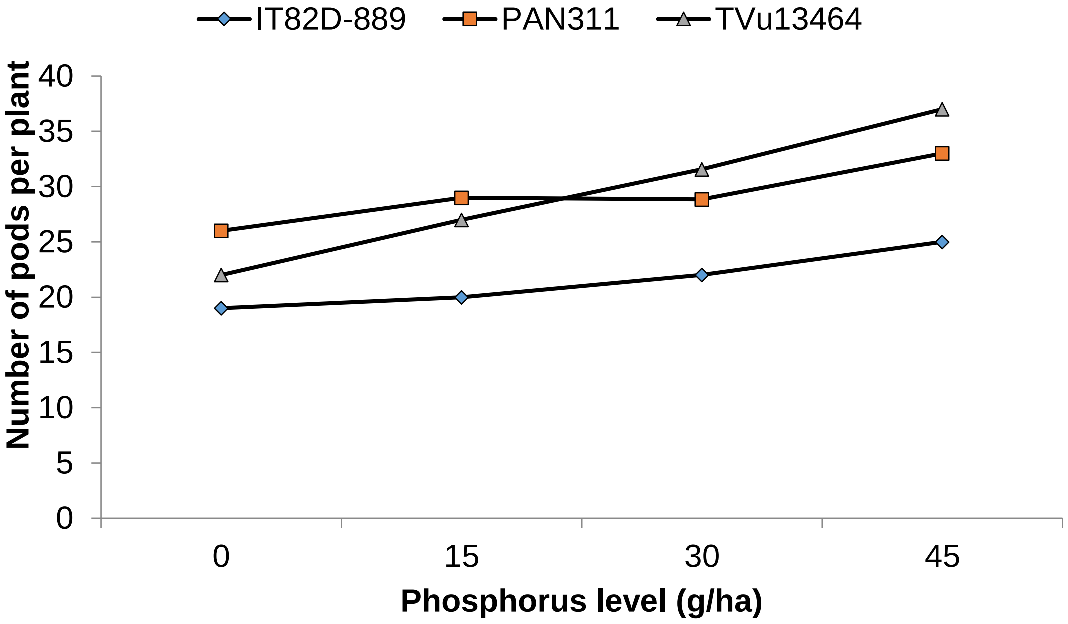

Figure 10: Interaction plot of P levels and cowpea varieties on number of pods for 2014/15 trial

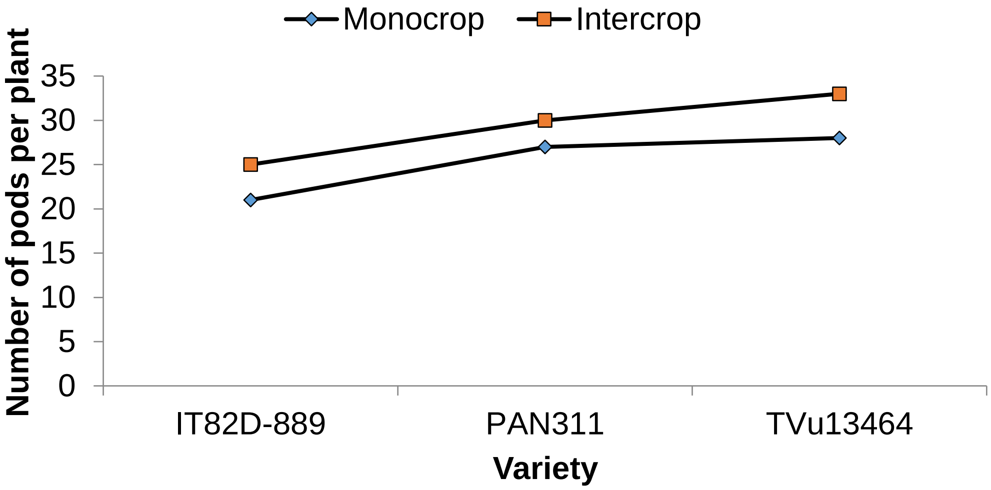

Figure 11: Interaction plot of cowpea varieties and cropping system on number of pods per plant for 2014/15 trial

4.1.1.6 Pod length

The effect of cropping system and P level on the length of cowpea pods were not significant (Tables 8 and 9). This however, did not conform to the results reported by Ayodele and Oso (2014) when they tested cowpea responses to P fertiliser application in South-West Nigeria, they found that increasing P application increased pod length. The interaction of variety*P was significant on the pod length of cowpea (Table 8). There were significant differences among the pod lengths of cowpea varieties across P levels (Table 8). IT82D-889 had significantly longer pod length of 18.49 cm whereas the shortest was TVu13464 (10.49 cm) (Table 10). This is due to different genetic makeup of the varieties.

Table 8: Analysis of variance for pod length for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	11.8354476	5.9177238	3.48	0.0470
P	3	2.3566950	0.7855650	0.46	0.7111
P*rep	6	19.5600571	3.2600095	1.92	0.1188
Variety	3	929.7675289	232.4418822	136.83	<.0001
Variety*P	9	90.3626756	7.5302230	4.43	0.0009
Variety*P*rep	18	160.9729000	5.0304031	2.96	0.0038
Cropping system	1	1.4563556	1.4563556	0.86	0.3637
Cropping system*P	3	0.3521778	0.1173926	0.07	0.9759
Variety*cropping system	3	1.0080444	0.5040222	0.30	0.7460
Variety*cropping system*P	9	3.0490222	0.5081704	0.30	0.9312

4.1.1.7 Dry pod weight

Application of P had no significant effect on the net dry pod weight, however, varieties showed significant ($P<0.05$) differences with PAN311 exhibiting higher dry pod weight of 2562.6 kg/ha (Table 10). Contrary results were reported by Mawo *et al*. (2016), who found significant difference with various P levels. This could be attributed to the fact that their study and the present study did not use the same cowpea varieties. Interaction of P*variety increased dry pod weight of PAN311 with increasing P application. Cropping system showed a significant ($P<0.05$) difference on the weight of dried pods (Table 12). Across varieties, intercropping produced higher dry pod weight (1207.5 kg/ha) than monocropping (952.2 kg/ha). This could be attributed to the fact that component crops tend to use natural resources more efficiently for crop growth and development.

4.1.1.8 Grain yield

There were no significant ($P>0.05$) difference in the grain yield due to the application levels of P, however varieties differed significantly (Table 11). Table 10 shows that PAN311 produced higher yield (2491.60 kg/ha) compared to TVu13464 (1820.40) and IT82D-889 (1205.40) kg/ha). This could be attributed to the fact that varieties behave differently due to selection from narrow genetic base. IT86D-1010 had a poorer germination and emergence, hence there was not enough data for it to be collected. This variety and IT82D-889 were dropped when selecting varieties to be used on the second season due to their low performance and grain yield. This led to the selection of two promising cowpea varieties (PAN311 and TVu13464) for the second season.

Significant difference ($P<0.05$) was observed between the cropping systems for grain yield. Intercropping (1115 kg/ha) was better than monocropping (900 kg/ha). This could be attributed to the fact that crops under intercropping system tends to use natural resources more efficiently for growth and development which may have resulted in increased number of pods, pod length, pod weight and total grain yield. Furthermore, cowpea production in a diversified agro-ecosystem can be a reservoir for the naturally occurring biological control agents. Soil moisture, soil temperature and microclimate are normally higher in intercropping system compared to monocropping system (Seran and Brintha, 2010).

Table 9: Analysis of variance for cowpea grain yield for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	0.26623333	0.13311667	6.94	0.0042
P	3	0.03891662	0.01297221	0.68	0.5752
P*rep	6	0.06770000	0.01128333	0.59	0.7366
Variety	3	2.69323056	0.67330764	35.09	<.0001
Variety*P	9	0.39578722	0.03298227	1.72	0.1251
Variety*P*rep	18	0.91310833	0.02853464	1.49	0.1590
Cropping system	1	0.00020000	0.00020000	0.01	0.9195
Cropping system*P	3	0.13961111	0.04653704	2.43	0.0904
Variety*cropping system	3	0.04230833	0.02115417	1.10	0.3483
Variety*cropping system*P	9	0.23111389	0.03851898	2.01	0.1042

Table 10: Effect of phosphorus application level on cowpea yield parameters for 2014/15 trial

P level (kg/ha)	Pod length (cm)	Peduncle length (cm)	Grain yield (kg/ha)
0	14.59^{a}	35.83^{a}	1232^{a}
15	14.32^{a}	36.81^{a}	1266^{a}
30	14.21^{a}	34.72^{a}	1370^{a}
45	14.01^{a}	35.06^{a}	1450^{a}
P Value	ns	ns	ns
LSD $_{(0.05)}$	-	-	-

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥0.05

Table 11: Cowpea yield parameters across P levels for 2014/15 trial

Variety	Pod length (cm)	Peduncle length (cm)	Dry pod weight (kg/ha)	Grain yield (kg/ha)
IT82D-889	18.49^{a}	43.00^{a}	1933.3^{a}	1205.4^{a}
PAN311	14.84^{b}	36.47^{b}	2562.6^{b}	2491.6^{b}
TVU13464	10.49^{c}	27.90^{c}	1820.4^{c}	1317.4^{c}
P Value	<0.0001***	<0.0001***	<0.0001***	<0.0001***
LSD $_{(0.05)}$	1.62	4.33	0.21	0.14

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥0.05, ***= Highly significant at P≤0.0001

Table 12: Effect of cropping system on cowpea yield parameters.

Cropping system	Pod length (cm)	Peduncle length (cm)	Pod weight (kg/ha)	Grain yield (kg/ha)
Monocrop	14.16^{a}	34.13^{a}	952.2^{a}	900.5^{a}
Intercrop	14.50^{a}	37.90^{b}	1207.5^{b}	1115.7^{b}
P Value	ns	0.0125**	0.05*	0.05*
LSD $_{(0.05)}$	-	0.5999	0.0811	0.05

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥ 0.05, *= significant at P≤0.05, **= High significant at P≤0.05

4.1.2 Maize performance

4.1.2.1 Number of days to flowering

Phosphorus application and cropping system did not significantly (P>0.05) influence days to 50% tasseling and silking of maize varieties (Table 13 and 14). The results are in line with the study of Nndwambi (2015) who reported non-significance of maize flowering due to various P rates and cropping system. Contrary to this, Amanullah (2015) reported that number of days to tasseling and silking were enhanced with the increase in phosphorus application. Varieties differed significantly (P<0.05), with ZM1423 being the earliest to flower at 68 days for 50% tasseling and silking compared to WE3127 at 74 days (Table 17). This could be attributed to the variations of their genetic makeup.

Table 13: Analysis of variance for number of days to 50% maize tasseling for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	816.968750	408.484375	42.10	<.0001
P	3	44.682292	14.894097	1.53	0.2075
P*rep	6	403.364583	67.227431	6.93	<.0001
Variety	1	2180.255208	2180.255208	224.70	<.0001
Variety*P	3	24.848958	8.282986	0.85	0.4666
Variety*P*rep	8	73.083333	9.135417	0.94	0.4841
Cropping system	1	0.630208	0.630208	0.06	0.7992
Cropping system*P	3	0.557292	0.185764	0.02	0.9964
Variety*cropping system	1	4.380208	4.380208	0.45	0.5026
Variety*cropping system*P	3	0.807292	0.269097	0.03	0.9937

Table 14: Analysis of variance for number of days to 50% maize silking for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	466.625000	233.312500	26.91	<.0001
P	3	34.750000	11.583333	1.34	0.2646
P*rep	6	390.375000	65.062500	7.51	<.0001
Variety	1	2028.000000	2028.000000	233.94	<.0001
Variety*P	3	19.166667	6.388889	0.74	0.5314
Variety*P*rep	8	57.333333	7.166667	0.83	0.5802
Cropping system	1	0.000000	0.000000	0.00	1.0000
Cropping system*P	3	0.000000	0.000000	0.00	1.0000
Variety*cropping system	1	0.000000	0.000000	0.00	1.0000
Variety*cropping system*P	3	0.000000	0.000000	0.00	1.0000

Table 15: Effect of phosphorus application level on growth and yield parameters of maize varieties for 2014/15 trial

P level (kg/ha)	Days to 50% tassel	Days to 50% silking	Plant height (cm)	Root weight (g)	Cob weight (kg)	Grain yield (kg/ha)
0	71.87^{a}	71.25^{a}	200.25^{a}	46.20^{a}	0.31^{a}	2778^{a}
15	70.75^{a}	70.46^{a}	204.34^{a}	47.56^{b}	0.43^{b}	2820^{a}
30	71.67^{a}	71.46^{a}	198.31^{a}	48.74^{c}	0.29^{a}	3210^{b}
45	70.89^{a}	70.58^{a}	205.36^{a}	49.13^{d}	0.27^{a}	4742^{c}
P Value	ns	ns	ns	0.0001***	0.0001***	0.0001***
LSD $_{(0.05)}$	-	-	-	0.46	0.18	0.34

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$. LSD= Least significant difference, ns= non-significant at $P \geq 0.05$, ***= Highly significant at $P \leq 0.0001$

4.1.2.2 Plant height

There was no significant difference in plant height of maize varieties due to application levels of P (Table 16). This could be attributed to inefficient utilisaton of phosphorus fertiliser by crops due to deficient soil moisture. Similar results were reported by Umeri *et al*. (2016) who found no significant effect on plant height. Contrary to this, Masood *et al*. (2011) found significant difference on the height of maize due to P applications. This was probably due to better development of root system and nutrient absorption. There was a significant difference ($P<0.05$) amongst the plant height of maize varieties (Table 16). Table 17 shows that WE3127 was significantly taller (207 cm) than ZM1423 (197 cm). This could be attributed to different genetic constitution of the varieties. Cropping system and interactions had no significant effect on the height of maize (Table 16).

Table 16: Analysis of variance for plant height of maize for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	10330.62060	5165.31030	14.85	<.0001
P	3	1605.70403	535.23468	1.54	0.2066
P*rep	6	5528.76710	921.46118	2.65	0.0178
Variety	1	4127.09703	4127.09703	11.86	0.0007
Variety*P	3	367.33703	122.44568	0.35	0.7878
Variety*P*rep	8	1691.66562	211.45820	0.61	0.7704
Cropping system	1	377.35671	377.35671	1.08	0.2992
Cropping system*P	3	1753.97651	584.65884	1.68	0.1733
Variety*cropping system	1	45.65925	45.65925	0.13	0.7176
Variety*cropping system*P	3	1039.68122	346.56041	1.00	0.3962

4.1.2.3 Root weight

There was a significant ($P<0.05$) difference on the maize root mass due to P application (Table 26). Increasing levels of P application increased root mass of maize varieties, higher root weight were recorded at plots applied with 30 and 45 kg P/ha. In conformity to the results, Ragothama (2005) reported that P application increases root growth and the potential of root hydraulic conductance. Table 17 shows that varieties significantly differed in their root mass with ZM1423 (48.93 g) being superior over WE3127 (46.75 g). The interaction of P*variety had a significant ($P<0.0001$) effect on root mass which shows great variation amongst the performance of the varieties across P levels (Table 18). Cropping system had no significant effect on maize root mass (Table 21).

Table 17: Growth and yield parameters of maize varieties for 2014/15 trial

Variety	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Root weight (g)	Cob weight	Grain yield (kg/ha)
WE3127	74.67^a	74.19^a	206.70^a	46.75^a	0.34^a	3462^a
ZM1423	67.92^b	67.69^b	197.43^b	48.93^b	0.32^a	3306^a
P Value	0.0001***	0.0001***	0.0007**	0.0001***	ns	ns
LSD $_{(0.05)}$	1.00	0.89	4.84	0.12	-	-

Means in the same column followed by the same letter are not significantly different at P=0.05. LSD= Least significant difference, ns= non-significant at P≥0.05, ***= Highly significant at P≤0.0001

Table 18: Analysis of variance for maize root weight for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	0.3522667	0.1761333	0.37	0.6892
P	3	232.0412562	77.3470854	163.85	<.0001
P*rep	6	5.2737500	0.8789583	1.86	0.0905
Variety	1	227.8972521	227.8972521	482.76	<.0001
Variety*P	3	12.9877729	4.3292576	9.17	<.0001
Variety*P*rep	8	1.1233500	0.1404188	0.30	0.9660
Cropping system	1	0.0000000	0.0000000	0.00	1.0000
Cropping system*P	3	0.0000000	0.0000000	0.00	1.0000
Variety*cropping system	1	0.0000000	0.0000000	0.00	1.0000
Variety*cropping system*P	3	0.0000000	0.0000000	0.00	1.0000

4.1.2.4 Cob weight

Various P application rates showed a significant (P<0.05) effect on the cob weight (Table 19). Phosphorus plays an important role in several plant structures such as phospholipids and enhance grain formation and crop quality (Olusegun, 2015). Rana and Chauhan (2003) reported similar results where various P applications significantly influenced cob weight. There was no varietal significant differences in cob weight. Cropping system showed no significant difference in cob weight (Table 21). Similar results were reported by Legwaila (2012), who found that cob weight was not affected by intercropping systems.

Table 19: Analysis of variance for weight of maize cob for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	0.78708750	0.39354375	11.31	<.0001
P	3	0.76021042	0.25340347	7.28	0.0001
P*rep	6	0.83635833	0.13939306	4.01	0.0009
Variety	1	0.02566875	0.02566875	0.74	0.3916
Variety*P	3	0.00135208	0.00045069	0.01	0.9980
Variety*P*rep	8	0.19610417	0.02451302	0.70	0.6871
Cropping system	1	0.04320000	0.04320000	1.24	0.2668
Cropping system*P	3	0.03052917	0.01017639	0.29	0.8307
Variety*cropping system	1	0.00053333	0.00053333	0.02	0.9016
Variety*cropping system*P	3	0.01010417	0.00336806	0.10	0.9617

4.1.2.5 Grain yield

There was a significant ($P<0.05$) effect on the grain yield as a result of various P applications (Table 20). Increasing levels of P increased grain yield. Higher grain yield (4742 kg/ha) was obtained at P level 45 kg/ha wheras low yield of 2778 kg/ha obtained at 0 kg P/ha across varieties (Table 15). Application of P enhanced the yield, this is evident from the yield difference of 1964 kg/ha between high and low P level. Grain yield is exceptionally low due to frost occurrence during the grain filling stages of the maize crop (Figure 1). Olusegun (2015) reported that P application significantly influenced grain yield with 30 kg P/ha producing grain yield of 3091.5 kg/ha. Varieties did not show significant difference in grain yield (Table 17). Interaction of P*variety had no significant effect on the grain yield (Table 20). Cropping system did not show any significant differences on the grain yield (Table 21).

Table 20: Analysis of variance for grain yield of maize for 2014/15 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	2679312.238	1339656.119	9.93	<.0001
P	3	3411882.915	1137294.305	8.43	<.0001
P*rep	6	4618906.874	769817.812	5.71	<.0001
Variety	1	32552.604	32552.604	0.24	0.6239
Variety*P	3	53709.308	17903.103	0.13	0.9404
Variety*P*rep	8	930614.334	116326.792	0.86	0.5494
Cropping system	1	220050.729	220050.729	1.63	0.2033
Cropping system*P	3	274127.567	91375.856	0.68	0.5670
Variety*cropping system	1	6429.913	6429.913	0.05	0.8274
Variety*cropping system*P	3	32374.546	10791.515	0.08	0.9708

Table 21: Effect of cropping system on growth and yield parameters of maize varieties

Cropping system	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Root weight (g)	Cob weight (kg)	Grain yield (kg/ha)
Monocrop	71.35^a	70.93^a	203.47^a	47.84^a	0.31^a	3180^a
Intercrop	71.23^a	70.00^a	200.67^a	48.25^a	0.34^a	3588^a
P Value	ns	ns	ns	ns	ns	ns
LSD $_{(0.05)}$	-	-	-	-	-	-

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$. LSD= Least significant difference, ns= non-significant at $P \geq 0.05$

4.1.2.6 Land equivalent ratio (LER)

The productivity of intercropping maize with cowpea was assessed using LER. According to Dariush *et al*. (2006), when LER is greater than one, it indicates advantageous intercropping system. The calculated LERs for maize and cowpea varieties ranged from 1.90 to 2.87 (Table 22). Figure 12 shows that PAN311 increased the LER value from 0-30 kg P/ha but beyond that point started decreasing. TVu13464, IT86D-1010 and IT82D-

889 had a similar increasing trend increasing from 0-45 kg P/ha, except for TVu13464 which dropped gradually beyond 30 kg P/ha. This shows that TVu13464 and PAN311 had a similar trend of reducing LER values beyond P application of 30 kg/ha. The study of Masvaya *et al*. (2017) reported LER values ranging from 1.8-2.5. For this study, LER values ranged from 1.9-2.87. The calculated LER values were greater than one, which conforms to the study of Nyasasi and Kisetu (2014). The LER range for this study under strip intercropping of maize with cowpea shows that this form of intercropping is better compared to other intercropping systems in terms of greater efficiency of land utilisation.

Table 22: Total LER for the component crops in the intercrop at different phosphorus rates during 2014/15 growing season

Variety	**Total LER at various phosphorus levels**			
	0	**15**	**30**	**45**
IT82D-889	1.98	2.09	2.38	2.51
IT86D-1010	2.15	1.99	2.17	2.66
PAN311	1.9	2.71	2.87	1.96
TVu13464	2.17	2.05	2.18	2.05
Mean	2.05	2.21	2.4	2.295

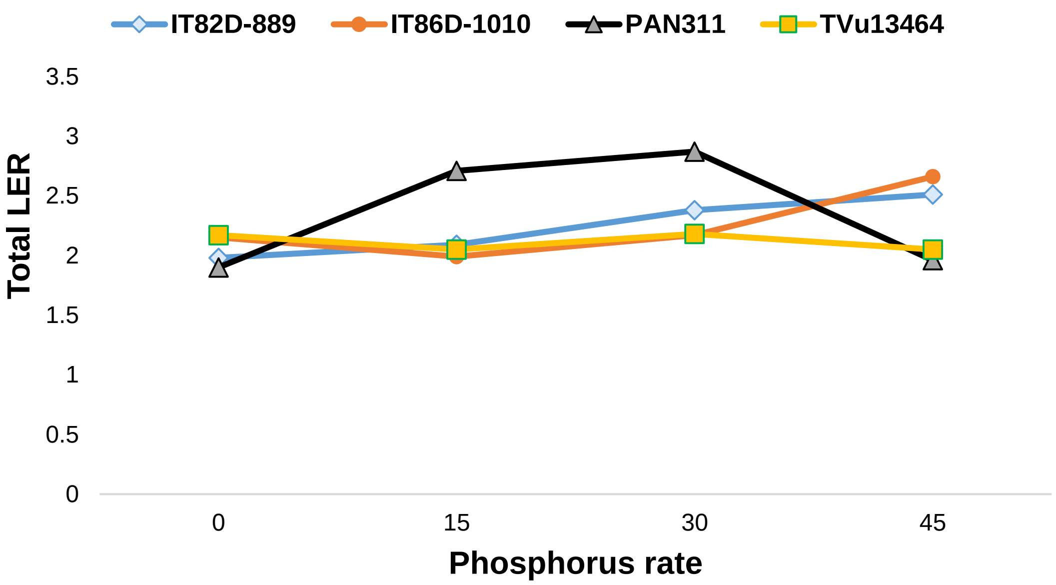

Figure 12: Interaction plot of LER values across various P levels

4.2 Second season experiment (2015/16)

4.2.1 Cowpea performance

4.2.1.1 Number of days to flowering

There was no significant (P>0.05) difference on the number of days to 50% flowering due to various P application levels (Table 23). Ayodele and Oso (2014) found results which do not conform to the results of this present study, they reported that P application increased the number of flowers as compared to the plots with low or no P application. This may probably be due to different materials used in these studies. Varieties differed significantly (P<0.05) on the number of days to 50% flowering with PAN311 (52 days) flowering earlier than TVu13464 (Table 32). This could be attributed to different genetic constitution of the varieties (Singh *et al*., 2011). Cropping system did not show any significant difference (Table 33). There were no significant differences amongst the interactions

Table 23: Analysis of variance for the number of days to 50% cowpea flowering for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	18.50106838	9.25053419	7.26	0.0053
P	3	6.82683983	2.27561328	1.79	0.1881
P*rep	6	6.72635135	1.12105856	0.88	0.5303
Variety	1	15.37974684	15.37974684	12.07	0.0029
Variety*P	3	7.84848485	2.61616162	2.05	0.1446
Variety*P*rep	8	52.37500000	6.54687500	5.14	0.0022
Cropping system	1	0.52742616	0.52742616	0.41	0.5286
Cropping system*P	3	0.73160173	0.24386724	0.19	0.9008
Variety*cropping system	1	0.18987342	0.18987342	0.15	0.7043
Variety*cropping system*P	3	0.40259740	0.13419913	0.11	0.9558

4.2.1.2 Number of days to physiological maturity

Phosphorus application significantly (P<0.05) influenced the number of days to 90% physiological maturity (Table 24). Increasing application of P reduced the number of days to physiological maturity (Table 31). Cowpea matured early (99 days) at 45 kg P/ha. This might be attributed to the fact that P fertilisation hastens maturity date of a crop. Mawo *et al*. (2016) reported similar results where the number of days to pod maturity was influenced by phosphorus levels. Varieties differed significantly (P<0.05) with PAN311 maturing earlier at 97 days (Table 32). Singh *et al*. (2011), reported that the variability of the varieties was as a result of their genetic makeup.

There was no significant difference in physiological maturity due to cropping system (Table 33). Ssebuliba *et al*. (2014) found similar results between sole and intercropped cowpea in terms of required days to reach physiological maturity. The reduction in number of days to physiological maturity under monocropping system might be attributed to less competition effects for natural resources especially soil moisture which when deficient can result in lower metabolic process in plants thus reducing maturity date (Lemlem, 2013). The interactions did not differ significantly.

Table 24: Analysis of variance for the number of days to 90% cowpea maturity for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	71.727404	35.863702	10.09	0.0013
P	3	106.493939	35.497980	9.99	0.0005
P*rep	6	53.144200	8.857367	2.49	0.0646
Variety	1	1888.621097	1888.621097	531.57	<.0001
Variety*P	3	28.498268	9.499423	2.67	0.0802
Variety*P*rep	8	93.600000	11.700000	3.29	0.0185
Cropping system	1	17.498734	17.498734	4.93	0.0404
Cropping system*P	3	2.948485	0.982828	0.28	0.8415
Variety*cropping system	1	6.241350	6.241350	1.76	0.2026
Variety*cropping system*P	3	13.480952	4.493651	1.26	0.3180

4.2.1.3 Plant height

Various levels of P significantly ($P < 0.05$) influenced height of cowpea (Table 31). P levels of 30 kg/ha (54.33 cm) and 45 kg/ha (55.19 cm) produced taller plants as compared to 0 kg/ha (51.70 cm) and 15 kg P/ha (50.12 cm). This could be attributed to the fact that phosphorus is required in large quantities in shoot and root tips where metabolism is high and cell division is rapid (Mullins, 2009). The results are in line with the study on Nkaa *et al*. (2014). Furthermore, this indicates that the cowpea varieties used applied P efficiently in growth and development processes. Table 32 shows that the plant height of the two varieties differed significantly ($P<0.05$) with TVu13464 (40.06 cm) being the shortest than PAN311 (65.20 cm). There was no significant difference observed on the cowpea plant height due to cropping system (Table 33). This could be attributed to the shading effect imposed by the taller maize crops (Seran and Brintha, 2010).

Table 25: Analysis of variance for cowpea plant height for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	3.014330	1.507165	0.12	0.8843
P	3	167.981223	55.993741	4.60	0.0156
P*rep	6	419.677492	69.946249	5.75	0.0020
Variety	1	7746.316508	7746.316508	636.41	<.0001
Variety*P	3	102.647890	34.215963	2.81	0.0707
Variety*P*rep	8	460.694907	57.586863	4.73	0.0034
Cropping system	1	7.576002	7.576002	0.62	0.4410
Cropping system*P	3	94.645725	31.548575	2.59	0.0865
Variety*cropping system	1	12.101319	12.101319	0.99	0.3327
Variety*cropping system*P	3	19.470400	6.490133	0.53	0.6657

4.2.1.4 Root weight

Phosphorus application had no significant effect on cowpea root mass (Table 26). Table 1 of the soil tests results indicate that the soil P level was 23.2 mg/kg Bray 1. According to Marx *et al*. (1999) this is a medium level P, so it might be that the crop did not respond significantly to the applied P. However, varieties differed significantly (P<0.05) with PAN311 (5.29 g) being the highest (Table 32). Differences in these varieties is likely to be the result of their genetic constitution (Singh *et al*., 2011). Cropping system did not show any significant difference in cowpea root weight (Table 33). There was a significant difference on the interaction of variety*cropping system, except for variety*phosphorus and variety* cropping system*phosphorus.

Table 26: Analysis of variance for cowpea root weight for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	10.94590385	5.47295192	1.52	0.2478
P	3	15.59973377	5.19991126	1.44	0.2659
P*rep	6	9.64423198	1.60737200	0.45	0.8384
Variety	1	32.80010338	32.80010338	9.09	0.0078
Variety*P	3	5.63505844	1.87835281	0.52	0.6740
variety*P*rep	8	80.87850000	10.10981250	2.80	0.0354
Cropping system	1	2.44710759	2.44710759	0.68	0.4217
Cropping system*P	3	6.14207143	2.04735714	0.57	0.6441
Variety*cropping system	1	25.79959705	25.79959705	7.15	0.0160
Variety*cropping system*P	3	1.76198485	0.58732828	0.16	0.9200

4.2.1.5 Number of pods per plant

Various P application rates did not significantly influence the number of pods per plant (Table 27). This could be the result of non-significant difference on root mass, which when improved plays an important role in absorption of nutrients and soil moisture needed for grain filling stages. Contrary to the findings of this study, Singh *et al*. (2011) reported significant difference in the number of pods per plant due to P application. There was significant (P<0.05) difference among the number of pods per plant for cowpea varieties.

TVu13464 (17) was significantly higher compared to PAN311 (11) in number of pods per plant (Table 32). Singh *et al*. (2011) attribute this to the differences in genetic makeup of the varieties. There was no significant difference in number of pods per plant due to cropping system (Table 33). Similar results were reported by Legwaila *et al*. (2012) where there was no significant difference in the number of cowpea pods between intercropping and monocropping.

4.2.1.6 Pod length

There was no significant difference due to P application on the pod length (Table 28). Contrary to this findings, Ayodele and Oso (2014) found that increasing P application increased pod length. Table 32 shows that the varieties differed significantly ($P<0.05$) in pod length with PAN311 (15.89 cm) being superior over TVu13464 (11.08 cm). Singh *et al*. (2011) reported that this could be due genetic constitution of the varieties. There was no significant difference due to cropping system and amongst the interactions observed.

Table 27: Analysis of variance for number of cowpea pods per plant for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	126.8854167	63.4427083	1.37	0.2834
P	3	80.3072917	26.7690972	0.58	0.6389
P*rep	6	539.8645833	89.9774306	1.94	0.1362
Variety	2	335.6510417	167.8255208	3.61	0.0507
Variety*P	3	28.3906250	9.4635417	0.20	0.8923
variety*P*rep	8	342.9166667	42.8645833	0.92	0.5236
Cropping system	1	9.6302083	9.6302083	0.21	0.6550
Cropping system*P	3	30.5572917	10.1857639	0.22	0.8816
Variety*cropping system	1	35.8802083	35.8802083	0.77	0.3925
Variety*cropping system*P	3	72.7239583	24.2413194	0.52	0.6734

Table 28: Analysis of variance for cowpea pod length for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	3.1354167	1.5677083	1.08	0.3622
P	3	1.3489583	0.4496528	0.31	0.8175
P*rep	6	14.1979167	2.3663194	1.63	0.2017
Variety	2	281.4427083	140.7213542	97.19	<.0001
Variety*P	3	0.1822917	0.0607639	0.04	0.9881
variety*P*rep	8	19.8333333	2.4791667	1.71	0.1712
Cropping system	1	2.2968750	2.2968750	1.59	0.2259
Cropping system*P	3	12.7239583	4.2413194	2.93	0.0655
Variety*cropping system	1	4.3802083	4.3802083	3.03	0.1012
Variety*cropping system*P	3	7.0572917	2.3524306	1.62	0.2231

4.2.1.7 Biomass

Cowpea biomass was not significantly influenced as a result of P application (Table 29). Statistically, varieties did not differ significantly (Table 29), however, PAN311 (2445 kg/ha) was higher than TVu13464 (1650 kg/ha). This could mean a great advantage for smallholder farmers who will use cowpea biomass for livestock feeding. There was no significant difference observed for cowpea biomass due to cropping system (Table 33). Furthermore, amongst the observed interactions there was no significant difference.

Table 29: Analysis of variance for cowpea biomass for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	14635.94792	7317.97396	1.00	0.3905
P	3	18062.35417	6020.78472	0.82	0.5012
P*rep	6	32628.55208	5438.09201	0.74	0.6243
Variety	2	10989.14714	5494.57357	0.75	0.4886
Variety*P	3	10260.45833	3420.15278	0.47	0.7098
variety*P*rep	8	52545.33333	6568.16667	0.90	0.5423
Cropping system	1	1073.52083	1073.52083	0.15	0.7071
Cropping system*P	3	10447.10417	3482.36806	0.47	0.7042
Variety*cropping system	1	1121.33333	1121.33333	0.15	0.7009
Variety*cropping system*P	3	29694.70833	9898.23611	1.35	0.2937

4.2.1.8 Grain yield

Cowpea grain yield was not significantly influenced by levels of P application (Table 30). Despite lack of statistical difference in grain yield, in terms of monetary value P application levels of 30 kg/ha (1569.4 kg/ha) and 45 kg/ha (1722.2 kg/ha) could give a smallholder farmer a good income return as compared to 15 kg/ha (1413.9 kg/ha). Varieties differed significantly ($P<0.05$) in grain yield (Table 32). Table 32 shows that PAN311 variety (2066.7 kg/ha) significantly yielded higher than TVu13464 (1248.6 kg/ha). Cropping system showed a significant ($P<0.05$) difference in the grain yield (Table 33), with intercropping (1759.7 kg/ha) being significantly higher than monocropping (1418.7 kg/ha) (Table 33). According to Seran and Brintha (2010), component crops in an intercropping system use natural resources more efficiently for growth and development.

Table 30: Analysis of variance for grain yield of cowpea for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	691713.662	345856.831	2.14	0.1504
P	3	577844.375	192614.792	1.19	0.3449
P*rep	6	605130.431	100855.072	0.62	0.7094
Variety	2	5210411.313	2605205.656	16.10	0.0001
Variety*P	3	95068.153	31689.384	0.20	0.8977
variety*P*rep	8	5612775.833	701596.979	4.34	0.0061
Cropping system	1	1625570.116	1625570.116	10.05	0.0059
Cropping system*P	3	293961.569	97987.190	0.61	0.6209
Variety*cropping system	1	585210.542	585210.542	3.62	0.0754
Variety*cropping system*P	3	288035.106	96011.702	0.59	0.6283

Table 31: Effect of phosphorus application levels on the cowpea growth and yield parameters across varieties for 2015/16 trial

P level (kg/ha)	Days to 50% flowering	Days to 90% maturity	Plant height (cm)	Root weight (g)	Number of pods	Pod length (cm)	Biomass (kg/ha)	Grain yield (kg/ha)
0	60.66^{a}	104.92^{a}	51.70^{a}	4.27^{a}	14.73^{a}	13.92^{a}	1741.08^{a}	1633.3^{a}
15	60.58^{a}	104.17^{a}	50.12^{a}	4.40^{a}	12.33^{a}	13.50^{a}	1623.92^{a}	1413.9^{a}
30	60.08^{a}	102.15^{b}	54.33^{b}	4.11^{a}	15.75^{a}	13.41^{a}	1695.21^{a}	1569.4^{a}
45	59.75^{a}	99.00^{b}	55.19^{b}	5.59^{a}	15.17^{a}	13.29^{a}	1893.25^{a}	1722.2^{a}
P Value	ns	0.000***	0.015	ns	ns	ns	ns	ns
LSD $_{(0.05)}$	-	2.94	8.27	-	-	-	-	-

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥0.05, ***= Highly significant at P≤0.0001

Table 32: Cowpea growth and yield parameters across P levels for 2015/16 trial

Variety	50% flowering	90% Maturity	Plant height (cm)	Root weight (g)	Number of pods	Pod length (cm)	Biomass (kg/ha)	Grain yield (kg/ha)
TVu13464	60.83^a	109.45^a	40.06^a	3.80^a	17.06^a	11.08^a	1650^a	1248.6^a
PAN311	52.64^b	96.88^b	65.20^b	5.34^b	11.83^b	15.89^b	2445^a	2066.7^b
P Value	0.0029**	<0.0001***	<0.0001***	0.0079*	0.0507*	<0.0001***	ns	0.0001
LSD $_{(0.05)}$	1.68	2.25	5.00	2.09	12.83	3.08	-	1641.5

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥0.05, *= significant at P≤0.05, **= High significant at P≤0.001, ***= Highly significant at P≤0.0001

Table 33: Effect of cropping system on cowpea growth and yield parameters across varieties for 2015/16 trial

Cropping system	50% flowering	90% Maturity	Plant height (cm)	Root weight (g)	Root length (cm)	Number of pods	Pod length (cm)	Biomass (g)	Grain yield (kg/ha)
Monocrop	60.28^a	103.44^a	53.46^a	4.34^a	18.20^a	14.98^a	13.80^a	144.82^a	1418.7^a
Intercrop	60.16^a	102.62^a	52.29^a	4.85^a	18.93^a	14.00^a	13.27^a	154.25^a	1759.7^b
P Value	ns	ns	ns	ns	ns	ns	ns	ns	0.0059*
LSD $_{(0.05)}$	-	-	-	-	-	-	-	-	243.69

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥ 0.05, *= significant at P≤0.05

4.2.2 Maize performance

4.2.2.1 Number of days to flowering

Phosphorus application significantly ($P<0.05$) influenced number of days to 50% tasseling of PAN6479 (Table 34). Increasing P application reduced the number of days to tasseling (Table 39). The reason for early tasseling with higher P application levels might be due to better root development resulting in more P exploration for rapid plant growth and development. The findings are in line of those of Amanullah (2015) who reported early tasseling with high level of P. Cropping system did not show any significant difference on number of days to tasseling and silking of maize (Table 40). There was no significant difference on the interaction of phosphorus*cropping system.

Table 34: Analysis of variance for number of days to 50% maize tasseling for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	72.5416667	36.2708333	1.46	0.2473
P	3	913.7291667	304.5763889	12.26	<.0001
P*Rep	6	66.9583333	11.1597222	0.45	0.8401
Cropping system	1	20.0208333	20.0208333	0.81	0.3760
Cropping system*P	3	119.7291667	39.9097222	1.61	0.2072

4.2.2.2 Plant height

PAN6479 variety was significantly ($P<0.05$) influenced by the application of P with taller plants (178.70 cm) recorded at 45 kg P/ha as compared to shorter plants of 125.64 cm at 0 kg P/ha (Table 39). This could be the result of efficiently utilisation of P in growth of the crop (Mullins, 2009). Masood *et al*. (2011) reported similar results where various P application rates increased maize plant height. The study of Ram *et al*. (2016), revealed that various P application levels showed significant effect on maize plant height. Increase in plant height due to P application as attributed to better root growth and nutrient uptake (Hussein *et al*., 2014). There was no significant difference on maize plant height due to cropping system nor interaction of P*cropping system (Table 40).

Table 35: Analysis of variance for maize plant height for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	2186.60528	1093.30264	4.37	0.0210
P	3	20222.70352	6740.90117	26.96	<.0001
P*Rep	6	4256.32662	709.38777	2.84	0.0250
Cropping system	1	176.14172	176.14172	0.70	0.4076
Cropping system*P	3	350.04542	116.68181	0.47	0.7076

4.2.2.3 Root weight

Phosphorus application had significant ($P<0.05$) effect on the root mass of maize variety (Table 36). Application levels of 30 kg P/ha (116.83 g) and 45 kg P/ha (145.83 g) produced plants with vigorous root growth (Table 39). This could be attributed to the fact that P application increases root growth and the potential of root hydraulic conductance. Furthermore, phosphorus fertilisation improves the root growth which has a great effect on the overall plant growth performance (Masood *et al*., 2011). According to Gyaneshwar *et al*. (2002), adequate P is required by crops in root tips where there is high metabolism and rapid cell division. Ram *et al*. (2016) reported that increase in application of P enhanced root elongation and in turn increases root weight. Cropping system did not show any significant difference in maize root mass (Table 36).

Table 36: Analysis of variance for maize root weight for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	16066.66667	8033.33333	2.87	0.0713
P	3	35530.72917	11843.57639	4.23	0.0125
P*Rep	6	8358.33333	1393.05556	0.50	0.8052
Cropping system	1	9213.02083	9213.02083	3.29	0.0790
Cropping system*P	3	12047.39583	4015.79861	1.44	0.2508

4.2.2.4 Number of cobs per plant

There was significant (P<0.0001) difference on the number of cobs per plant due to P application (Table 37). Maize plants applied with 45 kg P/ha produced many cobs (3) than 0 kg P/ha which produced an average of 2 cobs per plant (Table 39). This might probably be due to the fact that optimum availability of P has been associated with increased rapid growth and development, thus those plots which received optimum P produced more cobs per plant as compared to no or low P plots. These findings are in line with the study of Masood *et al*. (2011) who reported significant difference on the number of cobs per plant when testing different levels of phosphorus on the yield components of maize. Contrary to these findings, Rana and Chauhan (2003) reported that different phosphorus levels did not significantly affect the number of cobs per plant. They attributed this to the reason that the number of cobs per plant is basically an inherent capability of a crop per plant and is influenced by crop nutrition. Cropping system nor interactions had no significant difference on the number of cobs per plant (Table 37).

Table 37: Analysis of variance for the number of maize cobs for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	2.04166667	1.02083333	5.60	0.0082
P	3	13.41666667	4.47222222	24.53	<.0001
P*Rep	6	2.45833333	0.40972222	2.25	0.0637
Cropping system	1	0.00000000	0.00000000	0.00	1.0000
Cropping system*P	3	0.16666667	0.05555556	0.30	0.8217

4.2.2.5 Biomass

Maize biomass differed significantly (P<0.0001) among P application levels (Table 38). Increasing P application increased maize biomass (Table 39). Higher biomass (5316.16 kg/ha) was recorded from plots applied with 45 kg P/ha. The increase in biomass might be attributed to better growth and development of the plants which was associated with increased root growth due to which the plants explore more soil nutrients and moisture throughout the growing period. These results are in line agreement with Amanullah (2015) who stated that application of P fertiliser significantly increased maize biomass. There was no significant difference in maize biomass due to cropping system (Table 40).

Table 38: Analysis of variance for maize biomass for 2015/16 trial

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	4.24666667	2.12333333	2.47	0.1008
P	3	30.34062500	10.11354167	11.75	<.0001
P*Rep	6	4.92500000	0.82083333	0.95	0.4714
Cropping system	1	0.54187500	0.54187500	0.63	0.4333
Cropping system*P	3	0.07729167	0.02576389	0.03	0.9929

Table 39: Effect of phosphorus application on growth and yield components of PAN6479 maize variety for 2015/16 trial

Phosphorus level (kg/ha)	Days to first tassel	Days to 50% tassel	Days to silking	Plant height (cm)	Root weight (g)	Number of cobs	Biomass (kg/ha)
0	85.08^{a}	95.91^{a}	98.75^{a}	125.64^{a}	83.75^{a}	1.58^{a}	2333.33^{a}
15	86.08^{a}	94.83^{a}	96.25^{a}	138.44^{a}	78.33^{b}	1.50^{a}	2316.67^{a}
30	80.83^{b}	88.83^{b}	91.33^{b}	161.83^{b}	116.67^{c}	1.91^{a}	4516.52^{b}
45	77.33^{c}	85.50^{b}	85.58^{c}	178.70^{c}	145.83^{d}	2.83^{b}	5316.25^{b}
P Value	0.0001***	<0.0001***	<0.0001***	<0.0001***	0.012*5	0.0001***	0.0001***
LSD $_{(0.05)}$	6.36	3.33	3.64	26.60	37.28	0.63	0.90

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥0.05, *= significant at P≤0.05, ***= Highly significant at P≤0.0001

Table 40: Effect of cropping system on growth and yield parameters of PAN6479 maize variety for 2015/16 trial

Cropping system	Days to first tassel	Days to 50% tassel	Days to silking	Plant height (cm)	Root weight (g)	Number of cobs	Biomass (kg/ha)
Monocrop	81.58^{a}	90.50^{a}	92.29^{a}	153.06^{a}	120.0^{a}	1.95^{a}	3800^{a}
Intercrop	83.08^{a}	91.79^{a}	93.66^{a}	149.23^{a}	92.29^{a}	1.75^{a}	3450^{a}
P Value	ns	ns	ns	ns	ns	ns	ns
LSD $_{(0.05)}$	-	-	-	-	-	-	-

Means in the same column followed by the same letter are not significantly different at P≤ 0.05. LSD= Least significant difference, ns= non-significant at P≥0.05, *= significant at P≤0.05

CHAPTER 5: GENERAL DISCUSSION

5.1 Growing conditions during 2014/15 and 2015/16 seasons

Frost occurred in both seasons, however, more severe frost damage occurred during the second season where it damaged maize plants during cobbing stage. During February and March of the first growing season, temperatures were high with little rainfall of 24.13 and 14.47 mm respectively. However, during the same months in second growing season, temperatures were high with higher rainfall of 57.13 and 126.73 mm. Around April of second growing season, rainfall started decreasing with decreasing temperatures where the maize crop was in its sensitive growth stages. These impacted negatively on grain filling and consequently grain yield. There is a need to adjust planting dates of maize in Limpopo Province particularly in frost sensitive areas.

The soil pH (H_2O) ranged from 7.80 to 8.00 whereas pH (KCl) ranged from 6.53 to 6.71 in both seasons. The pH (H_2O) range is not within the range for normal cowpea or maize growth, however, pH (KCl) range is normal for crop growth. Soil results from laboratory indicated that P level in both seasons ranged from 23 to 26 ppm (Table 1). According to Marx *et al*. (1999), soil P ranging between 20 to 40 ppm is regarded as medium. The relatively high soil P and pH may therefore reduce the responses to P for this study.

5.2 Performance of cowpea

5.2.1 Effect of phosphorus levels on cowpea performance

Phosphorus application showed a significant effect on number of days to flowering during the first season except in the second growing season. Ayodele and Oso (2014), found that P application on cowpea increased the number of flowers Mawo *et al*. as compared to the plots with low or no P application (2016) reported that varieties in pots with high P application flowered earlier than pots with no application of P. This could be attributed to the fact that P is an important nutrient element in flower setting and grain formation (Mullins, 2009).

Ninety percent physiological maturity was significantly influenced by P application in both seasons. Increasing P application (30-45 kg/ha) hastened physiological maturity of cowpea varieties. This could be attributed to the fact that increasing P application on crops influences early growth and development (Mullins, 2009). Varieties matured earlier in the first growing season compared to the second season. This could be the result of little amount of rainfall received in the first season, but in the second season, there was a peak of rainfall in March (126.73 mm) which could have delayed maturity due to resumption of vegetative growth and new flushes. Peksen (2007) reported that pod filling stages is one of the most sensitive crop growth stages and could be affected by environmental factors.

Phosphorus significantly influenced the plant height of cowpea in both seasons. Taller plants were recorded from plots applied with low P levels (0-15 kg/ha) whereas shorter plants were recorded at high P rates (30-45 kg/ha). The results are in line with the study of Turuko and Mohammed (2014) who found out that high P rates resulted in shorter plants. This could be attributed to the formation of nutrient interaction when P fertiliser is applied in high dose and this negatively affects other nutrient availability important for growth of the legumes.

Cowpea root weight was significantly higher at 30 and 45 kg P/ha in both seasons. Gyaneshwar *et al*. (2002) reported that increasing P application improves root growth and potential of hydraulic conductance. IT82D-889 scored a higher root mass than PAN311 and TVu13464, and this could be due to their differences in genetic constitution (Singh *et al*., 2011). According to Ram *et al.* (2016), increased P application enhances root elongation and in turn increases root weight. This may be due to the fact that P inflow have direct effect in root weight which in turn increases density of root branching, therefore these effects lead to increase P acquisition as well as other nutrients.

Phosphorus application had significant effect on number of pods per plant. Singh *et al*. (2011), found similar results, where P application increased the number of pods per plant, and this was attributed to the fact that P enhances cowpea nodulation which resulted in higher nitrogen fixation and eventually the number of pods per plant. Furthermore, phosphorus plays an important role in translocation of assimilates to the pods being a constituent of protoplasm, which may be responsible for increased length of pods and number of pods per plant. Despite statistically non-significant on the grain yield due to various P applications, in terms of monetary value, P application of 30 and 45 kg/ha could give a smallholder farmer a remarkable money return and therefore improve their livelihoods. This is evident because in case of maize where at P level of 45 kg/ha it gave a yield of 4742 kg/ha and at 0 kg P/ha it gave 2778 kg/ha, there is a yield difference of 1964 kg/ha. PAN311 outperformed other varieties in both seasons, and it could be attributed to the number of pods yielded by this variety. Grain yield of PAN311 was 2491 kg/ha in the first season, whereas in the second season it was 2066.7 kg/ha.

5.2.2 Effect of cropping system on cowpea performance

Cropping system had significant effect on number of days to flowering in the first season. The reduction in number of days to physiological maturity under monocropping system might be attributed to competition effects for natural resources especially soil moisture which when deficient can result in lower metabolic process in plants thus reducing maturity date (Lemlem, 2013). Ssebuliba *et al*. (2014) found that there was no significant difference between sole and intercropped cowpea in terms of required number of days to reach flowering and physiological maturity. There was no significant difference in cowpea plant height due to cropping system. Varieties differed significantly with IT82D-889 being taller than PAN311 and TVu13464. These results are in conformity with the findings of Ssebuliba *et al*. (2014) who reported that IT82D-889 was significantly taller (51.78 cm) than other cowpea varieties. This could be the result of differences in their genetic makeup.

Cropping system significantly increased cowpea root mass with IT82D-889 and TVu13464 varieties exhibiting higher root mass under intercropping system, whereas PAN311 was best under monocropping system. Component crops tend to use natural resources for growth and development better and efficiently in a diversified agroecosystem (Seran and Brintha, 2010). Number of pods per plant were not significantly influenced by the cropping system. Legwaila *et al*. (2012), reported similar results where there was non-significant difference in the number of cowpea pods per plant between sole cowpea and intercropping with wider spacing. Contrary to this, Thobatsi (2009) found that intercropping significantly reduced the number of pods per plant of all the varieties except PAN311.

Cropping system showed a significant effect on grain yield with intercropping being the best over monocropping. This could be attributed to the fact that crops under intercropping system tends to use natural resources more efficiently for growth and development which resulted in increased number of pods, pod length, pod weight and total grain yield. Furthermore, cowpea production in a diversified agro-ecosystem can be a reservoir for the naturally occurring biological control agents. Soil moisture, soil temperature and microclimate are normally higher in intercropping system compared to monocropping system (Seran and Brintha, 2010).

5.3 Performance of maize

5.3.1 Effect of phosphorus levels on maize performance

Phosphorus application did not show any significant difference on the number of days to flowering in the first season, but did in the second season. Mazengia (2011) reported non-significant difference on number of days to tasseling and silking due to P rates. Effect of varieties was significant on maize tasseling and silking. ZM1423 tasseled earlier than WE3127. Maize height was not significantly influenced by the application of P during the first season. The results are in line with the study of Nndwambi (2015) who reported non-significant in maize plant height during both seasons. During the second season, application of P had a significant effect on maize height. WE3127 (207 cm) was significantly taller than ZM1423 (197 cm). This could be due to differences in genetic composition of the varieties (Singh *et al*., 2011).

Phosphorus application significantly improved root growth of maize in both seasons. Higher root weight were recorded from plots applied with P of between 30 and 45 kg/ha. In line with the results, Ragothama (2005) reported that P application increases root growth and the potential of root hydraulic conductance. According to Farooq *et al*. (2009), inadequate soil moisture reduces shoot and root biomass of crops.

Increasing P application levels increased the number of cobs per plant in the second growing season. Significantly high number of cobs were recorded at 45 kg P/ha. Maize biomass was significantly influenced by the application of P. Increase in maize biomass could be attributed to better growth and development of the plants due to balanced and more availability of nutrients which was associated with increased root growth due to which the plants explore more soil nutrients and moisture throughout the growing period. In conformity to the results, Amanullah (2015) reported similar results where the biomass yield was significantly increased with the application of P. Grain yield was significantly influenced by the application of P. The highest yield of 4742 kg/ha was obtained at P application of 45 kg P/ha. This might be implicated to the effect of phosphorus on promoting root mass, and this was evident to this study that increasing P applications increased root mass which tends to explore more nutrients and soil moisture and directly promoting the grain yield.

5.3.2 Effect of cropping system on maize performance

Almost all the maize parameters showed no significant response to cropping system in both seasons. Nndwambi (2015) also reported similar results whereby almost all the parameters on maize did not show any response to cropping system during both seasons except grain yield during 2010/11 season. Ssebuliba *et al.* (2014), reported contrary results where cropping system significantly influenced maize yield in both seasons. The study of Hamd Alla *et al*. (2014) confirms the results of present study where there was no significant difference on most of measured maize parameters due to cropping system except for plant height. Alhaji (2008), found that intercropping maize with cowpea significantly reduced maize plant height. Despite non-significant in almost all parameters, intercropping was better than monocropping and this may be due to competition of associated crops for natural resources. Despite non-significance, high grain yield may be attributed to increasing root mass which resulted in more exploring of natural resources, and also increasing yield components such as cob mass. Generally, intercropping yield was higher compared to monocropping. The measured LER values were >1 which therefore shows greater land use efficiency of strip intercropping compared to monocropping.

CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Cowpea responded well to P application in both seasons. Highest yield were recorded between 30 and 45 kg P/ha. The study showed the importance of P application in improving cowpea yield in cowpea-maize strip intercropping. Cropping system did influence number of growth and yield parameters of cowpea. Cowpea planted in an intercropping system performed better compared to monocropping system. Maize crop was affected by the frost damage in both seasons, but the damage was more severe during the second season because there was an early frost at Syferkuil farm. Maize varieties performed well at 30 and 45 kg P/ha. WE3127 performed better than ZM1423.

Intercropping system performed better than monocropping system. The cowpea-maize strip intercropping system was advantageous compared with growing each crop separately because LER values were greater than one. This showed greater efficiency of land utilisation in intercropping system. Based on obtained grain yields, cowpea performed better than maize due to its shorter duration of growth and maturity. In the first growing season, two promising cowpea varieties (PAN311 and TVu13464) performed well and were selected based on their early maturity, drought tolerance and high yield. After selection, these varieties in the second season performed well though they were bit low in yield compared to the first season and this could be attributed to the low rainfall in the second season.

This implies that these two varieties can be grown under dryland rainfed condition as well as irrigated condition. Smallholder farmers in Limpopo Province can increase their productivity of their intercrop using these varieties under their dryland or rainfed production. Increasing P application (30-45 kg/ha) increased cowpea grain yield. Optimum P levels for cowpea-maize strip intercropping were between 30 and 45 kg/ha. Application of P above 30 kg/ha may not attract corresponding net yield, therefore it is recommended that poor resource farmers could apply P up to this level. Dropping temperatures towards the end of the growing season could suggest early planting of the maize crop or choosing shorter duration cultivars to avoid frost damage. Crop yields could be improved by enhancing nutrient efficiency under soil moisture stressed conditions.

REFERENCES

AGRICULTURAL RESEARCH COUNCIL-GRAIN CROP INSTITUTE (ARC-GCI). 2015. Maize Information Guide. Shereno Printers, South Africa.

AGRISA. 2016. A Raindrop in the drought. Report to the Multi-Stakeholder Task Team on the Drought: AgriSA's status report on current drought crisis. South Africa.

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.

ALTIERI, M.A. 1999. Applying agroecology to enhance the productivity of peasant farming systems in Latin America. *Environment, Development and Sustainability,* 1:197-217.

AMADOR, M.F. and GLIESSMAN, S.R. 1990. An ecological approach to reducing external inputs through the use of intercropping. Springer-Verlag, New York.

AMANULLAH, K.S. 2015. Phenology, Growth and Biomass Yield Response of Maize (Zea mays L.) to Integrated Use of Animal Manures and Phosphorus Application With and Without Phosphate Solubilizing Bacteria. *Journal of Microbial and Biochemical Technology,* 7:439-444.

ANDREWS, D.J. 1967. Intercropping in Low-Resource Agriculture in Africa: Contractor Report Prepared For the Office of Technology Assessment. Springfield, VA.

ASIWE, J.A.N. 2009a. Insect mediated outcrossing and gene flow in cowpea (*Vigna unguiculata* (L.) Walp): Implication for seed production and provision of containment structures for genetically transformed cowpea. *African Journal of Biotechnology*, 8 (2): 226-230.

ASIWE, J.A.N. 2009b. Needs assessment of cowpea production practices, constraints and utilization in South Africa. *African Journal of Biotechnology*, 8 (20): 5383-5388.

AYODELE, O.J. and OSO, A.A. 2014. Cowpea Responses to Phosphorus Fertilizer Application at Ado-Ekiti, South-West Nigeria. *Journal of Applied Science and Agriculture*, 9 (2): 485-489.

BALEMI, T. and NEGISHO, K. 2012. Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production. *Journal of Soil Science and Plant Nutrition*, 12 (3): 547-561.

BEEGLE, D.B. and DURST, P.T. 2002. Agronomy Facts 13: Managing Phosphorus for Crop Production. Pennsylvania State University, USA.

BEETS, W.C. 1990. Raising and Sustaining Productivity of Smallholder Systems in the Tropics: A Handbook of Sustainable Agricultural Development. Agbe Publishing, Alkmaar, Netherlands.

BELANE, A.K., ASIWE, J.A.N. and DAKORA, F.D. 2011. Assessment of N_2 fixation in 32 cowpea (*Vigna unguiculata* L. Walp) genotypes grown in the field at Taung in South Africa, using ^{15}N natural abundance. *African Journal of Biotechnology*, 10 (55): 11450-11458.

DAHMARDEH, M., GHANBARI, A., AYAHSAR, B. and RAMRODI, M. 2010. The role of intercropping maize (*Zea mays L*.) and cowpea (*Vigna unguiculata L*.) on yield and soil chemical properties. *African Journal of Agricultural Research*, 5 (8): 631-636.

DARIUSH, M., AHAD, M. and MEYSAM, O. 2006. Assessing the land equivalent ratio (LER) of two corn (*Zea mays*) varieties intercropping at various nitrogen levels in Karaj, Iran. *Journal of Central European Agriculture*, 7 (2): 359-364.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, (DAFF). 2008. Maize. Directorate of Plant Production. Pretoria, South Africa.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, (DAFF). 2011. Production guidelines for Cowpeas. Directorate Agricultural Information Services. Pretoria, South Africa.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES, (DAFF). 2013. Trends in the Agricultural Sector. Pretoria, South Africa.

DU PLESSIS, J. 2003. Maize Production. Department of Agriculture. Pretoria, South Africa.

DUDENHOEFFER, C.J. 2012. Enhanced Efficiency Phosphorus Application For Corn. MSc Thesis. University of Missouri, USA.

DUGJE, I.Y., EKELEME, F., KAMARA, A.Y., OMOIGUI, L.O., TEGBARU, A., TELI, I.A. and ONYIBE, J.E. 2008. Guide to safe and effective use of pesticides for crop production in Borno State, Nigeria. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

DUGJE, I.Y., OMOIGUI, L.O., EKELEME, F., KAMARA, A.Y. and AIEIGBE, H. 2009. Farmers' Guide to Cowpea Production in West Africa. International Institute of Tropical Agriculture, Ibadan, Nigeria.

EGHBALL, B. and MARANVILLE, J.W. 1993. Root development and nitrogen influx of corn genotypes grown under combined drought and nitrogen stresses. *Agronomy Journal,* 85: 140-152.

FAROOQ, M., WAHID, A., KOBAYASHI, N., FUJITA, D. and BASRA, S.M.A. 2009. Plant drought stress: Effects, mechanisms and management. pp. 153-188. In E. Lichtfouse *et al* (eds.) Sustainable agriculture. Springer, Dordrecht, Netherlands.

FEDERER, W.T. and SCHWAGER, S.J. 1982. On the distribution of land equivalent ratios. Technical Report BU-777-M, Biometrics Unit, Cornell University, Ithaca, USA.

FEED THE FUTURE. 2014. Feed the Future Progress Report: Accelerating Progress to End Hunger, Washington DC.

FERNANDEZ, F.G. and HOEFT, R.G. 2012. Illinois Agronomy Handbook: Managing Soil pH and Crop Nutrients. Illinois University, USA.

FRANCIS, C.A. 1986. Multiple Cropping Systems. MacMillan. New York.

GLIESSMAN, S.R. 1980. Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture. University of California, Santa Cruz California.

GLIESSMAN, S.R. 2000. Agroecology: Ecological Processes in Sustainable Agriculture. CRC Press, Boca Raton, Florida, USA.

GOVEREH, J., JAYNE, T.S., SOKOTELA, S. and LUNGU, O.I. 2003. Raising maize productivity of smallholder farmers in Zambia: What can fertiliser consumption alone do or not do? Working Paper Food Security Research Project. Lusaka, Zambia.

GYANESHWAR, P., NARESH KUMAR, G., PAREKH, L.J. and POOLE, P.S. 2002. Role of soil microorganisms in improving P nutrition of plants. *Journal of Plant and Soil*, 245: 83-93.

HALL, T.D. 1940. Soil fertility in Southern Africa. *Journal of the Royal African Society*, 39 (155): 160-169.

HAMD ALLA, W.A., SHALABY, E.M., DAWOOD, R.A. and ZOHRY A.A. 2014. Effect of Cowpea (*Vigna sinensis* L.) with Maize (*Zea mays* L.) Intercropping on Yield and Its Components. *International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering*, 8 (11): 1263- 1269.

HENRICK, S. and PEETER, P. 1997. Reduction of stem borer damage by intercropping maize with cowpea. *Agriculture, Ecosystem and Environment*, 62:13-19.

HULUGALLE, N.R. and LAL, R. 1986. Soil water balance in intercropped maize and cowpea grown in a typical hydromorphic soil in Western Nigeria. *Agronomy Journal*, 77: 86-90.

HUSSEIN, M.M., AL-ASHRY, S.M. and CAMILIA, Y.E. 2014. Cowpea Growth and Yield Components as Affected by Drought and PK Soil Fertilization. *International Journal of Science and Research*, 3 (12): 2200-2207.

IOWA STATE UNIVERSITY, (ISU). 1999. Strip Intercropping. University Extension, USA.

JIN, J., LAURICELLA, D., ARMSTRONG, R., SALE, P. and TANG, C. 2015. Phosphorus application and elevated CO_2 enhance drought tolerance in field pea grown in a phosphorus-deficient vertisol. *Annals of Botany,* 116 (6): 975-985.

JONES, C.A., JACOBSEN, J.S. and WRAITH, J.M. 2003. The effects of P fertilisation on drought tolerance of malt barley. *Western Nutrient Management Conference*, 5: 88-93.

KUUN, P.J.C., OBERON, P.T., BEZUIDENHOUT, J.D. and CLAASSENS, A.S. 2006. Juta's Agricultural Sciences. Juta Gariep. Cape Town, South Africa.

LAMBERS, H., SHANE, M.W., CRAMER, M.D., PEARSE, S.J. and VENEKLAAS, E.J. 2006. Root structure and functioning for efficient acquisition of phosphorus: matching morphological and physiological traits. *Annals of Botany*, 98: 693-713.

LEGWAILA, G.M., MAROKANE, T.K. and MOJEREMANE, W. 2012. Effects of Intercropping on the Performance of Maize and Cowpeas in Botswana. *International Journal of Agriculture and Forestry*, 2 (6): 307-310.

LEMLEM, A. 2013. The effect of intercropping maize with cowpea and lablab on crop yield. *Herald Journal of Agriculture and Food Science Research*, 2 (5): 156-170.

M'MBOYI, F. AND MUGO, S., MWIMALI, M. and AMBANI, L. 2010. Maize Production and Improvement in Sub-Saharan Africa. African Biotechnology Stakeholders Forum. Nairobi, Kenya.

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

MASOOD, T., GUL, R., MUNSIF, F., JALAL, F., HUSSAIN, Z., NOREEN, N., KHAN, H., and KHAN, H. 2011. Effect of different phosphorus levels on the yield and yield components of maize. *Sarhad Journal of Agriculture*, 27 (2): 167-170.

MASVAYA, E.N., NYAMANGARA, J, DESCHEEMAEKERB, K., and GILLERB, K.E. 2017. Is maize-cowpea intercropping a viable option for smallholder farms in the risky environments of semi-arid southern Africa? *Field Crops Research*, 209: 73-87.

MAWO, Y.M., MOHAMMED, I.B. and GARKO, M.S. 2016. Effect of phosphorus levels on growth, yield and development of cowpea (*Vigna unguiculata* (L.) Walp) varieties. *International Journal of Scientific Engineering and Applied Science*, 2 (5): 302-312.

MAZENGIA, W. 2011. Effects of Methods and Rates of Phosphorus Fertilizer Application and Planting Methods on Yield and Related Traits of Maize (Zea mays L.) on Soil of Hawassa Area. *Innovative Systems Design and Engineering*, 2 (4): 315-335.

MINDE, I., PEDZISA, T. and DIMES, J. 2008. Improving access and utilisation of fertilizers by smallholder farmers in the Limpopo Province of South Africa. Report No.3. ICRISAT. Bulawayo, Zimbabwe.

MPANDELI, N.S., NESAMVUNI, E. and MAPONYA, P. 2015. Adapting to the Impacts of Drought by Smallholder Farmers in Sekhukhune District in Limpopo Province, South Africa. *Journal of Agricultural Science*, 7 (2): 115-124.

MSANGI, J.P. 2014. Food security among small-scale agricultural producers in Southern Africa. Springer International Publishing, Switzerland.

MULLINS, G. 2009. Phosphorus, Agriculture and the Environment. Virginia State University, USA.

NKAA, F.A., NWOKEOCHA, O.W. and IHUOMA, O. 2014. Effect of Phosphorus fertilizer on growth and yield of cowpea (*Vigna unguiculata*). *Journal of Pharmacy and Biological Sciences*, 9 (5): 74-82.

NNDWAMBI, F.H. 2015. Evaluation of dryland maize/pigeonpea intercropping under variable phosphorus application rates. M Agric Thesis. University of Limpopo, South Africa.

NYASASI, B.T. and KISETU, E. 2014. Determination of land productivity under maize-cowpea intercropping system in agro-ecological zone of Mount Uluguru in Morogoro, Tanzania. *Global Science Research Journals*, 2 (2): 147-157.

ODHIAMBO, J.J.O. and NEMADODZI, L.E. 2007. Soil fertility management practices by smallholder farmers in Vhembe district, Limpopo Province. *South African Journal of Agricultural Extension,* 36 (1): 53-61.

OLUSEGUN, O.S. 2015. Nitrogen (N) and Phosphorus (P) Fertilizer Application on Maize (*Zea mays* L.) Growth and Yield at Ado-Ekiti, South-West, Nigeria. *American Journal of Experimental Agriculture*, 6 (1): 22-29.

PARKER, R. 2004. Introduction to Plant Science. Thomson Delmar Learning, USA.

PEKSEN, E. 2007. Yield Performance of Cowpea (*Vigna unguiculata* L. Walp.) Cultivars Under Rainfed and Irrigated Conditions. *International Journal of Agricultural Research*, 2: 391-396.

PIERRE, W.H. and NORMAN, A.G. 1953. Soil and Fertilizer Phosphorus in Crop Nutrition. Agronomy Volume 4. Academic Press Inc., Publishers. New York.

RAGOTHAMA, K.G. 2005. Phosphorus and plant nutrition: An overview. pp. 355-378. In: J.T. Sims and A.N. Sharpley (eds.) Phosphorus: Agriculture and the Environment. Agronomy Monograph No. 46. American Society of Agronomy, Madison, WI.

RAM, K.M., LAL, P.A. and SADIKSHYA, A. 2016. Assessing the effect of phosphorus application on early growth of maize at Sunderbazar, Lamjung, Nepal. *Journal of Maize Research and Development*, 2 (1): 117-122.

RAMARU, J., MAMABOLO, Z. and LEKGORO, J. 2000. Improving soil fertility management in South Africa: Learning through participatory extension approaches. Managing Africa’s Soils No.19. Russell Press, Nottingham, United Kingdom.

RANA, M.I. and CHAUHAN, H.Q.I. 2003. Effect of Phosphorus Levels on Yield Components, Grain Yield and Harvest Index of Two Maize Varieties. *Asian Journal of Plant Sciences*, 2: 800-803.

SERAN, T.C. and BRINTHA, I. 2010. Review on Maize Based Intercropping. *Journal of Agronomy*, 9 (3): 135-145.

SHEAHAN, C.M. 2012. Plant guide for cowpea (*Vigna unguiculata*). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, New Jersey.

SINGH, A., BAOULE, A.L., AHMED, H.G., DIKKO, A.U., ALIYU, U., SOKOTO M.B., ALHASSAN, J., MUSA, M. and HALIRU, B. 2011. Influence of phosphorus on the performance of cowpea (*Vigna unguiculata* (L) Walp.) varieties in the Sudan savanna of Nigeria. *Agricultural Sciences*, 2 (3): 313-317.

SMITH, B. 2006. The Farming Handbook. University of KwaZulu-Natal Press, South Africa.

SOUTH AFRICAN MAIZE TRUST, (SAMT). 2016. Prospectus on the South African Maize Industry. South Africa.

SSEBULIBA, J.M., KAWOOYA, R. BISIKWA, J., DDUNGU, S.P., BIRUMA, M. and OKELLO, D.K. 2014. Influence of intercropping on the performance of elite cowpeas (*Vigna unguiculata* L. (Walp)) varieties and maize (*Zea mays* L.) in Eastern Uganda. *African Journal of Applied Agricultural Sciences and Technologies*, 1 (1): 42-51.

SURYAWANSHI, L., KUSHWAH S.S. and BARCCHIYA, J. 2017. Effect of phosphorus nutrition on growth, yield and quality attributes of cowpea (*Vigna unguiculata* L. walp.). *International Journal of Agriculture Sciences*, 9 (20): 4211-4213.

SYERS, J.K., JOHNSTON, A.E. and CURTIN, D. 2008. Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soil phosphorus behaviour with agronomic information. Food and Agriculture Organization of the United Nations. Rome, Italy.

THOBATSI, T.J. 2009. Growth and yield responses of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) in an intercropping system. MSc Dissertation. University of Pretoria, South Africa.

TURUKO, M. and MOHAMMED, A. 2014. Effect of Different Phosphorus Fertilizer Rates on Growth, Dry Matter Yield and Yield Components of Common Bean (*Phaseolus vulgaris* L.). *World Journal of Agricultural Research*, 2 (3): 88-92.

UARROTA, V.G. 2010. Response of Cowpea (*Vigna unguiculata* L. Walp.) to Water Stress and Phosphorus Fertilization. *Journal of Agronomy*, 9: 87-91.

UMERI, C., MOSERI, H. and ONYEMEKONWU, R.C. 2016. Effects of Nitrogen and Phosphorus on the Growth Performance of Maize (*Zea mays*) in Selected Soils of Delta State, Nigeria. *Advances in Crop Science and Technology,* 4: 207-209.

VAN RENSBERG, B.J. 2015. Drought and disease development in maize. *Farmer's Weekly*. South Africa.

WHITBREAD, A., AYISI, K. and ASIWE, J. 2009. Cowpea: A Grain Legume Crop. South Africa.