RESPONSE OF SELECTED COWPEA LINES TO LOW SOIL PHOSPHORUS AND MOISTURE STRESS CONDITIONS AT UKULIMA FARM IN LIMPOPO PROVINCE

by

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A MINI-DISSERTATION

Submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in

AGRICULTURE (AGRONOMY)

in the

FACULTY OF SCIENCE AND AGRICULTURE

(School of Agricultural and Environmental Sciences)

at the

UNIVERSITY OF LIMPOPO

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2015

DECLARATION

I declare that the mini-dissertation hereby submitted to the University of Limpopo, for the degree of master of science (MSc) in Agriculture (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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Thosago S.S (Mr) Date

DEDICATION

I dedicate this mini-dissertation to my beloved parents (Linah Sehume Mathobela and Jack Mabule Thosago), my grandparents (Matjatji Elecia Mathobela and Godfrey Lekgema Mathobela), my little sister (Precious Tisane Thosago) and my brother (Kenneth Tholo Thosago).

ACKNOWLEDGEMENTS

Firstly, I thank God, the Almighty, for making everything possible for me through His power, mercy and love.

I would like to acknowledge my supervisors Profs I.K Mariga and F.R Kutu for their guidance, encouragement, patience and their support throughout my study. My sincere appreciations to Prof Jimmy Santiago Burridge, Johan Prinsloo and Larry Matthews York from Pennsylavia State College, USA for assistance during establishment of the field trial and root images analyses. Also, my thanks to my colleagues, Mr Fhatuwani Nndwambi, Moswatsi Mabore Sele, Rodney, Tsitso Mokoena, Vincent and other co-workers at Ukulima Farm for assistance with data collection and Ms RL Molatudi for her assistance with corrections and finalising of the dissertation.

I thank my immediate and extended family members and grandparents Lihan Sehume Mathobela, Jack Mabule Thosago, Elecia Matjatji Mathobela Godfrey Lekgema Mathobela, Kenneth Tholo Thosago and Tisane Precious Thosago for their support and encouragement during the study. Furthermore, I am particularly grateful to the Agricultural Sector Education Training authority (AGRISETA) and Prof T.P Mafeo for helping me with financial assistance during the study periods.

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ABSTRACT

Cowpea (*Vigna unguiculata L.* Walp) is an important grain legume grown in many parts of the world mostly by smallholder (SH) farmers. Low soil phosphorus (P) and drought stress are major constraints to legume production and threaten food security. Root architecture is a spatial configuration of the root system which is influenced by moisture status and P uptake. A field experiment was conducted at Ukulima farm near Modimolle in Waterberg district during 2012/13 summer growing season. The treatments comprised of two levels each for soil P (low and high) and moisture status (water stress and well-watered); and eight cowpea genotypes (Tvu 4632, Tvu 6365, Tvu 9848, Tvu 15445, Tvu 16408, Tvu 15143, Oloyin and IT00K-1217). The low P level implied the available P in the soil measured *in situ*, which was less than 8 mg kg^{-1} while the high P level entailed fertilization at the rate of 40 kg P ha^{-1} application to achieve approximately 35 mg P kg^{-1} of soil . The root traits measured included angle of adventitious and basal roots, number of basal roots, tap root diameters at 5, 10, 15 and 20 cm soil depths; lateral branching densities at depth 5,10 and 15 cm, nodule score, deep score, shallowness score, 3rd order branching density, and 1.5 branching densities at 5 and 10 cm depth. Plant parameters measured were plant height, number of pods per plant, number of seeds per pod, length of the pods, unshelled weight, shelled weight and number of primary and secondary branches. Photosynthetic parameters measured were photosynthetic rate, intercellular CO_2 concentration, water conductance, transpiration rate, vapour pressure deficits, sample cell CO_2, sample cell H_2O and relative humidity in the cell. All treatment factors were combined as split-split plot arrangement fitted into randomized complete block design; with four replicates.

Results indicate that the lateral root branching density at 5 and 10 cm differed significantly ($P \leq 0.05$) across cowpea genotypes. Genotype showed significant effect on taproot diameter at 10 cm. Moisture status and P level exerted significant effect on cowpea genotypes 15 cm. There were significant differences ($P \leq 0.05$) for lateral root branching density observed at 5 and 10 cm depth in P rates x genotype interaction. Statistical analysis showed that P levels and cowpea genotypes had significant effects ($P \leq 0.05$) on mean plant height, biomass and highly significantly effects ($P \leq 0.01$) on

number of branches, days to physiological maturity and mean pod length. The interaction between cowpea genotype and moisture stress condition significantly ($P \leq 0.05$) affected hundred (100) seed weight. Cowpea genotype Tvu16408 obtained highest grain yield of 3240 kg ha^{-1} and lowest was by IT00K1217 which obtained grain yield of 1256 kg ha^{-1}.

Results showed that photosynthetic rate, water conductance, transpiration rate, sample cell CO_2, sample cell H_2O, relative humidity in the cell, intercellular CO_2 and vapour pressure deficit differed significantly ($P \leq 0.05$) across cowpea genotypes. Soil moisture condition and cowpea genotype exerted significant ($P \leq 0.01$) effect on photosynthetic rate, water conductance, transpiration rate, sample cell CO_2, sample cell H_2O and relative humidity in the cell. Variation in P levels had no significant effect on the measured photosynthetic parameters. Oloyin genotype had the highest photosynthetic rate followed by Tvu 4632 while cowpea genotype Tvu 9848 had the least photosynthetic rate. Interaction of moisture stress and cowpea genotype had a significant effect on intercellular CO_2 concentration. Water stress reduced the intercellular CO_2 concentration of Oloyin, Tvu 6365 and 4632 but resulted in a significant increase in intercellular CO_2 concentration in Tvu 9848 genotype.

Results showed that variation in soil P level exerted a significant ($P \leq 0.05$) effect on grain tissue P content and uptake, and a highly significant ($P \leq 0.01$) difference in P content across the various cowpea genotypes. Moisture stress exerted a significant ($P \leq 0.05$) difference on P uptake. The results showed that P levels and cowpea genotype variation exerted significant ($P \leq 0.05$) effects on P content, P uptake and nitrogen (N) uptake. Moisture status and cowpea genotype variation exerted significant ($P \leq 0.05$) effects on total N and N uptake. Cowpea genotype Tvu 9848 obtained more total N content (4.37%), while the lowest total N content was obtained by cowpea genotype Tvu 15445 with 3035 mg kg^{-1}. The interaction between cowpea genotype and moisture status exerted a significant ($P \leq 0.05$) effect on N and P uptake of immature green pods harvested. There is a need to conduct more studies to identify cowpea genotypes, their root architecture and agronomic measures that can do well under drought stress and low soil P conditions. Research needs to be conducted to enhance cowpea productivity under both low soil P and drought stress.

Keywords: cowpea genotypes; moisture stress; phosphorus fertilisation; root traits

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background information of the study

Cowpea (*Vigna unguiculata* L. Walp) is an indigenous African leguminous crop that is widely cultivated in semi-arid tropical regions (Singh *et al.,* 2002). Drought stress is a major constraint within these regions due to low rainfall conditions. Cowpea is one of the most important grain legumes grown by farmers especially in smallholder (SH) farmers' communities. It is considered as the most economically important traditional legume crop in Africa (Langyintuo *et al.,* 2003). Due to its taproot and lateral spreading in the soil, the crop is well adapted to harsh environmental conditions such as low soil fertility and can withstand high temperatures and drought conditions (Turk *et al.,* 1980). Its leaves and grains are consumed and even sold to generate income. Furthermore, tender cowpea leaves, green pods and green seeds are consumed as vegetables. Cowpea is reported to contain high levels of lysine and tryptophan (Santos, 2000) while the plant is reported to fix 80% of its N needs (Asiwe *et al.,* 2009) thereby reducing N fertiliser demand and cost for growing the crop.

Phosphorus (P) is an essential nutrient for the general health and vigour of all plants based on its contribution to the biomass as a macronutrient (Goldstein *et al.,* 1988). Legumes have high P requirement to stimulate root development and plant growth, initiate nodule formation as well as promote the efficiency of the rhizobium-legume symbiosis (Aquilar and Van Diest, 1981). However, it is one of the least available and least mobile mineral nutrients to plants in many cropping environments. Low availability of P is a major constraint in developing countries such as Africa where most farmers rarely buy or use inorganic fertilisers. Low soil P is caused by continuous cultivation and nutrient depletion (Magani and Kuchinda, 2009).

The P use efficiency (PUE) of crops differs; and it is categorized into P acquisition efficiency (PAE) and P utilization efficiency (PUE) (Atkinson, 1991). PAE refers to mobilization of P from poorly soluble sources or to take up the soluble P available in the soil solution while PUE is the ability to produce biomass or yield efficiently using the limited acquired P (Bayuelo-Jimenez *et al.,* 2013). Numerous studies have revealed that increase in PAE is associated with root morphology and root architecture while PUE is associated with the efficient use of P in the plant (Ramaekers *et al*., 2010; Bayuelo-Jimenez *et al.,* 2013). Roots play an important role in plants not only for support and anchor but also moisture and for nutrient uptake from the soil. Root morphology and root architecture are both affected by drought stress condition in the field. Tolerance to drought stress and efficiency of P extraction are often associated with root morphology. Deep lateral roots extract moisture efficiently while shallower lateral roots tend to be more efficient in P extraction.

Drought is a major environmental stress that causes reduction in yield and low crop productivity in most of the crops globally. Furthermore, it also affects N fixation in legumes. Drought stress also limits plant productivity and inhibits growth and photosynthesis (Taiz and Zieger, 1998). Crops have several mechanisms to survive or cope during drought stress and their mechanisms are namely drought avoidance, drought escape and drought tolerance (Mitra, 2001). Transpiration rate and water potential in the crop are reduced during water stress.

1.2 Problem statement

Most farmers in Africa do not have access to P fertilisers because inorganic P fertilisers are often expensive. The problem of low soil P availability is a major constraint to cowpea production on most farmlands. Though cowpea has been reported to be drought tolerant (Abayomi and Abidoye, 2009), it is highly sensitive to drought stress condition, particularly during flowering stage (Zimmermann *et al*., 1988; Lobato *et al.,* 2008), which consequently exerts a depressive effect on its grain yield. Cowpea is an essential crop in areas where drought stress is the major problem for its production (Santos, 2000). Biotic stress (insects and diseases) and abiotic stress (low soil fertility and drought stress) cause the yield of cowpea to be very low. Cowpea genotypes respond differently towards drought stress conditions (Hall *et al.,* 2003). Thus, there is a need to identify and select cowpea lines that produce high yields and have high P-use efficiency under low soil P and water-stress field conditions typical of the Limpopo

Province. Such identified lines could therefore serve as sources of breeding materials for greater adaptation to the variable production conditions in farmers' fields.

1.3 Motivation of the study

Cowpea is a hardy and multi-functional crop that provides nourishment for humans and livestock; and also serves as a valuable and dependable revenue-generating commodity for farmers and grain traders (Langyintuo *et al*., 2003). Good agronomic practices are required to guarantee high yield and production level. Improvement of crop produce will help to mitigate hunger, food scarcity, poor nutrition, low soil fertility and consequently poverty in the SH farming sector. As part of the drive to promote climate smart agricultural practices in response to climate change, global warming and food insecurity challenges, the development of high-yielding crops, such as cowpea genotypes that are tolerant to drought and nutrient stress conditions, represents a key strategy.

1.4 Aim

The aim of this study was to assess the response of eight selected cowpea lines to low soil P and moisture stress conditions so as to identify the source materials for breeding and adaptation to the diverse agricultural conditions of South Africa.

1 .4.1 Objectives

The objectives of this study included among others, determination of:

i. Growth, grain yield and root characteristics (volume, weight, distribution and morphology) of cowpea under low soil P level

ii. Growth, grain yield and root characteristics of cowpea lines under low moisture stress

iii. Varietal differences in root characteristics (root architecture, volume, weight, distribution and morphology), growth and grain yield

iv. Interaction effect of P level x moisture stress on cowpea growth, grain yield and root morphology

v. Interaction effect of P level x variety on cowpea growth, grain yield and root morphology

vi. Interaction effect of variety x moisture stress on cowpea growth, grain yield and root morphology

1.4.2 Hypotheses

i. The soil P level of the field does not affect cowpea growth, yield and root characteristics.

ii. The moisture status of the field does not affect cowpea growth, yield and root characteristics.

iii. Varietal characteristics of the different cowpea lines do not influence growth, yield and root morphology.

iv. There is no interaction effect of P level X Moisture status on cowpea growth, yield and root morphology.

v. There is no interaction effect of P level X Variety on cowpea growth, yield and root morphology.

vi. There is no interaction effect of Variety X Moisture status on cowpea growth, yield and root morphology.

vii. There is no interaction effect of Soil P X Moisture status X Variety on cowpea growth, grain yield and root morphology

CHAPTER 2

LITERATURE REVIEW

2.1 Origin of cowpea

Cowpea is one of the earliest food sources for humans and it has been used as a crop during Neolithic times (DAFF, 2011). The name probably originated from the fact that the crop is used as an important source of hay in other parts of the world (Timko *et al.,* 2007). Ng and Marechal (1985) reported that the crop originated and was domesticated in Africa. According to Singh *et al.* (1997), the centre of origin of *Vigna unguiculata* is established as northern region of South Africa due to the availability of the most primitive wild varieties. Cowpea seed originated from Africa but the place the crop was first domesticated is still undeterminate (Kitch *et al*., 1998).

2.2 Botany and characterization of cowpea

Cowpea is a herbaceous short term, annual leguminous plant which is grown in many tropical and subtropical countries (Singh and Sharma, 1996); and is also a summer legume crop which has trifoliate leaves. The crop is characterised by a very strong taproot and more lateral branching roots spreading in top soil layer as compared to other legume crops such as soybean (*Glycine max Merr),* common bean (*Phaseolus vulgaris L.*) and chickpea (*Cicer arietinum L.*). Furthermore, the categorization of the crop includes number of pod per plant, number of days to reach flowering and pod formation (Cobbinah *et al.,* 2011). It has different names such as Southern pea, black eye pea, Crowder pea, *lubia*, *niebie*, cowpea or frijole (Davis *et al.,* 1991) and *dinawa* in Sepedi. According to Singh *et al*. (1997), cowpea is a dicotyledonous plant classified in the family *Fabaceae,* subfamily *Faboideae,* tribe *Phaseolinae,* order *Fabales* and genus *Vigna*. The growth habit varies among different genotypes; it may be erect, semi- erect, trailing, climbing or bushy. The crop is more tolerant to low soil fertility due to its high rates of N fixation (Elawad and Hall, 1987), effective symbiosis with mycorrhizae (Kwapata and Hall, 1985); and has the ability to grow better and tolerates soils over a wide range of pH when compared with other grain legumes (Fery, 1990). It requires well-drained sandy loam or sandy soil where the soil pH ranges from 5.5 to 6.5 (Davis *et al.*, 1991).

2.3 Economic importance and nutrient composition of cowpea plant parts

Cowpea is a major staple food in most developing African countries particularly, in rural areas. Most SH farmers use the crop as a vegetable crop at all stages of its growth. Mostly, farmers harvest leaves and seeds for human consumption. In many parts of Africa, cowpea is used as vegetable where removing young leaves is a common practice among farmers (Barrett *et al.,* 1997). As a leguminous crop, it is used in cropping systems to improve soil fertility by not only helping to fix atmospheric N into the soil but also providing biomass as plant residues and ground cover to suppress weeds and reduce soil erosion. Medicinally, the leaves can be chewed and applied on burns and to also treat headache; with the root paste also used as an antidote for snake bites (van Wyk and Gericke, 2000). Similarly, cowpea seeds are used to treat several diseases such as bilharzias, liver complaints and amenorrhoea (van Wyk and Gericke 2000). Cowpea seed contains 20-24% protein, 63.3% carbohydrates and 1.9% fat (Davis, 1991); and thus serves as a valuable plant-protein source where people cannot afford to buy meat. According to Philips *et al*. (2003), cowpea is also considered a significant component of diets in developing countries of Africa, Latin America and Asia where it is used as a dietary protein to complement cereals. The leaves of cowpea contain carbohydrate whose concentration is higher in older leaves with the protein content in such older leaves comparable to that in seeds (Bubenheim *et al.,* 1990). According to Sebetha *et al*. (2010) cowpea leaf protein ranges from 24.1 to 28.1% and 26.0 to 30.7 for Red caloona and Pan 311, respectively. Cowpea provides nutritious fodder for livestock while the grain and haulms are sources of valuable protein for the humans and livestock, respectively.

2.4 Cowpea production in South Africa

In South Africa, 7000 tons of cowpea was produced from 13,500 ha during the year 2003 (FAOSTAT, 2004). Major cowpea producing areas in South Africa include all the districts in Limpopo Province; the Gertsibande, Nkangala and Ehlanzeni districts in

Mpumalanga; the Central, Dophirim and Southern parts of North West Province; and Umgungundlovu in Kwazulu Natal (NDA, 2009). The crop is mainly produced by many small-scale farmers in rural areas under dryland farming conditions mainly through intercropping with cereals such as sorghum and maize. According to FAOSTAT (2013), South Africa produced 5674 tons of cowpea in the 2011 and 2012 growing seasons. Nigeria is still the largest cowpea producer accounting for 2.3 million metric tons. Most SH farmers in South Africa grow spreading types of cowpeas, mainly for consumption of the leaf as a vegetable. Cultivation of grain type cowpeas is not common.

2.5 Potential contribution of cowpea towards food security in Africa

Tshuma (2012), citing FAO (2002), regarded food security at individual, household, national, regional and global levels as being achieved when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Increasing the growing of indigenous crops such as cowpea would be important and may contribute towards global food security. The evolvement of new improved cultivars that are more tolerant to drought may be an important solution in the world (Rogerio, 2003); and this can help mitigate poverty in many poor rural communities. This is so because most SH farmers in developing countries are resource-poor and they rely solely on their crops as source of food and income.

The Department of Agriculture, Forestry & Fisheries (DAFF, 2011), citing FAOSTAT (2004), reported that agriculture plays an important role to food security in many parts of the world. Food insecurity in many parts of world is caused by many factors such as low income rate, lack of food and loss of employment. Increased cultivation of grain legumes such as cowpea and other indigenous and traditional crops could contribute towards food security, poverty alleviation, job creation opportunities, increasing farm income and wages in Africa. Numerous studies have shown that indigenous and traditional foods, including cowpea, play a major role in maintaining food security at household level in developing countries such as South Africa (Matenge *et al*., 2012; Vorster *et al*., 2008). Cowpea, as a multi-purpose leguminous crop, can be used to improve soil fertility thereby reducing the cost of fertilizer. Also, it is an important source of vegetables and grains that are rich in vitamin and protein as well as high quality fodder for livestock in poverty stricken communities.

2.6 Major cowpea production constraints

2.6.1 Biotic stress - pathogens

Cowpea is highly vulnerable to a wide variety of pathogens that attack it. These include insects, bacteria, viruses and fungi (Hapton *et al.,* 1997). In cowpea, fungal diseases include stem and root rots and leaf spots, while mosaic disease and mottle symptoms are often caused by viruses that attack cowpea (IITA, 2004). Cowpea production is limited by pathogens and environmental conditions which cause a serious yield loss. Under poor storage and unfavourable conditions such as high humidity and temperature, deterioration of the seed occurs resulting in the occurrence of some fungal pathogens that may produce toxic secondary metabolites called mycotoxins (Richard *et al*., 2009). Insect damage is one of the major constraints in cowpea grain production. The breeding of insect-resistant cowpeas would have significant impact on food availability globally (Timko *et al.,* 2007). Cowpea is attacked by major pests such as flower thrips (M*egalurothrips sjostedti*), pod borer (M*aruca virata*), and pod sucking bugs (Kafua, 2010). Stored grain is attacked by bruchids.

2.6.2 Abiotic stress

The most important abiotic stress is drought stress which is a limiting factor for cowpea production (Hall, 2004) and threatening food security globally. According to Ashley (1993), drought tolerance is the ability of a plant to live, grow and yield satisfactorily with a limited soil water supply or under periodic water deficiencies. Turk and Hall (1980) reported that cowpea is highly sensitive to water stress during the flowering and pod-filling stages. During drought stress conditions, the leaflets of the crop change the position and become paraheliotropic and oriented parallel to the sun’s rays (Schakel and Hall, 1979). Several authors have studied the mechanisms that plants use to cope with drought stress. These mechanisms are divided into three categories, namely drought escape, drought avoidance and drought tolerance (Agbicodo *et al.,* 2009, Mitra, 2001). Furthermore, during drought stress crops use one mechanism at a time to cope with drought conditions (Agbicodo *et al*., 2009).

Cowpea uses various mechanisms to survive under drought conditions (Hall *et al.*, 1997). The drought stress mechanisms are important for improving crop production including that of grain legumes. Drought escape is the ability of a plant to complete its life cycle before serious soil and plant water deficits occur (Agbicodo *et al.,* 2009, Mitra, 2001). It involves rapid phenological development, developmental plasticity and remobilization of pre-anthesis photo-assimilates. Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture. Plants develop strategies for maintaining turgor pressure by increasing root characteristics (density, depth and length) for efficient root system to maximize water uptake, and by reducing water loss through reduced epidermal conductance, decrease absorption of radiation, by leaf rolling or folding and reduced leaf area are mechanisms regulating water use and decreasing injury (Agbicodo *et al.,* 2009, Mitra, 2001). Drought tolerance is the ability of plants to withstand water-deficit with low tissue water potential (Agbicodo *et al.,* 2009, Mitra, 2001). Plants that use the tolerance mechanism maintain turgor through osmotic adjustment, increased cell elasticity, decreased cell volume and resistance to desiccation through protoplasmic resistance (Agbicodo *et al.,* 2009, Mitra, 2001).

2.6.3 Effect of morphological, physiological and biochemical traits on crop production

Crops have morphological, physiological and biochemical traits that play important roles in plant growth and production and are crucial in breeding programs. Better understanding of these mechanisms could be used to select or develop varieties that will adapt to various stress conditions, such as the problems of low soil P and drought stress, arising from global warming and climate change (Lobell *et al*., 2008).

2.6.3.1 Morphological responses of crops to drought stress

Morphological traits may contribute to drought adaptation through the delayed leaf senescence (DLS) attribute (Gwathmey *et al*., 1992). DLS trait helps to improve plant survival after mid-season drought damage. A typical example is the first flush of pods that enable a substantial second flush to be produced, which allows the crop to stay alive through mid-season drought and recover when rainfall resumes (Agbicobo *et al.,* 2009). The DLS trait appears to be conferred by a single gene and may involve resistance to premature death caused by *Fasarium solani* (Ismail *et al.,* 2000). Drought stress causes a decrease in number of leaves per plant and reduced leaf size of the crop. Mitra (2001), as cited by Agbicobo *et al*. (2009), reported that plants develop strategies for maintaining turgor by increasing root depth or developing an efficient root system to maximize water uptake, and by reducing water loss through reduced epidermal (stomatal and lenticular) conductance, reduced absorption of radiation by leaf rolling or folding and reduced evapo-transpiration surface (leaf area).

2.6.3.2 Physiological responses of crops to drought stress

Water-use efficiency (WUE) is an important physiological trait in legumes. It is a complex and single trait that is important for the improvement for drought tolerance in crops (Zhou *et al.,* 2011). It is defined as the efficiency of the crop to use water in producing dry matter and harvest index (Siddique *et al.,* 2001), which varies among crop species. It is affected by various soil factors such as soil structure and depth as well as root distribution (Yada, 2011). Drought stress decreases WUE, leaf production and root proliferation; and consequently crop productivity (Farooq *et al.,* 2009). It is therefore, important to identify or develop new genotypes of cowpea that are sufficiently drought tolerant and possess better WUE so as to provide solutions to the multiple challenges of global and household food insecurity. When crops experience drought stress, physiological mechanisms such as stomatal closure, reduced transpiration and reduced photosynthetic rate take place as responses to insufficient water availability (Costa and Lobato, 2011).

2.6.3.3 Biochemical response to drought stress

Global warming and climatic change cause drought stress that affects growth and productivity of crops by lowering tissue water status and turgor (Hussain *et al.,* 2009). Osmotic adjustment is considered by accumulation of organic and inorganic solutes used to maintain the cell turgor (Kuznetsov and Shevyakova, 1997). Plants develop osmotic adjustment, which is an important mechanism developed by plant to tolerate drought stress (Costa, 1999), is responsible for protection of plant cell membrane (Martinez-Ballesta *et al*., 2004). Osmotic adjustment plays an important role in adaptation of crops at cellular level to reduce the drought induced damage in crops (Blum, 2005). It maintains leaf turgor and improves stomatal conductance for efficient intake of CO_2 (Kiani *et al*., 2007). It also stimulates root for more water uptake ability (Chimenti *et al*., 2006). Proline, an important solute that accumulates in plants exposed to dehydration stress (Perez-Perez *et al.*, 2009), is an amino acid synthesized in large amount due to pathogen infection (Lobato *et al*., 2010), abiotic stress (Costa *et al*., 2008), and salt stress (Silveira *et al.,* 2003).

2.6.4 Phosphorus availability in soil in relation to cowpea production

One of the seventeen essential nutrient elements required by plants for growth and development is P (Raghothama, 1999), which is a macronutrient that can limit growth and productivity. During the early stages of growth, the crop requires adequate amount of P for optimum crop production (Grant *et al.,* 2001). Grain legumes such as cowpea require P in large amounts because it also helps during photosynthesis for energy transfer and root development. It is also required for flower initiation, delayed physiological maturity, plant growth, increased N fixation through improved nodulation and N utilization (Reamaekers, 2001). Insufficiency of P is the greatest limitation in agricultural production (Lynch and Brown, 2008). Crops absorb nutrients from the soil through soil solution and P is absorbed in the form of phosphate ions. In the soil, phosphate ions can react readily and become part of the soil particle.

2.6.4.1 Low soil P conditions and impact on cowpea production

Land degradation and soil infertility are the major causes of low agricultural productivity, which in turn leads to food insecurity globally (Sanchez, 2010). The major problem of crop production, especially among local SH farmers, is insufficiency of nutrients such as P and N in the soil. For example, Kgonyane *et al*. (2013) reported low P content of 3.0, 3.0 and 1 mg kg^{-1}, respectively in soils from Phaudi, Perskebult and Bokgaga due low inherent fertility and continuous cultivation while only soil from Tshebela had relatively higher P (34 mg kg^{-1}) content. The problem of P deficiency often results from soil erosion, P removal in harvested crops and depletion of P through continuous cultivation. Most soils are inherently low in P and N which consequently leads to poor crop yield in the world. The problem of P deficiency in soil can be mitigated through the application of concentrated fertilisers that provide soluble inorganic P (Pi) for the plant (Lynch and Brown, 2008).

The problem of low soil P remains a major constraint to crop production. According to Zhu and Lynch (2004), low P availability in soils affects root traits such as the lateral root branching, the root density and length of root hairs (Ma *et al.,* 2001) and also parenchyma formation (Fan *et al.,* 2003). Additionally, it also affects the root morphology, delays root emergence in crops, and reduces root hair numbers and physiological characteristics that are associated with P uptake (Pellerin *et al.,* 2000; Kimiti *et al.,* 2001). Insufficiency of P in common bean has been reported to stimulate shallower basal root growth angles (Liao *et al*., 2001), increased adventitious root production (Miller *et al.,* 2003) and overall, promotes shallow root systems for P-efficient genotypes (Lynch and Brown, 2001; Liao *et al.,* 2001). Insufficiency of P in plant shoots has also been reported to lead to decrease in photosynthesis and stomatal conductance and consequently results in restricted plant growth (Ghannoum and Conroy, 2007).

2.6.4.2 Mechanisms for plant adaptation to low P condition in the soil

Morphological, physiological and biochemical mechanisms have been developed in plants to allow plants to respond to P insufficiency (Suriyagoda *et al.,* 2010). Plant morphological mechanisms to deal with insufficient P availability in soil include prolific root development such as higher root: shoot ratios, finer roots, longer root hairs and the development of arbuscular mycorrhizas, all of which facilitate exploration of a greater soil volume (Raghothama, 1999). The main mechanism of roots is the ability to extract P from the soil (Niu *et al.,* 2012). Mechanisms that enhance P acquisition from the soil include soil-P mobilization through root exudates, symbioses with soil microbes such as vesicular-arbuscular mycorrhiza and enriched root growth and activity (Ho, 2004). Mycorrihizae are the important type of arbuscular mycorrhiza fungi used in agricultural crops (Smith and Read, 2008). Root exudates play an important role in the maintenance of root and soil contact, which is especially important for plants under drought conditions, when hydraulic continuity is lost (Walker *et al*., 2003). The mechanisms for P uptake by plants include genetic variation among crop species for P uptake and P-use efficiency (Atemkeng *et al.,* 2011). The existence of genetic variation for P efficiency offers the possibility to develop bean genotypes with superior adaptation to low P soils (Lynch, 1998).

2.6.4.3 Legume root traits for adaptation to low soil P conditions

Roots can help to improve yield under drought conditions and poor soil fertility. Several morphological and physiological traits are affected by drought tolerance in legumes. Grain legumes such as cowpea have root traits such as adventitious roots, basal roots and rooting density. Changes in rooting depth and rooting density exist among many crop species (Smit *et al.,* 1994). Extraction of P from the soil by plant depends on the root physiological and morphological properties such as root length, root exudates, high-affinity for inorganic P transporter and arbuscular mycorrhizal colonization (Quan *et al.,* 2010). These traits are responsible for showing continued variations that are called quantitative traits that are controlled by genes called quantitative trait loci, QTLs (Khan *et al.,* 2012). Legume roots can be adapted to low soil P condition by increasing root growth such as basal and adventitious roots, modified root architecture (Lynch, 1995) and the ability to extract P from the soil (Niu *et al*., 2012). These have been reported to be root traits that are necessary for adaptation of drybean to P limiting environments. Miller *et al.* (2003) reported that increase in production of adventitious roots in common beans helps in P acquisition by improving plant foraging in the most P rich soil environment and shallower root system were more competitive than deep root systems for topsoil P. In common bean low soil P availability increases the shallowness of basal roots, especially in P-efficient genotypes (Miller *et al.,* 2003).

2.6.5 Importance of root architecture in crop production

Root architecture is a spatial configuration of the root system which is categorised into three parts namely root morphology, topology and root distribution. It is important for plant productivity under edaphic stress, to determine underground nutrient acquisition

(Lynch, 1995); and also important for the measurement of plant growth and productivity. It determines plant ability to exploit spatial heterogeneous soil resources (Lynch and Brown, 2001). Low soil P availability improves root architecture traits including the primary root length, root branching, number and length of lateral roots and enhancement of root hairs and cluster root formation (Jin *et al.,* 2012). Monocotyledonous and dicotyledonous crops vary greatly in terms of their root system and morphology. Environmental conditions such as drought stress and low nutrients play an important role influencing root characteristic traits such as rooting depth and density (Kumar *et al*., 2010). Rooting depth and density are important during drought avoidance; and constitute traits identified to confer seed yield in chickpea under terminal drought environments (Turner *et al.,* 2001, Kumar *et al.,* 2010). Consequently, genetic variation in root architecture among species is associated with adaptation and environments (Lynch, 2005).

2.6.6 Effect of drought stress on N fixation in cowpea

Drought stress is one of the environmental stresses that can cause reduction in N fixation (Sinclair *et al.,* 1987), and also cause significant crop yield losses. Nitrogen fixation in legumes is highly sensitive to drought conditions (Wery *et al.,* 1994). Drought stress affects the nodule formation and function (Serraj, 2003) as well as their longevity. Due to its high rates of N fixation (Martins *et al.,* 2003) and effective symbiosis with mycorrhizae (Kwapata and Hall, 1985), cowpea does not deplete the soil N and P natural reserves, and many experimental findings confirm that soil N levels increase by about 40–80 kg N ha^{-1} following cowpea in rotation (Quin, 1997). Symbiotic N_2 fixation is sensitive to abiotic stress conditions such as drought stress, soil salinity, low soil P, acidity, waterlogging, high/low temperature and other nutrient limitations (Serraj, 2003). Various physiological mechanisms have been reported to respond to symbiotic N_2 fixation under abiotic stress, such as drought stress, and these mechanisms include O_2 limitation, carbon shortage, feedback regulation and nodule carbon metabolism (Serraj, 2003, Marino *et al*., 2007). Oxygen permeability is a limiting factor for nodule functioning and it is also a controlling factor for BNF under various environmental stresses (Marino *et al*., 2007). N_2 fixation in legumes might be regulated under drought stress factor by feedback mechanism involving N metabolism and there is no mechanism of feedback inhibition yet demonstrated in legume nodule (Serraj, 2003). The study conducted by Marino *et al.* (2007) reported that BNF regulation can be provided by N feedback mechanism involving shoot N status. A reduction in nodule carbon flux has also been related to the inhibition of N fixation under drought stress (Marino *et al*., 2007).

2.6.7 Effect of drought stress on photosynthesis

Drought stress decreases rate of photosynthesis and decreases plant growth and development of crops thereby causing serious crop yield losses globally. Photosynthesis plays a major role in crop production; hence, limiting one factor such as water, light or carbon dioxide in crops can reduce the rate of photosynthesis. Photosynthesis and stomatal conductance change over time and are essentially sensitive to environmental variations (Gunderson *et al*. 2002). Determining photosynthesis in the morning and hot afternoon day may introduce more variation as shoot and stomatal conductance related traits become more important to plant root traits for water access. Stomatal diffusive factors control water evaporation as well as the CO_2 entry during photosynthesis and transpiration in cowpea (Hayatu and Mukhatur, 2010). The major role of stomata is to regulate water loss and carbon dioxide uptake. Stomatal conductance is influenced by factors such as light intensity, temperature, humidity, and internal CO_2 concentration (Magloire, 2005). Drought stress inhibits the photosynthesis of the plants by causing changes in chlorophyll content, by affecting chlorophyll components and damaging the photosynthetic apparatus (Mafakheri *et al.,* 2010). It also causes decrease in chloroplasts due to damage during the drought stress condition.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Description of experimental site and land preparation

The experiment was conducted during 2012/13-summer planting season at Ukulima Farm (24°32'58.1" S, 28°06'21.1" E, 1237 masl) near Modimolle in the Waterberg district of Limpopo Province. The area receives about 623 mm of rainfall per annum (Fenta, 2012) while soil at the farm is predominantly sandy loam and belongs to the Clovelly form. Land preparation at the trial site was performed through plough and harrow so as to obtain a fairly clean and good tilth for the planting of the trial.

3.2 Treatments, experimental design and layout

The experiment was laid out in a split-split plot arrangement fitted into a randomized complete block design (RCBD). Treatment factors consisted of two levels of P fertilization, two moisture status and eight cowpea genotypes. The P levels (unfertilized control plot with less than 8 mg P ha^{-1} as measured in the soil and inorganic P fertilization at the rate of 40 kg P ha^{-1} application to achieve approximately 35 mg P ha^{-1} of soil P (Bray 1) constituted the main plot factor, the moisture status (drip irrigation at regular interval to eliminate moisture stress condition and solely rain-fed condition that frequently triggers moisture stress status during the growth period) constituted the sub plot factor while the eight cowpea lines (Tvu 4632, Tvu 6365, Tvu 9848, Tvu 15445, Tvu 16408, Tvu 15143, Oloyin and IT00K-1217(local check)) constituted the sub-sub plot factor. Each sub-plot measured 9 m × 10 m (90 m^2) while the main plot measured 9 m x 20 m (180 m^2). Based on local agricultural practices, the plant spacing used for seed sowing was 75 cm x 20 cm with a calculated plant density of 66667 plant ha^{-1}.

All seeds planted were pre-treated with captan against soil insects and pathogens. Inorganic P fertilizer was applied at planting in the form of single super phosphate (10.5% P) at the rate of 1000 kg ha^{-1}. Plots with well-watered plants were uniformly irrigated on weekly basis using drip irrigation at 297.5 L hr^{-1} for 2 hours while the water stress plots were solely dependent on rainfall without any form of supplementary irrigation. Rainfall data were collected during the growing season from the weather station installed at the farm. Post-emergence weed control was achieved manually using hand hoes with weeding first carried out at 3 weeks after seedling emergence while subsequent weedings were performed by rogueing as required from time-to-time. Pests such as aphids observed on the field were controlled by regularly spraying dimethoate 40 EC at the rate of 750 ml ha^{-1} throughout the growing season.

3.3 Cowpea plant phenological and growth data collection

Phenological variables, namely days to 50% flowering and number of days to physiological maturity, as well as growth parameters, such as the number of trifoliate leaves per plant and plant height, were collected on biweekly basis starting from 6 weeks after planting until the R5 stage of the reproductive growth stage, which marks the stage of seed formation. Photosynthesis rate and the aboveground plant biomass on four randomly selected tagged plants per plot were taken and recorded at 8 weeks after plant emergence. Four plants were randomly harvested using a sharp edge knife from above the ground surface for biomass determination while twenty fresh immature green pods were also randomly harvested per plot prior to physiological maturity. Both sampled materials were weighed and oven dried at 60°C to a constant weight; they were then milled and used for tissue P analysis.

3.3.1 Soil core sampling for root morphology analysis

Two soil core samples were taken from well-watered, water stressed, high and low-soil P fertilized plots to check the root distribution in the soil across various soil depths. The soil cores were collected 10 cm away from each plant until 60 cm depth (Plate 1).

3.3.2 Plant and soil sampling for the Shovelomics

Shovelomics was done using a legume root phenotyping board and an electronic vernier caliper (Plate 2) on randomly harvested four plants per plot during the late vegetative stage. The plants were removed using “shovelomics technique (Lynch, 2011), during (R1) reproductive stage four plants were dug using a shovel about 20 cm away from each side of the plants and carefully removing the plant from the soil without disturbing the root system of the plant in the soil, and the roots were washed with water to remove the soil. For plant tissue sampling, ten leaf disks from two of the four plant samples harvested were sub-sampled, oven dried at 60°C, weighed, ground and used for plant tissue P analysis following the procedure described by Mitchell (1972) and Murphy and Riley (1962). Each soil core sample taken per plot was partitioned into six depths to observe root distribution at each depth; and the root content from each depth collected, arranged in well-labelled plastic bags, later washed using tap water and kept inside bottles containing little amount of water for scanning using a root image scanner (Espon perfection, Plate 3). Espon perfection is scanner which is used to scan root images that are used to determine root distribution in the soil (Plate 5).

Soil samples from the six different depths were collected and separately packed. Sub-samples (in duplicate) were taken, weighed and oven dried at 105°C to a constant weight for gravimetric soil moisture determination. Similarly, a Time-Domain Reflectometer, TDR, (Plate 4) was also regularly used for *in-situ* measurement of soil moisture content of undisturbed soil at (0-15 cm and 15-45 cm). Both pre-planting and post-harvest soil samples were collected and used for pH (KCl), available Bray 1 P and exchangeable K, Ca, Mg and Na determinations.

3.3.3 Root washing and scanning

After the soil core sampling was performed, samples were transferred to the laboratory and each sample was cut into 10 cm segments up to the 60 cm depth. Each segment was washed using a 2 mm size sieve and the roots remaining in the sieve were kept in urine cups with water and kept in a refrigerator. The washed and preserved roots were later scanned using a root scanner (Epson perfection).

3.4 Measurement of photosynthesis parameters

The Licor system (LI-6400, 4647 Superior Street Lincoln, Nebraska USA) was used for measurement of photosynthesis and transpiration parameters based on the differences in CO_2 and H_2O in an air stream that flows through the leaf cuvette model. The measurements were taken between 11:00 and 13:00 during the sunny day on the two top fully expanded leaves. These photosynthetic parameters were collected at the podding stage. The photosynthetic parameters measured were intercellular CO_2 (µmol CO_2 mol^{-1}), water conductance (mol H_2O m^{-2} s^{-1}), transpiration rate (mmol H_2O m^{-2} s^{-1}), and vapour pressure deficit measured based on the leaf temperature (kPa), single cell CO_2 (µmol CO_2 mol^{-1}), H_2O (mmol H_2O mol-^{1}) and relative humidity (RH %). Two fully expanded leaves were selected per plot and they were clipped to the head of the Licor 6400 to measure all required parameters. Only four of the eight cowpea genotypes (Oloyin, Tvu 4632, Tvu 6365 and Tvu 9848) were used for photosynthetic parameters for the purpose of managing time constraint during data collection and reducing the potential variation that may be associated with the measurement of parameters beyond the specified time.

3.5 Collection of data on root architecture

Shovelomics, a term used to describe the study of root imaging and biomass through phenotyping, was done during the (R1) reproductive stage. Legume root phenotyping board was used to determine root distribution and root shape. The root characteristics for the eight cowpea lines studied included nodule score which ranged from 5= many healthy nodules, 4=few heathy nodules, 3=heathy nodule, 2=less heathy nodules, 1= no heathy nodules) per plant, deep scores which from 5= deeper roots, 1= no deep roots, shallow scores which from 5= more shallower roots, 4=few shallow roots, shallow roots, 2=less shallow roots, 1=no shallow roots, disease scores which ranged from disease score 5 = no visible pathogen, 4=few visible pathogen3= nematode damaged, or 2= less damage, no nematode damage, 1= extensive pathogen or nematode damage, fresh and dried root weights, and root length. Others included tap root diameter at 5, 10, 15 and 20 cm soil depths, the basal root angle, adventitious root angle, and root branching density at 5, 10 and 15 cm soil depths, as well as the taproot density (Taproot diameter at 5 cm, taproot diameter at 10 cm, taproot diameter at 15 cm and taproot diameter at 20 cm). Roots were collected using soil cores in order to determine root distribution by soil depth. Traits that co-optimize water- and P-use efficiency at both temporal and spatial levels were considered in both high- and low-P as well as well-watered and water-stressed plots. These are the number of basal roots, and root angle.

Images of root systems of all samples were taken for reference. Taproot diameters at 5, 10, 15 and 20 cm and 1.5 branching densities at 5, 10 and 15 cm were measured using an electronic caliper. The taproot diameters were measured at the depths of 5, 10, 15 and 20 cm below the soil and above 1.5 branching roots densities were measured using caliper at different soil depths.

Plate 1: Soil core sampling for gravimetric moisture determination and root distribution study across soil depth

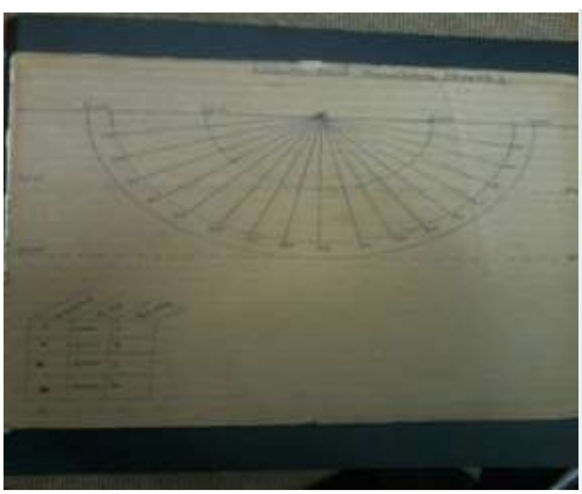

Plate 2: A legume root phenotype board (left) and an electronic vernier caliper (right) used for collecting root data

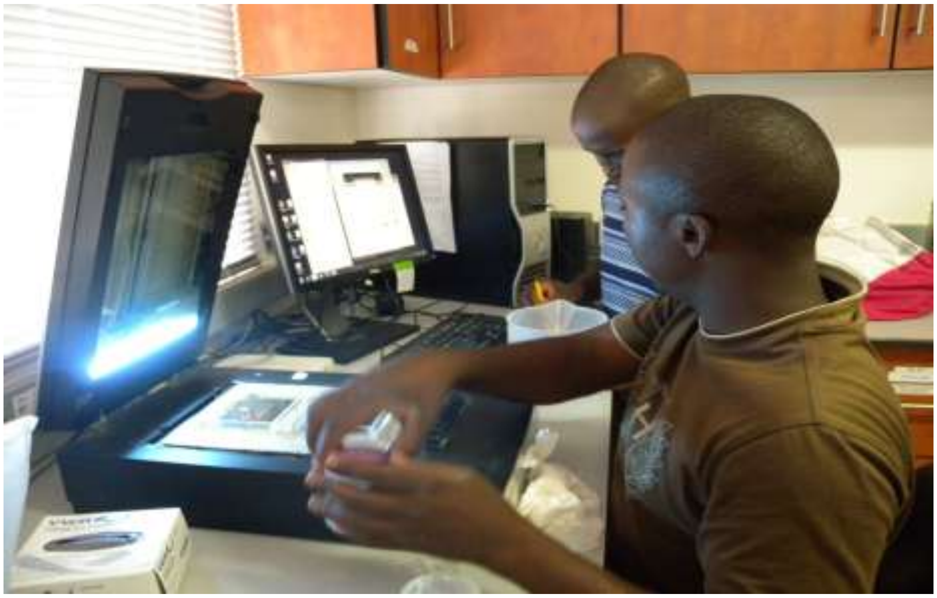

Plate 3: Root scan (using root scanner Epson perfection) equipment used at Ukulima Root Biology Center.

Plate 4: A TDR regularly used for *in-situ* soil moisture monitoring on the field

Plate 5: Steps involving root morphology analysis are soil coring (top left), transferring core samples into well-labelled plastic bags (top right), washing of roots on a sieve (middle left), transferring washed clean roots into labelled urine cups (middle right), and scanning of roots using an Epson root scanner to produce images (lower left and right)

3.6 Harvesting of cowpea and data collection

The crops were harvested manually when pods attained full harvest maturity and were sufficiently dried. Mature dried pods were hand-picked twice from each plot and the two harvests were combined for processing or threshing; and subsequently weighed. The number of dried pods per plant, number of seeds per pod, pod length, and the number of branches per plant were taken and recorded at harvest. Pod length and seed count per pod were determined on ten randomly harvested dry pods per plot while the pod length was measured using a ruler. The weight of grains per plot was obtained after threshing.

3.7 Total N and P determination in grain samples after harvest

Total N in plant tissue was determined using Micro Kjeldahl Acid Digestion Process. The sample was reacted with Salicylate and Sodium hypochlorite solution to produce a blue compound measured at 660nm. Nitroprusside was used as a catalyst (Method No G-188-97 Rev .5) (Jense, 1991; Bremner and Mulvaney, 1982). Thereafter, N uptake was calculated using the equation:

Nitrogen uptake= (total N content x grain yield)/100

Phosphorus content was determined following colorimetric method in which a yellow colour is formed by the reaction of phosphate with vanadomolybdate in an acidic medium. The concentration of the phospho-molybdovanadate complex was read on a UV spectrophotometer at 420nm (Method No G-130-94 Rev.1) (Murphy and Riley, 1962). Thereafter P uptake was calculated using the equation:

Phosphorus uptake= (total P x grain yield)/100

3.8 Data analysis

Soil analysis, growth and yield parameters generated, including all measured data on root characteristics, were subjected to analysis of variance using STATISTIX 8.1. Differences amongst treatment means were separated using the Turkey’s test at 5 % level of probability.

CHAPTER 4

RESULTS

4.1 Selected chemical properties of soil samples from the trial site prior to planting and after crop harvest

The chemical properties of the surface soil (0-15 cm) sample taken after crop harvest are presented in Tables 1 and 2. The Soil pH (KCl) measured in soil at the depth of 0-15 cm is 5.85, indicating moderate acidity. The pre-planting soil analysis showed that the mean availability P (Bray 1) level in the soil was medium (15.78 mg kg^{-1}), while the mean value of basic cations namely Ca, Mg, K and Na were 136, 43, 24 and 9.33 mg kg^{-1}, respectively. The value for exchangeable acid was below the critical level while P, Ca, Mg, K and ECEC were above the critical level and were hence considered adequate. The effective cation exchange capacity (ECEC) of the soil was 7.20 Mmol (+) kg^{-1}. The mean available P level in post-harvest soil samples from plots with high P fertilisation level in both well-watered and water-stressed plots was 40.5 mg kg^{-1} while the extractable Zn concentration was 7.95 and 8.25 mg kg^{-1}, respectively. Availability of P in soil samples from water stress and well-watered plots were 7.5 and 9.5 mg kg^{-1}, respectively. Extractable Zn concentration from plots with low P fertilisation level under water stress and well-watered condition were 8.76 and 7.76 mg kg^{-1}, respectively. The critical value for ECEC according to Sanchez (1976) is 4 Mmol (+) kg^{-1} possibly indicating that the soil was fertile.

4.2 Rainfall and temperature in 2012/2013 season

The rainfall distribution and temperature readings collected during 2012/2013 growing season are presented in Figure 1. The highest total monthly rainfall of 110.6 mm was recorded in December during the planting time while the lowest total monthly rainfall (15 mm) was received during vegetative stage in February. The highest average maximum monthly temperature of 23.38 $^{\circ}$C and the lowest average minimum monthly temperature of 10.37 $^{\circ}$C were recorded on February and May respectively. Reduced maximum and minimum monthly average temperatures were recorded in March during the growing season. Figure 2 presents the 2012/2013 growing season's mean monthly heat units, which were highest (25.9) in December during early crop establishment and lowest (20.9) in the month of September. Figure 3 presents the mean daily evapotranspiration during the growing season. During December the highest daily average of evapotranspiration was received 0.148 mm while the lowest average daily evapotranspiration was obtained in April (0.0189 mm).

Table 1: Results of pre-plant soil analysis from the trial site

Measured variables	Mean	SE mean	C.V (%)
pH(KCl)	5.85	0.23	11.8
P (Bray 1) (mg kg^{-1})	15.78	3.51	66.8
Ca (mg kg^{-1})	136	9.28	20.4
Mg (mg kg^{-1})	43	3.13	21.6
K (mg kg^{-1})	24	2.98	37.2
Na (mg kg^{-1})	9.33	0.17	5.4
Exchangeable acid (Mmol(+) kg^{-1})	1.14	0.08	20.6
ECEC (Mmol(+) kg^{-1})	7.20	0.45	18.7

ECEC implies effective cation exchange capacity

Table 2: Results of P and Zn concentration after crop harvest from the trial site

Phosphorus fertilisation level	P (Bray 1) (mg kg^{-1})		Zn (mg kg^{-1})	
	Water stressed	Well-watered	Water stressed	Well-watered
High	40.5	40.5	8.28	7.95
Low	7.5	9.5	8.76	7.76

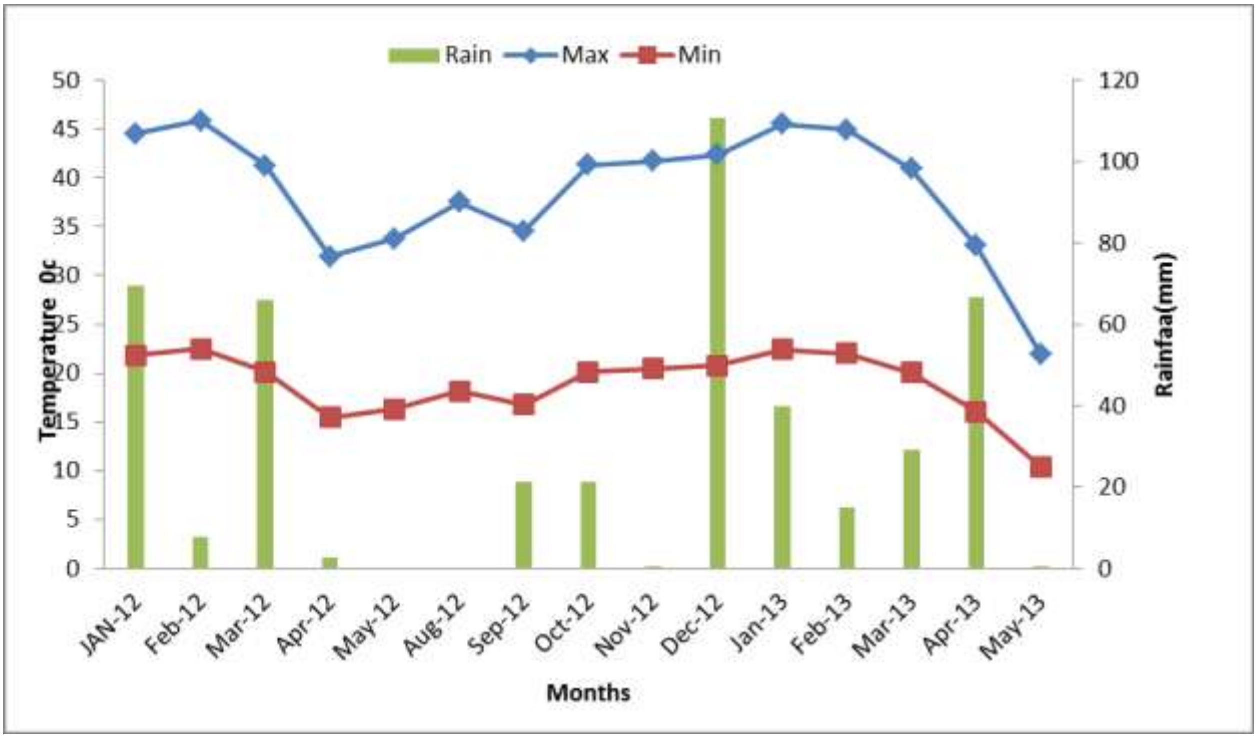

Figure 1: Monthly average rainfall, minimum and maximum temperatures at Ukulima farm in 2012/2013 growing season.

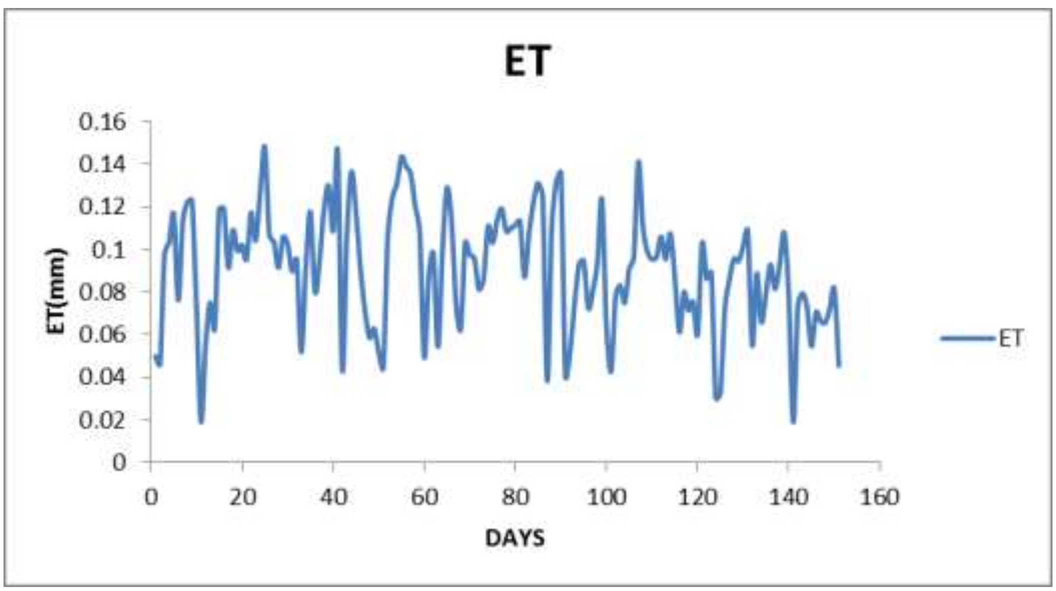

Figure 2: Daily average of evapotranspiration at Ukulima farm during the planting season

4.3 Cowpea phenological and growth parameters

4.3.1 Number of days to 50% flowering

The results of treatment effects on the mean number of days to 50% flowering as well as to 50% physiological maturity are presented in Table 3. Differences in cowpea genotypes exerted a significant ($P \leq 0.001$) effect on the duration to 50% flowering. The number of days to 50% flowering for cowpea genotypes Tvu15143, Tvu 15445 and Oloyin did not differ significantly from each other but were significantly ($P \leq 0.001$) different from that of genotype Tvu 16408. Cowpea genotypes Tvu 15143 and Tvu 15445 reached 50% flowering much earlier (approximately 53 days) than any other genotypes (longer than 55 days) while cowpea genotypes IT00K 1217 attained 50% flowering at 59 day after planting. There was no interaction between P level x moisture stress x cowpea genotype on phenological and growth parameters.

4.3.2 Number of days to 50% physiological maturity

Among the eight cowpea genotypes evaluated, Tvu15143 reached physiological maturity much earlier (76.0 DAP), followed by Tvu16408 (78.2 DAP) while IT00K1217, which is one of the two newly registered cowpea genotypes, took the longest number of days (83 DAP) to attain physiological maturity (Table 4). The mean number of days to physiological maturity for IT00K 1217, Oloyin, Tvu 9848, 6365 and Tvu 4632 were comparable and did not differ significantly. Moisture status and P level exerted no significant influence on the mean number of days to physiological maturity (Table 3).

4.3.3 Effect of cowpea genotype, P level and moisture status on growth parameters

Phosphorus level and cowpea genotype exerted significant ($P \leq 0.05$) effect on plant height at 4,6, 8 and 10 WAP and number of branches at 10 WAP (Table 3). Moisture status showed no significance difference on number of branches and plant height. Plant height and the mean number of branches per plant showed a statistically significant ($P \leq 0.01$) difference among the different cowpea genotypes (Table 3).

4.3.3.1 Plant height

Soil P level showed a significant ($P \leq 0.05$) difference on plant height. Soil P level increased plant height by 23 % at 4 WAP, while it increased plant height by 29 % at 6 WAP, while it increased plant height by 34 % at 8 and 10 WAP. Cowpea genotype Tvu 15445 at 4 WAP had the tallest plants (12.04 cm) (Table 3). There were no statistical differences among Tvu 9848, 4632, 16408 and 15143 but these were marginally taller than the two newly registered local genotypes (IT00K 1217 and Oloyin). Similarly, Tvu 15445 had the tallest plants (18.42 cm) at 6 WAP. However, cowpea genotype Tvu 15143 had the tallest plants at 8 WAP (24.97 cm) as well as at 10 WAP (31.94 cm) while Oloyin had the lowest plant height in both cases.

4.3.3.2 Number of branches

Soil P increased number of branches by 19 % and decrease by 16 %. The mean number of branches for cowpea genotypes Tvu 15445, Tvu 9848 and Tvu 16408 at 6 WAP did not differ significantly from each other but were significantly higher than those of IT00K 1217 and Oloyin; with Oloyin being the least. Cowpea genotype Tvu 16408 had the highest number of branches at 8 WAP while Oloyin had the lowest number. A significant ($P \leq 0.01$) cowpea genotype x P level interaction effect was obtained on mean plant height measured at 6 WAP and the mean number of days to physiological maturity (Table 4). The results revealed that cowpea genotype Tvu 15445 had the tallest plants under high soil P condition while the lowest plant height was obtained IT00K1217 under low soil P (Table 4). There was no interaction between P level x moisture stress x cowpea genotype on growth parameters.

Table 3: Effect of moisture stress condition and phosphorus level on growth parameters of different cowpea genotypes

Treatment	Days to flowering	Days to physiological maturity	Plant height 4 WAP	Plant height 6 WAP	Plant height 8 WAP	Plant height 10 WAP	Number of branches 6 WAP	Number of branches 8 WAP
Soil P level (P)								
Low	56.7a	80.8a	9.2b	11.9b	16.9b	21.8b	3.6b	4.6a
High	56.5a	80.4a	11.3a	15.3a	22.7a	29.2a	4.3a	5.9a
Moisture status (M)								
High	56.3a	80.4a	10.3a	14.3a	21.1a	27.5a	3.1a	4.1a
Low	56.9a	80.9a	10.2a	12.9a	18.6a	23.5a	3.9a	4.8a
Cowpea genotypes (V)								
IT00K1217	59.0b	83.0c	7.9d	10.4b	14.5de	19.5de	3.4b	4.3bc
Oloyin	57.6ab	83.0c	9.4cd	11.1b	14.4e	17.9e	3.2b	4.2c
Tvu 9848	57.6ab	82.6c	10.5bc	13.8ab	20.1bc	26.5abc	4.4a	5.2a
Tvu 6365	58.0ab	82.6c	9.9c	12.8ab	18.6cd	24.5cd	4.1ab	5.1ab
Tvu 4632	58.7b	82.6c	10.3bc	13.6ab	21.2abc	27.4abc	3.6ab	4.8abc
Tvu 15445	53.1a	77.3bc	12.0a	18.4a	21.6abc	25.9bc	4.2a	5.1ab
Tvu 16408	55.1bc	78.2b	10.4bc	13.9ab	23.2ab	30.5ab	4.5a	5.6a
Tvu 15143	53.6a	76.0a	10.5bc	14.8ab	24.1a	31.9a	3.9ab	4.9abc
Soil P level (P)	ns	ns	**	*	**	*	*	ns
Moisture (M)	ns	ns	ns	ns	ns	ns	ns	ns
C-genotypes (V)	***	***	***	**	**	***	***	***
PxM inter	ns	ns	ns	ns	ns	ns	ns	ns
PxV inter	ns	*	ns	**	ns	ns	ns	ns
VxM inter	ns	ns	ns	ns	ns	ns	ns	ns

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ *= significantly ($P \leq 0.05$), ** significantly ($P \leq 0.01$), ns= non-significantly ($P \leq 0.05$), P=Phosphorus, M= Moisture stress while C-genotypes implies cowpea genotypes, WAP= Weeks after planting.

Table 4: Cowpea genotypes x P levels interaction effects on days to 50% physiological maturity (PM) and plant height of eight different cowpea genotypes

Prates	Genotypes	Day to 50% PM	Plant height (cm) at 6 WAP
HP	Tvu 15445	76.0d	22.70a
HP	Tvu15143	76.0d	16.95ab
HP	Tvu16408	76.9cd	16.03ab
HP	Tvu4632	83.0a	15.23ab
HP	Tvu 9848	83.0a	14.56ab
HP	Tvu 6365	82.1ab	14.05ab
HP	Oloyin	83.0a	12.22b
HP	IT00K 1217	83.0a	10.89b
LP	Tvu 15445	78.6cd	14.14ab
LP	Tvu 15143	76.0d	12.55b
LP	Tvu 16408	79.5bc	11.81b
LP	Tvu 4632	82.1ab	11.98b
LP	Tvu 9848	82.1ab	13.13ab
LP	Tvu 6365	83.0a	11.47b
LP	Oloyin	83.0a	9.95b
LP	IT00K 1217	83.0a	9.88b
Significance		0.026*	0.0053**

Means followed by the same letter in a column are not significantly different at P ≤ 0.05 *= significant (P ≤ 0.05), ** = significant (P ≤ 0.01), ns= non-significant (P ≤ 0.05), WAP= Weeks after planting. LP= Low soil Phosphorus and HP= High Phosphorus

Significantly positive correlation was obtained between nodule score, grain yield and cowpea biomass. Significant correlation was obtained between nodule score and grain yield (Table 5). Highly positive and significant correlation was obtained between number of branches at 8 WAP and grain yield of cowpea. Strongly positive and significant correlation was obtained between number of branches at 8 WAP and grain yield (Table 6).

Table 5: Pearson correlation of nodulation, biomass and grain yield

	Biomass	Nodule score
Nodule	0.3966***	
Yield	0.2574**	0.1808*

Table 6: Pearson correlation of number of branches and grain yield

	Number of branches 6 WAP	Number of branches 8 WAP
Number of branches 8 WAP	0.7919***	
Grain yield	0.4454***	0.4213***

4.3.3.3 Treatment effects on leaf count per plant

The results shown in Table 7 reveal that soil P level and cowpea genotype exerted significant ($P \leq 0.05$) effect on the mean number of leaves at the different sampling dates. Although cowpea genotype x P level interaction had a significant effect on leaf count only at 6 and 8 WAP, the pattern of significant differences was unusual and cannot be explainable. Cowpea genotype Tvu 15143 consistently maintained the highest mean number of leaves per plant throughout the leaf count period while the IT00K1217 had the lowest number except at 12 WAP where Oloyin recorded the least mean leaf count per plant. Variation in soil moisture condition exerted no significant differences on the mean leaf count of the cowpea plant.

The interaction between cowpea genotype and moisture stress condition exerted significant effect on leaf count per plant at 6 and 12 WAP (Table 8). Tvu 15143 had more leaves under well-watered condition while Oloyin had the least at 6 WAP. Similarly at 12 WAP, cowpea genotype Tvu 15143 had the highest leaf count per plant under well-watered soil condition while Oloyin had the least regardless of the soil moisture condition. The mean number of leaf count obtained under high soil P condition was consistently higher than that under low soil P. Water stressed condition reduced number of trifoliate leaves per plant on the most cowpea genotypes. Cowpea genotype Tvu 15143 produced more number of trifoliate leave under well-watered condition as compared to water stress condition. Number of leaves were significantly affected by P level. Application of P level increased plant growth by increasing development of meristematic tissue which will result in greater number of leaves in cowpea. It help in division of cell growth and development of the new tissue and is found in large amount on new cell growth and play essential in transfer of energy such as ATP. Number of leaves during 6 and 8 WAP were collected in January from a field that received higher amount of rainfall which could have contributed toward an increased in leaves. Increase in amount of P level and rainfall increased number of leaves per plant.

Table 7: Effect of cowpea genotype, moisture status and phosphorus levels on mean number of trifoliate leaves per cowpea plant

Treatments	Leaf count per plant (weeks after planting)			
	6	8	10	12
Soil P level (P)				
Low	5.6b	12.1b	18.2b	19.5b
High	8.1a	16.6a	22.7a	25.0a
Moisture status (M)				
Stressed	6.8a	14.4a	19.1a	21.4a
Well watered	7.0a	14.3a	20.9a	23.1a
Cowpea genotypes (V)				
Tvu 4632	6.3b	13.0b	18.7bc	21.2bc
Tvu 6365	7.4b	15.4ab	21.0b	22.1b
Tvu 9848	6.5b	14.4b	20.0b	21.6bc
Tvu 15445	7.3b	14.9b	20.7b	22.6b
Tvu 16408	7.4b	15.7ab	22.0ab	24.6ab
Tvu 15143	9.9a	18.0a	25.4a	27.2a
Oloyin	5.8bc	13.8b	19.8b	17.4c
IT00K-1217	4.6c	9.7c	16.0c	21.2bc
P-values				
P	0.020*	0.009**	0.040*	0.048*
PxV interaction	0.046*	0.036*	0.712ns	0.680ns
MxV interaction	0.040*	0.609ns	0.162ns	0.044*

. Means followed by the same letter in a column are not significantly different at $P \leq 0.05$, *= significant ($P \leq 0.05$), **= highly significant ($P \leq 0.01$) ns= non-significant ($P \leq 0.05$).

Table 8: Cowpea genotypes X Moisture status interaction effects on the number of cowpea trifoliate leaves at different growth stages

Moisture status	Cowpea Genotype	6 WAP	12 WAP
Well-watered	Oloyin	4.7ef	17.4c
Water stressed	Oloyin	4.6f	17.3c
Well-watered	IT00K-1217	4.9def	20.19bc
Water stressed	IT00K-1217	6.8cdef	22.1abc
Well-watered	Tvu 9848	6.9bcdef	23.4abc
Water stressed	Tvu 9848	6.1cdef	19.9bc
Well-watered	Tvu 6365	7.0bcdef	22.0abc
Water stressed	Tvu 6365	7.8abc	22.6abc
Well-watered	Tvu 15445	8.1abc	26.0ab
Water stressed	Tvu 15445	6.4cdef	19.19bc
Well-watered	Tvu 4632	6.8bcdef	20.9bc
Water stressed	Tvu 4632	5.9cdef	21.4abc
Well-watered	Tvu 15143	10.1a	28.6a
Water stressed	Tvu 15143	9.4ab	25.8ab
Well-watered	Tvu 16408	7.5bcd	26.2ab
Water stressed	Tvu 16408	7.2bcde	23.0abc
SEM		0.7283	1.9628

Means followed by the same letter in a column are not significantly different at P ≤ 0.05; SEM implies standard error of mean. Means followed by the same letter in a column are not significantly different at P ≤ 0.05, *= significant (P ≤ 0.05), **= highly significant (P ≤ 0.01) ns= non-significant (P ≤ 0.05)

Plate 6: Visual observation of cowpea plants growing in well-watered plots under low soil P (left) and high soil P (right) conditions

The deficiency of P to plants results in stunted in growth, leaves often have an abnormal dark-green colour and the leaves of the crop turn yellow similar to N deficiency (plate 6). Phosphorus play an important role as a source of energy and it also play an important which help bacteria to convert atmopspheric N into ammonium so that it can be used by plant. Fertilisation with P helps the nodule to develop and become active and development of roots in crops. Early development of roots play an essential role during negative and abiotic and biotic stress condition. Adequate amount of P application can improve plant nutrition and reduced diseases reistance.

4.4 Measurement of photosynthetic parameters

The results show that soil moisture condition and cowpea genotype exerted significant ($P \leq 0.01$) effect on photosynthetic rate, water conductance, transpiration rate, sample cell CO_2, sample cell H_2O and relative humidity in the cell (Table 9). Variation in P levels had no significant effect on the measured parameters. The Oloyin genotype had the highest photosynthetic rate followed by Tvu 4632 while cowpea genotype Tvu 9848 had the least photosynthetic rate. Cowpea genotype Tvu 9848 had more intercellular CO_2

while Oloyin obtained the least intercellular CO_2. The Oloyin genotype also had more water conductance, transpiration rate, sample cell H_2O and relative humidity than any other genotype while genotype Tvu 9848 had the least concentration of these parameters. However, cowpea genotypes Tvu 9848 and Tvu 6365 had more sample cell CO_2 and vapour pressure deficit than any other genotypes. The least vapour pressure deficit was recorded in Oloyin.

4.4.1 Interaction of moisture status and cowpea genotype on photosynthetic parameters

Interaction of moisture stress and cowpea genotype had a significant effect on intercellular CO_2 concentration (Table 10). The condition of water stress reduced the intercellular CO_2 concentration of Oloyin, Tvu 6365 and 4632 but resulted in a significant increase in intercellular CO_2 concentration in Tvu 9848 genotype. The condition of well-water benefitted intercellular CO_2 concentration in the four genotypes studied. There was no interaction between P level x moisture stress x cowpea genotype on photosynthetic parameters collected.

Table 9: Treatment effects on photosynthetic and stomatal conductance parameters

Treatment source	photosynthetic rate (μmol m^{-2} s^{-1})	Intercellular CO_2 (μmol mol^{-1})	Water conductance (mmol H_2O m^{-2} s^{-1})	Transpiration rate (mmol H_2O m^{-2} s^{-1})	Sample cell CO_2 (μmol CO_2 mol-^{1})	Vapour pressure deficit (kPa)	Sample cell H_20 (mmol H_2O mol^{-1})	RH in the cell (%)
Soil P level (P)								
Low	16.71a	201.08a	0.28a	8.44a	330.59a	3.17a	15.50a	28.04a
High	17.82a	200.64a	0.29a	8.61a	329.14a	3.09a	16.10a	29.84a
Moisture status (M)								
Stressed	11.96b	199.33a	0.17b	5.67b	339.26a	3.42a	11.87b	21.54b
Well watered	22.57a	201.87a	0.40a	11.38a	320.47b	2.85b	19.83a	36.34a
Cowpea genotypes (V)								
Tvu 4632	18.06b	202.44ab	0.31a	8.96ab	328.41b	3.08bc	16.57ab	30.65ab
Tvu 6365	15.82c	201.00ab	0.26b	8.09bc	332.79a	3.10ab	15.16bc	27.76bc
Tvu 9848	13.92c	207.69a	0.22b	7.10c	335.09a	3.30a	13.75c	25.06c
Oloyin	21.25a	192.31b	0.35a	9.96a	323.17c	2.95c	17.92a	32.47a
P-values								
P	0.5613ns	0.9132ns	0.7172ns	0.5922ns	0.6894ns	0.8404ns	0.7119ns	0.5956ns
M	0.0004***	0.7359ns	0.0000***	0.0003***	0.0002***	0.0001***	0.0014**	0.0011**
V	0.0000***	0.0780ns	0.0000***	0.0000***	0.0000***	0.0070**	0.0000***	0.0000***
MxV	0.0674ns	0.0049**	0.9179ns	0.3345ns	0.1861ns	0.7241ns	0.2119ns	0.1425ns
PxMxV	0.9158ns	0.7823ns	0.9594ns	0.9789ns	0.9055ns	0.4675ns	0.9773ns	0.9451ns

Means followed by the same letter in a column are not significantly different at P ≤ 0.05; RH implies relative humidity

Means followed by the same letter in a column are not significantly different at P ≤ 0.05, *= significant (P ≤ 0.05), **= highly significant (P ≤ 0.01) ns= non-significant (P ≤ 0.05),

Table 10: Moisture status x cowpea genotype interaction effects on intercellular carbon dioxide concentration

Moisture status (M)	Cowpea genotypes	Intercellular CO_2 (μmol mol^{-1})
Ws	Oloyin	187b
Ww	Oloyin	198ab
Ww	Tvu 9848	196ab
Ws	Tvu 9848	220a
Ww	Tvu 6365	207ab
Ws	Tvu 6365	195ab
Ww	Tvu 4632	207ab
Ws	Tvu 4632	196ab
SEM		8.28

Means followed by the same letter in a column are not significantly different at P ≤ 0.05, *= significant (P ≤ 0.05), **= highly significant (P ≤ 0.01) ns= non-significant (P ≤ 0.05), Ws= water stress and Ww=well-watered condition

4.5 Biological and grain yield attributes

Cowpea grain yield and yield attributes as affected by the different treatments during 2012 planting season are presented in Table 11. The statistical analysis showed that P levels and cowpea genotypes had significant effects (P≤0.05) on mean hundred seed weight (HSW), pod length, pod dry weight and grain weight. All the pod characteristics measured namely the 100 seed weight, number seed per pod, pod length and number of pods per plant were significantly (P≤0.01) affected by differences in cowpea genotype. Genotypes IT00K1217 and Oloyin gave the highest HSW while Tvu 15143 had the least. Cowpea genotype Tvu 9848 had the longest pods and while the shortest pods were obtained by cowpea genotype IT00K 1217, which did not differ significantly from that of Tvu 16408. Cowpea genotype Tvu 9848 had higher number of seeds per pod, followed by Tvu 6365 and while the lowest number of seeds per pod was obtained by IT00K 1217. Cowpea genotype Oloyin obtained higher number of pods per plant, while the lowest number of pods per plant was obtained by Tvu 9848. Cowpea genotypes Tvu 63695, 15445 and 15143 did not differ significantly in the mean number of pods per plant. The fresh and dried weights of immature pods obtained from genotype Tvu 15445 were highest and the least was with Oloyin. The dried weights of the immature pods from Tvu 15445 and 15143 were not significantly different.

Dry matter percentage showed no significant response to P level and moisture stress conditions. Dry matter percentage showed significant response to cowpea genotype. Cowpea genotype Tvu 15143 obtained maximum amount of dry matter percentage while the lowest was obtained by Tvu 6365 (Table 11). There was no interaction between P level and moisture stress, moisture stress and cowpea genotypes, P level x cowpea genotypes, P level x moisture stress x cowpea genotype on DM %.

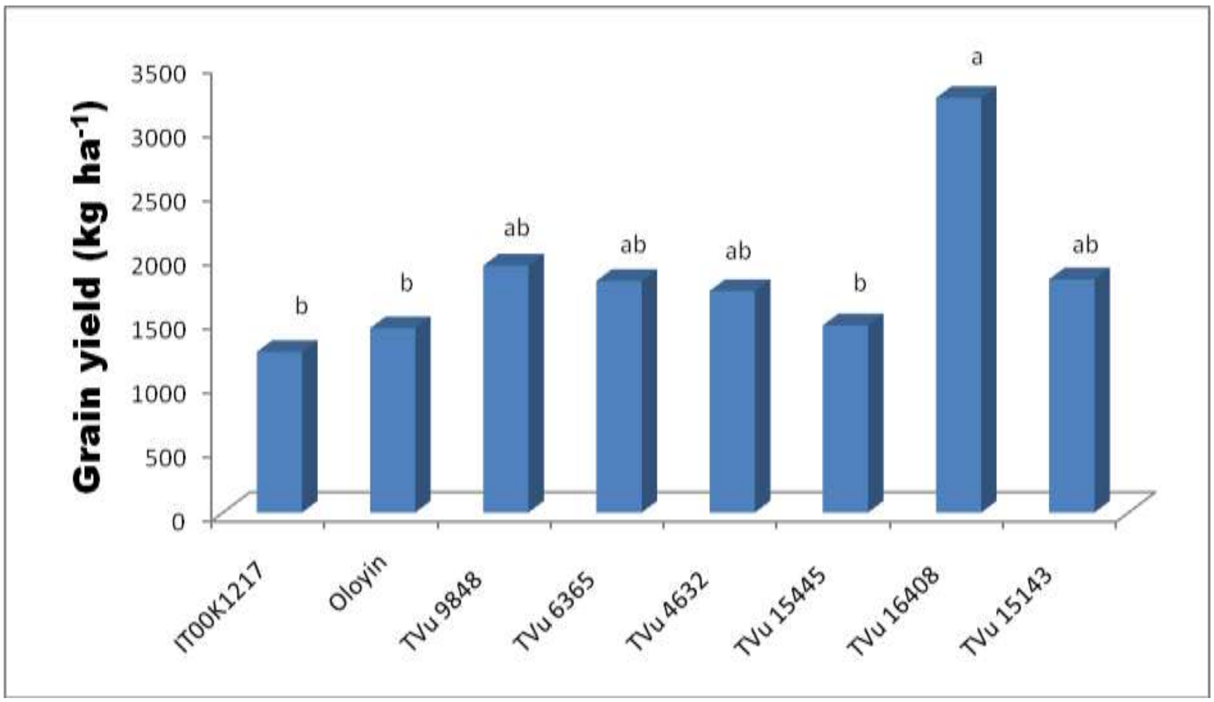

Fig. 3: Mean grain yield (kg ha^{-1}) of the various cowpea genotypes. Columns with similar letters are not significantly different at P≤0.05.

4.5.1 Grain weight

Table 11 shows that only the moisture stress and cowpea genotype variation exerted a significant ($P \leq 0.05$) effect on grain yield. Under well-watered condition cowpea genotype obtained higher grain yield while the lowest was obtained under water stress condition. Water stress caused reduction in yield and yield componements in cowpea. Cowpea genotype Tvu16408 had the highest grain yield while the lowest grain yield was given by cowpea genotype IT00K1217 (Figure 3). IT00K1217, Oloyin and Tvu 15445 had significantly lower grain yield than Tvu 16408.

Table 11: Effect of cowpea genotype on moisture stress condition and phosphorus levels on cowpea yield parameters

Treatment	Hundred seed weight(g)	Pod length (mm)	Number of seeds per pod	Number of pods per plant	FW of immature pods (g)	DW of immature pods (g)	‡Dried Biomass (kg ha^{-1})(10WAP)	Grain yield (kg ha^{-1})	Dry matter percentage
Soil P level (P)									
Low	17.0	17.7b	14.8a	19.1a	113.3a	24.3a	2907.8b	1710a	19.72a
High	17.7	18.2a	15.1a	20.1a	115.9a	25.1a	3669.0a	1963a	22.40a
Moisture status (M)									
Stressed	17.7	18.1	15.2a	21.6a	115.2a	23.8b	3224.6a	1614b	21.137a
Well watered	17.0	17.8	14.6a	19.3a	114.1a	26.5a	3352.1a	2059a	20.98a
Cowpea genotypes (V)									
IT00K1217	21.4a	17.1c	12.4c	21.8abc	103.1bc	19.8c	2895.5c	1256b	18.39b
Oloyin	21.4a	15.5d	10.8d	24.1a	78.6c	18.3c	2933.7c	1441b	24.12ab
Tvu 9848	19.1b	20.4a	16.3ab	17.1c	111.5b	21.7bc	2979.3bc	1960ab	18.38b
Tvu 6365	18.7b	19.5ab	15.2b	19.1bc	112.2b	20.1bc	3410.4abc	1810ab	18.37b
Tvu 4632	15.6c	17.1cd	15.1ab	20.1abc	107.5bc	23.7bc	3182.8abc	1732ab	20.61ab
Tvu 15445	15.1cd	18.1bc	16.1ab	19.0bc	167.1a	37.2a	3541.2abc	1463b	21.04ab
Tvu 16408	14.1de	17.7c	15.9ab	22.9ab	116.6b	25.8b	3710.6a	3240a	21.85ab
Tvu 15143	13.62e	18.03bc	16.1a	18.8bc	120.4b	33.7a	3653.6ab	1823ab	25.733a
Phosphorus(P)	ns	0.0036**	ns	ns	ns	ns	0.0007	ns	ns
Moisture(M)	ns	ns	ns	ns	ns	0.033*	ns	0.0210*	ns
Variety(V)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.0010	0.0145*	0.0016**
PxV inter	ns	ns	ns	ns	ns	0.002**	ns	ns	ns
VxM inter	0.0073**	ns	ns	ns	0.033*	0.032*	ns	ns	ns
PxMxV	ns	ns	ns	ns	ns	0.021*	ns	ns	ns

Means followed by the same letter in a column are not significantly different at P ≤ 0.05; *, ** & *** implies significant 5%, 1% and 0.1%, respectively; ns implies non-significant at 5% level of significance. FW & DW implies fresh and dried weight, respectively while ‡ implies data collected at the vegetative growth stage. WAP: Week after planting.

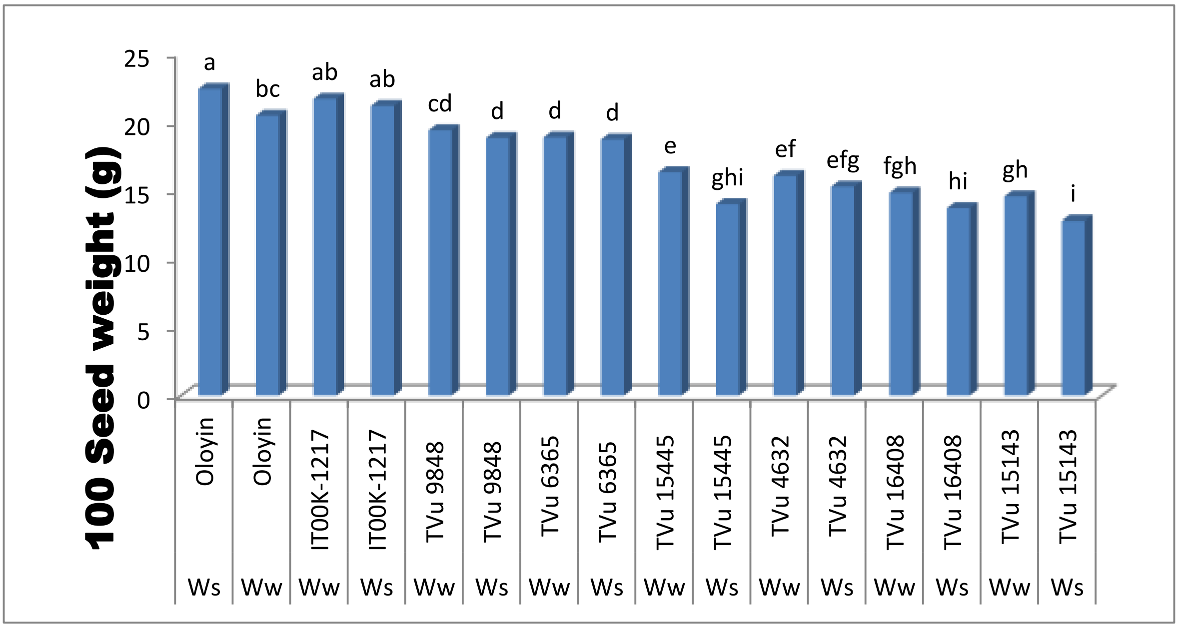

Fig. 4: Soil moisture status x cowpea genotypes interaction effect on 100 seed weight of the different cowpea genotypes (WS= Water stressed, WW= Well-watered). Columns that have similar letter are not significantly different at P≤0.05.

4.5.2 Biomass production (10 WAP) and other grain yield attributes

The results in Table 11 indicate that soil P level and cowpea genotype exerted significant differences (P≤0.01) on cowpea biomass. Cowpea genotypes Tvu 4632 and Tvu 16408 obtained the highest biomass while IT00K 1217 obtained least plant biomass at (R1) reproductive stage. Cowpea genotype 16408 obtained highest plant biomass while the lowest plant biomass was obtained from IT00K1217. The plant biomass produced by cowpea genotypes Tvu 4632, 6365 and 15445 were intermediate and not significantly different from each other. Low soil P reduced cowpea plant biomass. High P achieved 26.2 % higher cowpea plant biomass than the low soil P level.

The interaction between cowpea genotypes and moisture status exerted significant effects on the HSW as well as the fresh and dried weight of immature pods harvested (Table 12). Under water stress condition cowpea genotype Oloyin gave higher HSW while the least HSW was obtained from Tvu 15143 under water stress conditions (Fig 4). The HSW for cowpea genotype IT00K1217 under both water stress and well-watered field conditions did not show any significant difference (Fig 4). The same was also true of cowpea genotype Tvu 6365. Under well-watered condition cowpea genotype Tvu 15445 gave higher fresh and dried weight of immature pods while the lowest immature pod weight was given by Oloyin under well-watered condition (Table 12). Cowpea genotypes Tvu 4632 and 15143 did not show any significant differences on fresh and dried weight of immature pods under both water stress and well-watered conditions. Cowpea genotype Tvu 15445 gave higher dried pod weight under well-watered condition, while both IT00K1217 and Oloyin had the lowest pods dried weight. Cowpea genotype Tvu 6365 did not show any significant differences on dried weight of immature pods under water stress and well-watered field conditions. Soil P level and cowpea genotypes interaction had a significant ($P \leq 0.05$) effect on DM%, the homogeneous group format cannot be used because of the pattern of significant differences. There was no significant interaction between water status and cowpea genotypes on DM%.

Significant and positive correlation ($P \leq 0.05$) was obtained between grain yield and number of pods per plant and number of seeds per pod. Negative and significant correlation was obtained between grain yield and 100 seed weight (Table 13). A negative and significant correlation was obtained from pod length and number of pods per plant. Positive and significant correlation was obtained between pod length and number of seeds per pod. Negative and significant correlation between number of seed per pod and 100 seed weight (Table 13).

Significant and positive correlation ($P \leq 0.05$) was obtained between 6 WAP and 8, 10, 12 WAP, plant biomass and grain yield (Table 14). Significantly positive correlation was obtained between number of trifoliate leaves at 6, 8, 10 and 12 WAP and plant biomass. Significantly positive correlation was obtained between number of trifolites at 8, 10 and 12 WAP and cowpea grain yield. Significantly positive correlation was obtained between plant biomass and grain yield (Table 14).

Table 12: Interaction effect of cowpea genotype and water status on yield components of cowpea in 2012 planting season

Moisture status	**Genotypes**	**HSW**	**FW Immature Pods (g) (10 WAP)**	**DW immature Pod (g) (10 WAP)**
Ws	Oloyin	22.4a	90.4cd	20.3ef
Ww	IT00K-1217	21.6ab	100.8cd	17.4f
Ws	IT00K-1217	21.1ab	105.9bcd	22.1def
Ww	Oloyin	20.4bc	66.7d	16.4f
Ww	Tvu 9848	19.3cd	102.5bcd	20.0ef
Ww	Tvu 6365	18.8d	110.3bcd	20.1ef
Ws	Tvu 9848	18.8d	120.4bc	23.3def
Ws	Tvu 6365	18.7d	114.1bc	21.8def
Ww	Tvu 15445	16.3e	187.1a	40.1a
Ww	Tvu 4632	16.0ef	107.8bcd	22.4def
Ws	Tvu 4632	15.2efg	107.2bcd	25.0def
Ww	Tvu 16408	14.8fgh	123.3bc	24.0def
Ww	Tvu 15143	14.5gh	123.2bc	29.9bcd
Ws	Tvu 15445	13.9ghi	147.2ab	34.4abc
Ws	Tvu 16408	13.6hi	109.9bcd	27.6cde
Ws	Tvu 15143	12.7i	117.7bc	37.4ab
Significance		0.0073**	0.0332*	0.0321*

Means followed by the same letter in a column are not significantly different at P ≤ 0.05, *= significant (P ≤ 0.05), **= highly significant (P ≤ 0.01) ns= non-significant (P ≤ 0.05), Ws= water stress, Ww= well-watered; HSW = Hundred seed weight; FW and DW implies fresh and dried weight, respectively.

Table 13: Pearson correlation analysis for yield and yield parameters

	Yield kg ha^{-1}	Pod length	Number of pod per plant	Number of seed per pod
Pod length	0.1604			
Number of pod per plant	0.2818**	-0.1793*		
Number of seed per pod	0.2666**	0.6607***	-0.1446	
100 seed weight	-0.1908*	-0.1085	0.1663	-0.4028***

Table 14: Pearson correlation between number of leaves and biomass and grain yield

	Leaf count per plant (weeks after planting)				
	6 WAP	8 WAP	10 WAP	12 WAP	Biomass
8 WAP	0.8007***				
10 WAP	0.7980***	0.8265***			
12 WAP	0.7784***	0.7868***	0.9285***		
Biomass	0.6583***	0.6881***	0.7552***	0.7401***	
Grain yield	0.2631**	0.3831***	0.3781***	0.3782***	0.3991***

4.6 Nutrient content and uptake in mature green pods and cowpea grains

4.6.1 Nutrient content in mature green pods and dried cowpea grains

Statistical analysis showed that variation in soil P level exerted a significant effect on grain tissue P content and uptake across cowpea genotypes and a highly significant difference on P content across the various cowpea genotypes (Table 15). Moisture stress exerted a significant difference on P uptake. Cowpea genotypes Tvu 15445 and IT00K1217 had the highest total P content (0.52 %) and while Tvu 16408 had the lowest (0.44 %). Cowpea genotype Tvu 16408 achieved higher P uptake (13.13 mg kg^{-1}), while the lowest P uptake was obtained by cowpea genotype IT00K1217 with (6.38 mg kg^{-1}). Cowpea genotype IT00K1217 had more total nitrogen (N) content (4.38 %), while the lowest total N content was obtained from Tvu4632 with 3.84 %. Cowpea genotype Tvu 16408 had higher N uptake (125.58 mg kg^{-1}) while the lowest N uptake was achieved by cowpea genotype IT00K1217 with (53.08 mg kg^{-1}).

The interaction between cowpea genotypes and P rates showed no significantly effect on total N and N uptake and highly significant differences on P uptake (Table 16).

Table 15: Effect of P level, moisture status and cowpea variety on nutrient content and uptake of P and N in harvested cowpea grains

Treatment	Total P content (%)	P uptake (mg kg^{-1})	Total N content (%)	N uptake (mg kg^{-1})
Soil P level (P)				
Low	0.42b	6.72b	4.06a	67.69a
High	0.53a	10.43a	4.13a	80.81a
Moisture status				
Well-watered	0.48a	9.95a	3.97a	82.16a
Water stressed	0.47a	7.11b	4.23a	66.43a
Cowpea genotypes (V)				
IT00K1217	0.52a	6.38b	4.38a	53.08b
Oloyin	0.46bcd	6.67b	4.05ab	58.14b
Tvu 9848	0.47bcd	8.88b	3.96b	75.80b
Tvu 6365	0.49ab	8.97b	4.36a	79.09b
Tvu 4632	0.44cd	7.97b	3.84b	67.14b
Tvu 15445	0.52a	7.61b	4.03ab	58.58b
Tvu 16408	0.44d	13.13a	3.93b	125.58a
Tvu 15143	0.48abc	8.91b	4.19ab	76.95b
Soil P level (P)	0.0350*	0.003**	0.602ns	0.223ns
Moisture (M)	0.530ns	0.032*	0.122ns	0.145ns
Cowpea genotype (V)	0.002**	0.034*	0.035*	0.024*
PxV interaction	0.007**	ns	ns	ns

Means followed by the same letter in a column are not significantly different at P ≤ 0.05 * implies significantly different at P ≤0.05, ** implies significantly different at P≤0.01, ns implies non-significantly at P=0.05)

Table 16: Interaction of P and moisture status on cowpea grain N and P status

Phosphorus fertilisation Level	Moisture status	Total P content (%)	P uptake (mg kg^{-1})	Total N content (%)	N uptake (mg kg^{-1})
HP	WW	0.55a	12.67a	4.07a	94.6a
HP	WS	0.51a	8.19a	4.18a	67.2a
LP	WS	0.43a	7.23a	4.25a	65.7a
LP	WW	0.42a	6.21a	3.86a	69.7a
P≤0.05		0.32ns	0.13ns	0.33ns	0.26ns

HP= high phosphorus and LP=low phosphorus, WS=water stress and WW=well-watered. Means followed by the same letter in a column are not significantly different at P≤0.05. ns implies non-significantly at P=0.05

The results showed that P levels and cowpea genotype variation exerted significant ($P \leq 0.05$) effects on P content, P uptake and N uptake in immature green pods (Table 17). Moisture status and cowpea genotype variation exerted significant effects on total P content and N uptake in immature pods. Different cowpea genotypes responded differently towards P level and moisture stress condition. Cowpea genotype Tvu 9848 had more total P content, while the lowest total P content was obtained by Tvu 15143. Cowpea genotype Tvu 15445 had higher P uptake and the lowest P uptake was obtained by cowpea genotype Oloyin at 0.01 mg kg^{-1} in immature green pods (Table 17). Cowpea genotype Tvu 9848 obtained higher total N content (4.37 %), while the lowest total N content was obtained by cowpea genotype Tvu 15445 with 3.35 mg kg^{-1}. Cowpea genotypes Tvu 15445 obtained more N uptake, while the lowest N uptake was obtained by cowpea genotypes Tvu 6365.

The interaction between cowpea genotype and moisture status exerted a significant effect on N and P uptake of immature green pods harvested but not on total N and P content (Table 18). Cowpea genotype Tvu 15445 absorbed more P uptake in well-watered condition, while the lowest P uptake was obtained by Oloyin in well-watered condition. Cowpea genotypes Tvu 4632, 16408 and IT00K1217 did not show any significant difference in P uptake in immature pods. Cowpea genotype Tvu 15445 obtained more N uptake, while the lowest cowpea genotype to N uptake was Oloyin under well-watered condition. Cowpea genotype Tvu 4632 did not any significant effect on N uptake under water stress and well-watered condition. Different cowpea genotypes respond to water stress in different manner.

Table 17: Effect of P level, moisture status and cowpea variety on Content and uptake of P and N in harvested cowpea immature green pods

Treatment	Total P content (%)	P uptake (mg kg^{-1})	Total N content (%)	N uptake (mg kg^{-1})
Soil P level (P)				
Low	0.46b	0.13a	3.85a	0.89b
High	0.55a	0.10b	3.94a	0.96a
Moisture status (M)				
Well-watered	0.52a	0.12a	3.94a	0.89b
Water stressed	0.49b	0.12a	3.85a	0.97a
Cowpea genotypes (V)				
IT00K1217	0.57ab	0.11c	4.16ab	0.81b
Oloyin	0.54ab	0.01c	4.35a	0.79b
Tvu 9848	0.60a	0.12bc	4.37a	0.86b
Tvu 6365	0.54ab	0.11c	4.08abc	0.71b
Tvu 4632	0.49bc	0.11bc	3.71bcd	0.86b
Tvu 15445	0.43cd	0.15a	3.35d	1.23a
Tvu 16408	0.44cd	0.11bc	3.67cd	0.94b
Tvu 15143	0.41d	0.14ab	3.46d	1.15a
Soil P level (P)	0.0179*	0.0093**	0.1275ns	0.0203*
Moisture (M)	0.0327*	0.3234ns	0.1011ns	0.0286*
Cowpea lines (V)	0.0000***	0.0000***	0.0000***	0.0000**
PxV interaction	0.2159ns	0.0029**	0.0245*	0.0347*
VxM interaction	0.0920ns	0.0199*	0.7652ns	0.0251*

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$ * implies significantly different at $P \leq 0.05$, ** implies significantly different at $P \leq 0.01$, *** implies significantly different at $P \leq 0.001$; ns implies non-significantly different at $P = 0.05$)

Table 18: Interaction effect of soil moisture status and cowpea genotype on N and P content and uptake of immature green pods

Moisture Level	Cowpea Genotype	Total P content (%)	P uptake (mg kg^{-1})	Total N content (%)	N uptake (mg kg^{-1})
WW	Oloyin	0.56a	0.09c	4.42a	0.71e
WS	Oloyin	0.53a	0.11bc	4.29a	0.86cde
WW	IT00K-1217	0.63a	0.11bc	4.35a	0.75de
WS	IT00K-1217	0.51a	0.11bc	3.96a	0.86cde
WW	Tvu 9848	0.63a	0.10bc	4.46a	0.74de
WS	Tvu 9848	0.58a	0.13abc	4.29a	0.97bcde
WW	Tvu 6365	0.55a	0.11bc	4.01a	0.82cde
WS	Tvu 6365	0.54a	0.10bc	4.07a	0.77de
WW	Tvu 15445	0.42a	0.17a	3.30a	1.33a
WS	Tvu 15445	0.42a	0.14ab	3.31a	1.11abc
WW	Tvu 4632	0.49a	0.10bc	3.72a	0.81cde
WS	Tvu 4632	0.49a	0.12bc	3.70a	0.90cde
WW	Tvu 16408	0.43a	0.10bc	3.62a	0.87cde
WS	Tvu 16408	0.43a	0.12bc	3.73a	1.01abcde
WW	Tvu 15143	0.44a	0.13abc	3.378a	1.05abcd
WS	Tvu 15143	0.36a	0.14ab	3.37a	1.26ab
P- values		0.0920ns	0.0199*	0.7652ns	0.0251*

WS=water stress and well-watered; Means followed by the same letter in a column are not significantly different at P≤ 0.05 *= significantly (P≤ 0.05), ** significantly (P≤ 0.01), ns= non-significantly (P≤ 0.05)

The interaction between cowpea genotypes and P rate exerted a significant (P≤0.05) effect on total N in cowpea grain (Table 19). Cowpea genotype Tvu obtained more total N at high P level; Oloyin obtained more total N under low soil P and while the lowest total N content was obtained by Tvu 15445 in low soil P. Cowpea genotypes responded differently toward P level (Table 19)

Table 19: Interaction effect of Soil P level and cowpea genotype on total N on cowpea grains

Phosphorus level	Cowpea genotype	Total N (%)
HP	Tvu9848	4.44a
LP	Oloyin	4.38a
HP	IT00K1217	4.33ab
HP	Oloyin	4.32ab
LP	Tvu 9848	4.30ab
HP	Tvu 6365	4.16abc
HP	Tvu 4632	4.04abcd
LP	Tvu 6365	4.00abcd
LP	IT00K-1217	3.98abcde
LP	Tvu 16408	3.87abcde
LP	Tvu 15143	3.60bcde
HP	Tvu 16408	3.47cde
HP	Tvu 15445	3.45cde
LP	Tvu 4632	3.38de
HP	Tvu 15143	3.31de
LP	Tvu 15445	3.23e
Significance		0.0245*

Means followed by the same letter in a column are not significantly different at P≤ 0.05 HP= high P fertiliser status and LP=low soil phosphorus. *= significantly (P≤ 0.05).

4.7 Treatment effects on cowpea root characteristics

4.7.1 Lateral root branching density characteristics

The results show that cowpea genotype Tvu 6365 had higher branching density at 5 cm and 10 cm depths, while the lowest branching density at 5 cm and 10 cm depth were obtained by Tvu 15143 (Table 20). Cowpea genotype IT00K1217 had more 1.5 mm branching density at 5 cm and 10 cm depth, while the lowest was obtained by Tvu 15143 at 5 and 10 cm depth. Cowpea genotype Tvu 15143 had the highest 3rd order branching density, while the lowest 3rd order branching density was obtained by IT00K1217. Cowpea genotype Tvu 4632 obtained the highest deep score, while the lowest deep score was obtained by genotypes Tvu 9848 and Tvu 15445. Cowpea genotype Tvu 6365 obtained highest shallow score, while cowpea genotype Oloyin had the least shallow score. Cowpea genotype Tvu 6365 had higher number of basal roots, followed by Tvu 15445 while IT00K1217 had the lowest number of basal roots. Cowpea genotype Tvu 6365 had highest nodule score, while the lowest nodule score was obtained by Oloyin. Phosphorus level and moisture stress status had no influence on taproot diameter at 5 and 10 cm. Phosphorus level, moisture stress status and cowpea variety had no influence on taproot diameter at 5, 10, 15 and 20 cm depth. There was no significant interaction between P level and moisture stress on taproot diameter at 5, 10, 15 and 20 cm depth. The interaction between moisture stress x P level showed no significantly effect on taproot diameter at 5 cm, 10 cm, 15 cm and 20 cm depth. The interaction between moisture stress x cowpea variety showed no significantly effect on taproot diameter at 5 cm, 10 cm, 15 cm and 20 cm depth. The interaction between P level x moisture stress x cowpea variety showed no significantly effect on taproot diameter at 5 cm, 10 cm, 15 cm and 20 cm depth.

Phosphorus level, moisture status and cowpea genotype did not show any significance ($P \leq 0.05$) difference on disease score. There was no interaction between P level, moisture status and cowpea variety on disease score (Table 20).

The results showed that P levels, moisture status and cowpea genotype variation exerted significant ($P \leq 0.05$) effects on taproot diameter at 15 cm depth (Table 21). Only moisture status variation exerted significant differences on taproot diameter at 20 cm depth. There were significant differences in taproot diameter at 10 cm depth among the different cowpea genotypes. Cowpea genotypes Tvu 4632 and 6365 had higher taproot diameter at 10 cm, while the lowest taproot diameter at 10 cm was obtained by cowpea genotype Tvu 15445. On the other hand, genotype Tvu 4632 had thicker taproot at 15 cm while Tvu 15445 had the lowest. The taproot thickness decreased with depth (Table 21).

4.7.2 Treatment interaction effect on lateral root branching density characteristics

Although, soil P level and cowpea genotype interaction had a significant ($P \leq 0.05$) effect on branching densities at 5 and 10 cm depth, the homogeneous group format cannot be used because of the pattern of significant differences.

Table 20: Lateral root branching density characteristics of the different cowpea genotypes in response P rates, moisture status and cowpea variety

Treatments	Branching Density at 5cm	Branching density at 10 cm	Branching density at 15 cm	1.5 mm Branching density at 5 cm	1.5 mm branching density at 10 cm	3rd order Branching density	Deep Score	Shallow Score	Number of basal roots	Nodule Score	Diseases
Soil P level (P)l											
Low	14.0a	7.5a	2.3a	1.4a	0.6a	3.8a	5.5a	4.2a	7.7	3.2a	5.03a
High	15.4a	7.6a	2.6a	2.4a	0.6a	4.6a	6.3a	2.2a	8.2	4.1a	5.59a
Moisture status (M)											
Stressed	14.6a	7.6a	1.9a	1.7a	0.6a	4.1a	5.8a	4.1a	8.0	3.2b	5.68a
Well watered	14.8a	7.5a	2.1a	2.1a	0.6a	4.3a	6.0a	4.3a	7.9	4.1a	4.94a
Cowpea genotypes (V)											
Tvu 4632	15.5bc	7.9a	2.8a	1.9ab	0.8a	4.9ab	6.7a	4.6ab	8.2ab	3.0cd	5.6a
Tvu 6365	18.9a	8.2a	2.8a	2.0ab	0.3b	4.7ab	6.5ab	5.1a	9.8a	4.8a	5.3a
Tvu 9848	15.4bc	7.1ab	2.7a	1.9ab	0.4ab	4.0abc	5.2b	4.2ab	8.7ab	3.8abc	5.6a
TVu15445	15.3bc	7.3ab	1.1a	1.9ab	0.8ab	3.8abc	5.2b	4.9a	7.7b	3.2cd	5.7a
TVu16408	16.0ab	8.6a	3.4a	1.5b	0.3b	4.3abc	5.8ab	4.2ab	9.3ab	4.3abc	4.9a
TVu15143	13.0bcd	8.5a	2.7a	1.4b	0.3b	5.2a	5.5ab	3.9ab	7.3bc	4.5ab	5.4a
IT00K1217	10.1d	5.4b	1.2a	2.8a	1.1a	3.2c	6.2ab	3.5ab	5.3c	2.2d	5.6a
Oloyin	12.4cd	7.3ab	2.2a	1.8ab	0.1a	3.6bc	6.1ab	3.2b	7.5b	3.4cd	4.5a
Phosphorus (P)	0.46ns	0.91ns	0.59ns	0.12ns	0.56ns	0.20ns	0.13ns	0.91ns	0.62ns	0.09ns	ns
Moisture (M)	0.79ns	0.85ns	0.08ns	0.25ns	0.52ns	0.33ns	0.52ns	0.51ns	0.81ns	0.015*	ns
Variety (V)	0.000***	0.001**	0.11ns	0.024*	0.0001***	0.000***	0.009**	0.009**	0.000***	0.000***	ns
P x V interaction	0.021*	0.035*	0.80ns	0.09ns	0.37ns	0.18ns	0.73ns	0.63ns	0.09ns	0.14ns	ns

WW=Well- Watered, WS=Water Stress, Means followed by the same letter in a column are not significantly different at P ≤ 0.05;
*,** and *** implies significantly different at 5%, 1% and 0.1%, respectively, while ns connotes non-significant.

Table 21: Taproot diameter characteristics (mm) in response P rates, moisture status and cowpea variety

Treatments	Taproot Diameter (mm) at 5 cm	Taproot diameter (mm) at 10 cm	Taproot diameter (mm) at 15 cm	Taproot diameter (mm) at 20 cm
Phosphorus rates				
Low	4.9a	2.3a	0.9b	0.09a
High	5.5a	2.8a	1.3a	0.15a
Moisture status				
Low	5.2a	2.5a	0.8a	0.00b
High	5.2a	2.6a	1.4b	0.23a
Cowpea varieties				
Tvu 4632	5.7a	3.0a	1.5a	0.19a
Tvu 6365	5.5a	3.0a	1.3ab	0.32a
Tvu 9848	4.6a	2.2ab	0.9ab	0.14a
Tvu15445	5.0a	2.0b	0.7b	0.04a
Tvu16408	3.4a	2.7ab	1.1ab	0.00a
Tvu15143	4.5a	2.3ab	0.9ab	0.00a
IT00K1217	5.1a	2.5ab	1.0ab	0.12a
Oloyin	5.7a	2.9b	1.07ab	0.12a
Significance level				
Phosphorus (P)	0.08ns	0.07ns	0.047*	0.19ns
Moisture (M)	0.87ns	0.80ns	0.02*	0.033*
Variety (V)	0.0163*	0.001**	0.04*	0.16ns
PxM interaction	0.73ns	0.92ns	0.89ns	0.51ns
PxV interaction	0.93ns	0.76ns	0.96ns	0.40ns
MxV interaction	0.75ns	0.23ns	0.55ns	0.16ns

Means followed by the same letter in a column are not significantly different at P≤ 0.05
*= significantly (P≤ 0.05), ** significant (P≤ 0.01), ns= non-significantly (P≤ 0.05)

Results show that highly positive and significant correlation was obtained between angle of basal roots and angle of adventitious roots, branching density at 10 cm, shallow score, deep score and 3rd branching density (Table 22). Highly positive and significant correlation was obtained between angle of basal roots and stem diameter, branching density at 5 cm. strong positive and significant correlations was obtained on angle of basal root and taproot diameter at 10 cm, basal roots, and nodule score. There was no significant correlation between angle of angle of basal roots and cowpea grain yield (Table 22). Furthermore, strongly positive and significant correlation was obtained between stem diameter and taproot diameter at 5 cm, 10 cm, 15 cm, angle of adventitious roots, basal roots, branching densities at 5 cm,10 cm, 15 cm and 1.5 mm branching densities at 5 cm, 10 cm, shallow score, deep score, nodule score and diseases (Table 22). Highly positive and significant correlation was obtained between stem diameter and branching density at 15 cm and grain yields of cowpea.

Results show that highly positive and significant correlation was obtained between taproot diameter at 5 cm and adventitious roots, basal roots, branching density at 5 cm, 10 cm, 15 cm and 1.5 branching densities at 5 and 10 cm, shallow score, deep scores and diseases (Table 22). Highly positive and significant correlation was obtained between taproot diameter at 5 cm and grain yield of cowpea. Highly positive and significant correlation was obtained between taproot diameter at 10 cm and basal roots, branching densities at 5 cm, 10 cm, 15 cm, shallow scores, nodule scores, 3rd order branching density (Table 22). Strongly positive and significant correlation was obtained between taproot diameter at 10 cm and angle of adventitious and cowpea grain yield. Strongly positive and significant correlation was obtained between taproot diameter at 10 cm and 1.5 branching density at 5 cm, 10 cm and shallow scores. Highly positive and significant correlation was obtained between angle of adventitious roots and basal roots, branching density at 5 cm, 3rd order branching density, deep scores and diseases. Strongly positive and significant correlation was obtained between angle of adventitious roots and taproot diameter at 10 cm and shallow scores. Highly positive and significant correlation was obtained between angle of adventitious roots and branching density at 10 cm.

Highly positive and significant correlation was obtained between taproot diameter and branching densities at 10 and 15 cm, deep and nodule score, 3rd branching density and taproot diameter at 20 cm (Table 22). Highly positive and significant correlation was obtained between taproot diameter at 15 cm and basal roots. Strongly positive and significant correlation was obtained between taproot diameter at 15 cm and branching density at 5 cm, 1.5 mm branching density at 5 cm and 10 cm, disease and grain yield. Highly positive and significant correlation was obtained between basal roots and branching density at 5 cm, shallow scores, deep score, nodule score, diseases and 3rd branching density (Table 22). Highly positive and significant correlation was obtained between basal roots and branching density at 10 cm, 1.5 mm branching density at 5 cm and grain yield. Strong positive and significant correlation was obtained between basal roots and branching density at 15 cm (Table 22).

Correlation of root characteristics and grain yield

Results show that highly positive and significant correlation was obtained between the branching density at 5 cm and shallow score, deep score, nodule score, diseases and 3rd order branching density (Table 23). Strongly positive and significant correlation was obtained between branching density at 5 cm and taproot diameter at 20 cm. There was no significant correlation obtained branching density at 5 cm and grain yield. Highly positive and significant correlation was obtained between branching density at 10 cm and deep score, nodule score and 3rd order branching density. There was no significant correlation between branching density at 10 cm and cowpea grain yield (Table 23).

Furthermore, highly positive and significant correlation was obtained between branching density at 15 cm deep and nodule scores. Highly positive and significant correlation was obtained between branching density at 15 cm and 3rd order branching density. There was no correlation between branching density at 15 cm and grain yield (Table 23).

Significant positive correlation was obtained between 1.5 mm branching density at 5 cm and 1.5 mm branching density at 10 cm, shallow scores, deep scores, disease (Table 23). Highly significant positive correlation was obtained between on 1.5 mm branching density at 5 cm and 3rd order branching density. There was no significant positive correlation obtained between 1.5 mm branching density at 5 cm and grain yield. Strongly positive and significant correlation was obtained between the 1.5 mm branching density at 10 cm and deep scores. There was no significant correlation obtained between 1.5 mm branching density at 10 cm and cowpea grain yield (Table 23).

Highly significant positive correlation was between shallow scores and nodule scores, disease and 3rd order branching density. Strongly positive and significant correlation was obtained between shallow scores and deep scores and taproot diameter (mm) at 20 cm (Table 23). There was no significant correlation between shallow scores and cowpea grain yield. Highly positive and significant correlation was obtained between deep scores and nodules scores, nodule scores and disease. Highly positive and significant correlation was obtained between deep scores and taproot diameter (mm) at 20 cm and cowpea grain yield (Table 23).

Correlation of root characteristics and cowpea grain yield

Highly positive and significant correlation was obtained between nodule scores and 3rd order branching density (Table 24). Highly positive and significant correlation was obtained between nodules scores and disease. Strongly positive and significant correlation was obtained between nodule scores and taproot diameter (mm) at 20 cm and cowpea grain yield. Highly positive and significant correlation was obtained between disease and 3rd order branching density. There was no significant correlation between disease and cowpea grain yield. Strongly positive and significant correlation was obtained between 3rd branching density and taproot diameter (mm) at 20 cm (Table 24). There was no significant obtained between 3rd order branching density and cowpea grain yield. There was no significant correlation obtained taproot diameter (mm) at 20 cm and cowpea grain yield.

Table 22: Pearson correlation of root characteristics (taproot diameters, angles and basal roots) and cowpea grain yield

	Angle of basal roots	Stem diameter (mm)	Taproot diameter (mm) at 5 cm	Taproot diameter (mm) at 10 cm	Angle of adventitious roots	Taproot diameter (mm) at 15 cm	Basal roots
Angle of base roots	1.0000***						
Stem diameter (mm)	0.2329**	1.0000***					
Taproot diameter at 5 cm	0.1164	0.7607***	1.0000***				
Taproot diameter at 10 cm	0.1864*	0.6241***	0.8232***	1.0000***			
Angle of adventitious roots	0.5004***	0.4429***	0.3155***	0.2554**	1.0000***		
Taproot diameter at 15 cm	0.0636	0.4414***	0.5651***	0.7144***	0.1542*	1.0000***	
Base roots	0.18925*	0.4792***	0.3177***	0.3078***	0.2907***	0.2341**	1.0000***
Branching density at 5 cm	0.2522**	0.4588***	0.3158***	0.2940***	0.3728***	0.2088*	0.8088***
Branching density at 10 cm	0.3373***	0.3219***	0.4120***	0.3231***	0.2605**	0.3008***	0.2851**
Branching density at 15 cm	0.1056	0.2310**	0.3699***	0.4176***	0.1120	0.5913***	0.1630*
1.5 mm branching density at 5 cm	-0.0960	0.4364***	0.2972***	0.1861*	0.1308	0.1883*	0.2494**
1.5 mm branching density at 10 cm	-0.1671*	0.3181***	0.4580***	0.2135*	0.0619	0.0737	-0.0645
Shallow score	0.2895***	0.3672***	0.3476***	0.1829*	0.2189*	0.1924*	0.4484***
Deep score	0.3527***	0.6975***	0.7781***	0.8307***	0.4230***	0.6298***	0.3813***
Nodule score	0.1977*	0.4200***	0.2967***	0.2808**	0.2098*	0.4214***	0.5580***
Diseases	0.1255	0.4182***	0.3712***	0.3124***	0.2904***	0.2195*	0.3355***
3rd branching density	0.3108***	0.4499***	0.3646***	0.4166***	0.3164***	0.4158***	0.3912***
Taproot diameter at 20 cm	-0.0085	0.1348	0.2160*	0.3283***	0.3414	0.4220***	0.0862
Grain yield	0.0690	0.2454**	0.2472**	0.2469**	0.1408	0.1788*	0.2383**

*= significant (P≤0.05), **=highly significant (P≤0.01) and ***= highly highly significant (P≤0.001)

Table 23: Pearson correlation of root characteristics (branching densities, shallow roots and deep score) and cowpea grain yield

	Branching density at 5 cm	Branching density at 10 cm	Branching density at 15 cm	1.5 mm Branching density at 5 cm	1.5 mm Branching density at 10 cm	Shallow score	Deep score
Branching density at 5 cm							
Branching density at 10 cm	0.3358***						
Branching density at 15 cm	0.2057*	0.5217***					
1.5 branching density at 5 cm	0.2999***	-0.0595	0.0625				
1.5 branching density at 10 cm	-0.06777	-0.0494	-0.0363	0.3257***			
Shallow score	0.4934***	0.1535	0.0438	0.3284***	0.1317		
Deep score	0.3801***	0.3080***	0.3552***	0.3373***	0.2822**	0.1952*	
Nodule score	0.5395***	0.3709***	0.3612***	0.2945***	-0.0568	0.2900***	0.3579***
Disease	0.3938***	0.2060*	0.1234	0.3166***	0.1456	0.3311***	0.4510***
3rd order branching density	0.4500***	0.3956***	0.2753**	0.2842**	-0.0243	0.3313***	0.4832***
Taproot diameter (mm) at 20 cm	0.1816*	0.0366	0.0685	0.0953	0.0482	0.1940*	0.2708**
Grain yield	0.1562	0.1625	0.0752	0.0020	-0.0178	0.1183	0.2508**

*= significant (P≤0.05), **=highly significant (P≤0.01) and ***= highly highly significant (P≤0.001)

Table 24: Pearson correlation of root characteristics (taproot diameters, angles and basal roots) and cowpea grain yield

	Nodule score	Disease score	3RD order branching density	Taproot diameter at 20 cm
Nodule score				
Disease score	0.2804**			
3rd order branching density	0.6052***	0.3475***		
Taproot diameter at 20 cm	0.1776*	0.0698	0.2219*	
Grain yield	0.2026*	0.1163	0.1317	0.1292

*= significant (P≤0.05), **=highly significant (P≤0.01) and ***= highly highly significant (P≤0.001)

CHAPTER 5

DISCUSSION

5.1 Flowering and physiological maturity of cowpea

5.1.1 Effect genotype, P level and moisture stress on number of days to 50% flowering and physiological maturity

Phosphorus is an important element to promote the earliness of flowering but in this study phenological development was not affected by P. Lack of response to P may be due to the adequate initial P in the soil or that drought stress reduced P availability and uptake. Flowering and physiological maturity of the cowpea did not show any significant response to moisture stress. Flowering and physiological maturity of cowpea did not show any response to P application. Cowpea genotypes differed significantly in terms of days to reach flowering and physiological maturity. Cowpea genotype Tvu 15445 reached flowering early as compared to the local cultivar IT00K1217. Flowering early is significant trait that shows the crop can escape or avoid drought stress. Cowpea genotype Tvu 15445 flowered early, it can be used to escape drought stress. Flowering in a response to drought stress was found to be insignificant. The differences among eight cowpea genotypes are probably due to genetic differences or climatic conditions. The results from this study are in agreement with Khan *et al*. (2010) who reported that cowpea genotypes that he studied showed variation in maturity and these variations in maturity of different cowpea genotypes may be due to climatic conditions or genetic make-up of the tested genotypes. Significant difference ($P \leq 0.01$) was observed on days to physiological maturity between the eight cowpea genotypes. Cowpea genotype Tvu 15143 matured early as compared to the IT00K1217. Number of days to reach physiological maturity relies on time required to reach flowering in the cowpea genotypes. The treatments did not have effect on time to flowering. These results contradict those reported by El-Shaikh *et al.* (2010) who reported that P promotes earliness of flowering and yield in garden pea.

5.1.2 Interaction of P level and genotype on physiological maturity of cowpea

The interaction effect between cowpea genotype and P level influenced period to physiological maturity in cowpea. In this study high level of P shortened the time to physiological maturity, while low soil P increased period to physiological maturity in cowpea. Cowpea genotypes Tvu15445 and Tvu 15143 with high P reached physiological maturity early as compared to low soil P. High P promotes earliness to reach physiological maturity. Cowpea genotype Tvu 15143, under both high P, and low soil P reached maturity early in this study. Low soil P increased physiological maturity in Oloyin, Tvu 6365 and 9848 but genotype Tvu 15143 was not affected by insufficient P in the soil. IT00K1217 reached physiological maturity late in both high and low soil P. Cowpea genotypes differ significantly in their P uptake and usage on physiological maturity. Cowpea genotype Oloyin showed no significant difference on phenological in response to P application. These results generally agree with Marschner (2002) who reported that P application reduced days to physiological maturity by controlling some key enzyme reactions involved in hastening crop maturity.

5.2 Cowpea growth parameters

5.2.1 Effect of cowpea genotype, P level and moisture status on plant height

Soil P increased plant height. Moisture stress condition showed no significant difference on plant height. The taller the plant of cowpea the likely advantage to produce higher number of pods per plant and increase the seed number per plants. Thiyagarajan and Rajasekaran (1993) found that plant height also affects seeds per pod. Cowpea genotypes differed significantly in term of plant height (Table 3). Cowpea genotype Tvu 15445 obtained tallest plant height while Oloyin and Tvu 6365 obtained short plant height during 4 and 6 WAP. Cowpea genotype Tvu 15445 obtained tallest height and lowest was obtained by Oloyin during 8 and 10 WAP. Cowpea genotypes in this study differed in terms growth habit. Growth habitat such as bush/erect type will increase yield.

5.2.2 Effect of cowpea genotype, P level and moisture status on number of branches

Number of branches per plant differed significantly between eight cowpea genotypes. Cowpea genotype Tvu 16408 produced higher number of branches on 6 and 8 WAP than Oloyin (Table 3). The increase in P level also increased number of branches at 6 WAP but not at 8 WAP. Number of branches per plant in response to moisture status at different levels was found to be insignificant at 6 and 8 WAP (Table 3). Well-watered condition increased number of branches at 6 WAP by 11 % while decreased by 8 % at 6 WAP. Moisture status condition decrased number of branches by 12 % at 8 WAP. Application of P as single super phosphate increased number of branches, dry weight of cowpea and soybean plants (Amba *et al*., 2013). The higher the number of branches of a plant higher the chances to obtain higher grain yield. Results obtained by Ali *et al*. (2009) showed that significant differences in number of branches per plant were as a result of varietal differences in cowpea. The variation in number of branches was due to the genetic makeup of the cowpea genotypes. Highly correlation (R^2=0.1983) indicate that number of branches contribute to higher grain yield in cowpea. These findings agree with the study conducted by Kumari *et al*. (2010) who reported that number of branches showed a positive and significant correlation with seed yield in cowpea. Nakawuka and Adipala (1999) reported that number of branches, number of pods per plant and seeds per pod were the major direct contributors to grain yield in cowpea. There was no interaction effect between cowpea genotypes and phosphorus level and moisture stress conditions.

5.2.3 Effect of P level and cowpea genotype on number of leaves

Soil P increased number of leaves and moisture status showed no significant difference on number of leaves. The increase in P application increased cowpea number of leaves while low soil P reduced number of leaves. Number of leaves were higher where P was applied in the current study. Number of leaves per plant showed a significant ($P \leq 0.05$) difference among cowpea genotypes. Cowpea genotype Tvu 15143 obtained maximum number of leaves as compared to IT00K1217 at 6, 8, 10 and 12 WAP (Table 7). Different cowpea genotypes varied in the number of leaves produced per plant. Large variability was observed on number of leaves among eight cowpea genotypes. The findings are in line with those of Magashi *et al.* (2014) who reported that large variability was observed for root length, number of roots, root diameter, number of pods per plant, pod length, 100 seed weight, plant height, number of leaves, number of branches, number of flowers, in descending order. The growth habit of different genotypes differed from erect to creeping, with the creeping genotypes having higher number of leaves per plant. Low soil P decreased plant biomass and reduced leaf sizes Kugblenu *et al*. (2014). High P increased plant biomass and improved the quality of the crop. Furthermore, it helps plant to increase N-fixing capacity of legumes, and promotes root development and increased resistances to plant diseases. Decrease in leaf area and number of leaves contributes to reduce plant growth and biomass. Strong positive and significant correlation was between number of leaves on 6, 8, 10, 12 WAP and plant biomass. The results agree with Azad e*t al*. (2013) who found that number of leaves was positively correlated with plant biomass. Strong positive and significant correlation was between number of leaves on 6, 8, 10, 12 WAP and grain yield on cowpea. The results contradict with Kawooya (2014) who reported that number of leaves was weakly and negatively correlated to grain yield.

5.2.4 Interaction of moisture stress and cowpea genotypes on number of leaves

Interaction effect of moisture stress and cowpea genotypes reduced number of leaves per plant while Tvu 15143, IT00K1217 benefitted from well-watered condition as compared to moisture stress (Table 8). Cowpea genotype Tvu 15143 produced maximum number of leaves in well-watered condition as compared to water stressed condition while cowpea genotype Tvu 6365 produced maximum number of leaves under water stress condition as compared to the well-watered condition. Increased in number of leaves per plant will contribute toward biomass. Number of leaves per plant increased with an increase in water content in the study. According to Mustapha *et al*. (2014), water stress leads to reduction in the rate of leaf initiation and reduction in leaf area of previously formed leaves. They further added that this will result in lower photosynthetic activity in the affected leaves. The overall effect is a decrease in the rate of new leaf initiation and increase in leaf shedding thereby resulting to reduction in number of green leaves per plant. Drought stress is a very important limiting factor for both plant growth and establishment. Furthermore, both cell expansion and cell growth are suppressed by low turgor pressure (Jaleel *et al*., 2009). It will reduce plant growth by affecting photosynthesis, respiration and translocation. Reason for decrease in number of leaves with increase in drought might be that drought inhibits growth in relation with changes in cell size and division resulting in reduced leaf production and promoting senescence and abscission (Karamanos, 1980). Drought stress causes a major limit to plant growth, which will cause a serious reduction in number of leaves in cowpea. The findings agreed with EI-Juhany and Aref (2005) who observed reduction in number of leaves in *Leucaena leucocephala* under drought stress and Aderolu (2000) in cowpea.

5.2.5 Effect of P level and cowpea genotype on plant height

Increased P application resulted in increased plant height while the low soil P reduced plant height (Table 4). Cowpea genotype Tvu 15445 obtained taller plants under high P as compared to low soil P. Cowpea genotype IT00K1217 obtained short plant height under low soil P (Table 4). The increased in plant height was promoted by high P application while the decrease in plant height may be to lack of P in the soil. Plant height may contribute toward yield in the cowpea. These results are similar to the findings of Singh *et al.* (2009) who recorded 25 and 35 cm at 8 and 12 WAP as P rates increased from 9 to 45 kg ha^{-1}. Nkaa *et al.* (2014) found that P enhances branch length and width of leaves and increased plant height. Similarly, Sairam *et al.* (1984) reported that increasing P applications in the soil increased cowpea plant height. Low soil P is a major limiting nutrient for plant growth and productivity, including plant height. The results of Ayub *et al.* (2002) in maize reported that P application significantly increased dry matter and various plant characteristics like plant height, number of leaves and leaf area. Nkaa *et al.* (2014) observed that P application increased plant parameters such number of leaves, dry weight and nodule number of cowpea plants. The crop performed better under high P condition as compared to low soil P condition. The results from the current study suggest that the effect of soil P condition on cowpea plant height and the mean number of days to 50% physiological maturity is genotype specific. However, it must be noted that measurement of plant height is tricky when cowpea genotype exhibit erect and prostrate growth habits.

5.3 Photosynthetic parameters of cowpea

5.3.1 Effect of P level and moisture stress on photosynthetic parameters of cowpea

Phosphorus rates did not show any significant influence on photosynthetic rate. The results from this study showed that moisture stress reduced photosynthetic rate, water conductance, transpiration rate, sample cell CO_2, relative humidity in the cell, sample cell H_20 and vapour pressure deficit based on leaf temperature in cowpea leaves. Drought stress affects stomata closure limiting photosynthetic rate and transpiration rate (Table 9). Water stress decreased photosynthetic rate by 47 %, decrease water conductance by 58 %, decreased transpirate rate by 50 %, increased sample CO_2 by 6 %, decreased relative haumidity in the cell by 40 % and increased vapour pressure deficit by 20 %. Closing of stomata in the leaves decrease intercellular CO_2 concentration which cause shortage of CO_2 assimilation and it will results in imbalances between photochemical activity and photosynthesis Ohashi (2006). The results agree with Ohashi (2006) who reported that photosynthetic rate, transpiration rate and intercellular CO_2 concentration are reduced by water stress. Yan *et al*. (2011) and Mafakheri *et al.* (2010) reported that stomatal conductance and transpiration rate decreased with increase in water stress. For crops to respond to drought stress rapidly they must close their stomata to avoid loss of water through transpiration. Drought stress is a limiting factor to plant growth and development, and also decreases transpiration, water potential in the leaf and photosynthetic rate as a result of stomatal closure which will cause a reduction in cowpea leave photosynthesis. The findings of this study are in agreement with earlier findings reported by Soldatini *et al.* (1990) for maize. According to Sarker and Hara (2011), transpiration rate, stomatal conductance and photosynthetic rate are directly related to moisture stress. Under moisture stress conditions, transpiration rate is reduced on the leaf and under well watered condition transpiration rate increases due to the higher water content. Sarker and Hara (2011) who also added that transpiration rate and stomatal conductance of plant leaves responded well to water deficits. Under drought stress conditions, stomata close to conserve water in the leaves (Zhang and Outlaw, 2001). This closes the pathway for water, carbon dioxide and oxygen exchange, which will result in a decrease in photosynthetic rate (Karkanis *et al*., 2011). The effects of moisture stress vary among cowpea genotypes.

5.3.2 Effect of Cowpea genotype, P level and moisture status on photosynthetic parameters

Cowpea genotypes had a highly significant effect on photosynthetic rate, conductance of water, transpiration rate, sample cell CO_2, vapour pressure deficit based on leaf temp, sample cell H_20 and RH in the cell (Table 9). Phosphorus level showed no significant difference on photosynthetic parameters. Photosynthetic rate was high by 53% in cowpea genotype Oloyin (7.33) while reduced by 35 % in Tvu 9848. Water conductance was high by 59 %, tranpiration rate was high by 40 %, sample cell H_2O was high by 30 % and RH in the cell was high by 29.6 % in Oloyin while Tvu 9848 had the lowest water conductance by 37 %, transpiration rate had the lowest by 29 %, sample H_2O had the lowest by 23 % and RH in the cell had the lowest by 23%. Intercellular CO_2 was high by 8 %, sample cell CO_2 was high by 3.7 % and vapour pressure deficit was high by 12% in Tvu 9848 while Oloyin obtained the lowest intercellular CO_2 by 7 %, sample cell CO_2 by 23 % and vapour pressure deficits was low by 11% (Table 9). The function of stomata is to control of movement of water, carbon dioxide and oxygen into or out of the plant leaves. The genotypes responded differently towards the parameters that were measured in the study. Drought stress caused reduction in photosynthetic rate of cowpea genotypes Tvu 9848, water conductance, transpiration rate, sample cell H_2O and RH in the cell reduced in the leaves because of limited amount of water the crop it absorbed. Drought stress caused reduction in sample CO_2 and vapour pressure deficit in Oloyin. According to Tanaka *et al.* (2013), CO_2 fixation determines photosynthetic rate and CO_2 entry into the plant through the stomata. High vapour pressure deficit decreases stomatal holes/pores to restrict water losses. Cowpea genotypes which were least affected by soil moisture status are Oloyin and Tvu 9848.

5.3.3 Interaction of moisture status and cowpea genotype on intercellular CO_2 concentration in cowpea leaves

Interaction of moisture stress and cowpea genotype had a significant effect on intercellular CO_2 concentration (Table 10). Under water stress, cowpea genotype Tvu 9848 maintained high rate of intercellular CO_2 concentration in cowpea leaves while it was low in well-watered condition. Intercellular CO_2 concentration was reduced under water stress on cowpea genotypes Tvu 6365, Tvu 4632 and Oloyin as compared to well-watered condition (Table 10). The stomatal closure is caused by limitation of water which causes depletion of carbon dioxide in the intercellular spaces. Medrano *et al.* (2002), as cited by Fenta (2012), reported that decrease intercellular CO_2 concentration will result in reduction of CO_2 will results in O_2 assimilation by rubisco and enhancing photorespiration. Cowpea genotype Tvu 9848 maintained high rate of intercellular CO_2 concentration under water stress conditions as compared to other cowpea genotypes in well-watered conditions. Cowpea genotype Oloyin obtained the higher photosynthetic rate while the lowest was obtained from Tvu 9848. Cayon *et al*. (1997) who noted water stress causes a reduction in photosynthesis and intercellular CO_2 concentration in cassava leave. The intercellular CO_2 concentration is an important aspect that can affect the processes of photosynthesis. Under water stress condition intercellular CO_2 concentration decrease because low amount of CO_2 concentration is supplied for photosynthesis (Farquhar and Sharkey, 1982). Several authors revealed that intercellular CO_2 concentration decreased when crops were exposed to drought stress conditions. These results suggest that Tvu 9848 delays closing its stomata under drought stress to maintain turgor in the guard cells. The results obtained in the study suggests there is a narrow range in intercellular CO_2 in the genotypes tested.

5.4 Yield and yield component of cowpea genotypes

5.4.1 Effect of moisture status and cowpea genotype on yield attributes and grain yield

Numbers of pods per plant, number of seeds per pod and grain weight determine the cowpea grain yield. Number seeds per pod, pod length and number of pods per plant have a major contribution toward cowpea yield and grain weight. Cowpea genotypes differed significantly in terms of grain weight, pod length, number of seeds per pod and number pods per plant (Table 11). Number of pods per plant, 100 seed weight, pod length and number of seeds per pod were highly significantly different ($P \leq 0.01$) among cowpea genotypes. Long pod length indicate more number of seeds per pod which will contribute toward grain yield in cowpea. There was significant effect of cowpea genotypes on the number pods per plant. Oloyin obtained highest number of pods per plant, followed by Tvu 16408 while Tvu 9848 obtained lowest number of pods per plant (Table 11). Cowpea genotype Tvu 16408 obtained highest grain yield, followed by Tvu 9848 and the lowest grain yield was obtained by IT00K1217. A strong positive correlation between number of seeds per pod and number of pods per plant indicates that cowpea plant will produce more seeds and pods for grain yield. Although pod length did not contribute much towards cowpea grain yield ($R^2=0.256$) it may be due to genetic differences among genotypes tested. The results agree with Castro *et al*. (2006) who reported that this may be caused by factors affecting seed mass including genetic factors. A positive and significant correlation was obtained between number of pods per plant and number of seeds per pod. The results agree with Karasu and and Oz (2010) who found that positive correlation between number of pods per plant and number of seeds per pod. Significant correlation was obtained between number of pods per plant and grain yield. Chiulele *et al*. (2011) found that there was strong and positive correlation between yield and number of pod per plant ($R^2=0.079$) in a cowpea. A significant and negative correlation was obtained between pod length and number of pod per plant ($R^2=0.032$). The results agree with Kawooya (2014) who found that number of pods per plant was weakly and negatively correlated to pod length in cowpea. A strong significant and positive correlation was found between pod length and number of seeds per pod. This implies that pod length contribute toward number of seeds per pod. A significant and negative correlation was obtained between 100 seed weight and grain yield ($R^2=0.036$). A significant and negative correlation was also obtained between number of seeds per pod and 100 seed weight. This results are logical but the contradict with Kawooya (2014) who reported that number of seeds per pod was weakly and positively correlated to 100-seed weight.

Number of pod per plant was significantly different between eight cowpea genotypes. Cowpea genotype Oloyin produced maximum number of pods per plant while Tvu 9848 produced lowest number of pods per plant. Moisture stress showed no significant difference on number of pods per plant. These results agree with Addo-Quaye et *al.* (2011) who did not find significant difference on number of pods per plant under water regimes. The results contradict with the finding of Ndunguru *et al*. (1995) who reported moisture stress reduced number of pods per plant in groundnut. Genetic variation exists among different cowpea genotypes. Jana *et al.* (1983) reported that number of pods per plant affected pod fresh yield per plant. Number of pods per plant is controlled by genetic make-up. Fery (1985) confirmed in his work that dissimilarity in number of pods per plant among different varieties was due to genetic factors, and that was likely to be heritability of 53.1 percent accounted for the observed differences in the cowpea varieties he used.

5.4.2 Phosphorus level effect on yield attributes and grain yield

Low soil P reduced yield attributes. Number of pods per plant, number of seeds per pod and grain yield did not show any significant response to P application on different cowpea genotypes. Phosphorus fertilisers had a significant ($P \leq 0.01$) influence on pod length (Tables 11). Phosphorus stimulates root and plant growth development in crop production including cowpea. Phosphorus level did not influence number of pods per plant. The results contradict with the findings of Nkaa *et al.* (2014) which showed that increased P fertilizer application increased number of pods of cowpea plants. Yield attributes per plant did not show any response to P application. Phosphorus rates did not differ significantly. Despite the importance of P in crops, some parameters did not respond to it. Similar results were reported by Magani and Kuchinda (2009) who reported that there was no significant difference between 35.5 kg ha^{-1} and 70 kg ha^{-1} of P. The result agrees with Atakora *et al.* (2014) who reported that P application did not significantly increase cowpea yield. The significant differences in growth and yield attributes observed among various cowpea genotypes may be due to their differences in growth habitat.

The problem of low soil P causes a major crop yield losses and productivity. Low soil P gives lowest plant height; reduce leaf area while the high P gave tall plants. Phosphorus insufficiency in the soil leads to retarded plant growth and low productivity.

5.4.3 Effect of cowpea genotype, P level and moisture status on pod length and number of seeds pod

Phosphorus level greatly increased some of the yield attributes such as the pod length of the cowpea genotypes (Table 11). High P increased pod length by 2.28 % while low soil P decreased pod length by 2.7 %. Pod length and HSW were significant different between eight cowpea genotypes. Cowpea genotype Tvu 9848 increased pod length by 31.6 % while Oloyin decreased pod length by 24%. Oloyin and IT00K1217 increased HSW by 57 % while HSW of Tvu 15143 decreased by 36 %. Cowpea genotype Tvu 9848 produced longer pods in contrast to Oloyin (Table 11). Moisture stress did not have an influence on pod length and HSW. The results agree with the study conducted by Nkaa *et al*. (2014) who found that P increased pod length and number of pods per plants. Fery (1985) showed that pod length was highly heritable with average heritability estimate of 75.2 percent. Addo-Quaye *et al.* (2011) reported in their study and other studies that pod length could be under strong genetic control. Higher number of seeds per pod was found in Tvu 15143,15445 and 9848 and compared to other cowpea genotypes, while lowest number of seeds per pod was found in IT00K 1217 and Oloyin (Table 9). Addo-Quaye *et al*. (2011) also reported that one genetic factor conditioned seed number per pod in a crop. Cowpea genotype Oloyin recorded higher number of pods per plant (24) than variety Tvu 9848 (18). There was no significant effect of interaction of variety and P level on pod per plant and number of seed per pod. The findings agree with those of Singh *et al.* (2011) who reported no significant interaction between variety and P on pod per plant and number of seed per pod.

5.4.4 Effect of cowpea genotype, P level and moisture status on 100 seed weight

Yield parameters such as 100 seed weight, number of pods per plant and number of seeds per pod are the most important components that contribute towards cowpea yield (Table 11). Phosphorus level did not show any significant difference on HSW of cowpea genotype. Cowpea genotypes (Oloyin and IT00K1217) produced maximum weight then genotype Tvu 15143 (Table 11). Moisture stress did not show any significant different on HSW. Cowpea genotypes in the current study showed variation in 100 seed weight. The results are supported by khan *et al*. (2010) who found that highly significant variation for 100 seed weight occurred in cowpea tested genotypes they tested. The variation among cowpea genotypes may due to genetic variability and climatic conditions. The results obtained by Khan *et al*. (2010) suggested that the differences in seed weight might be due to the time factor for the accumulation of assimilates in the seed and the differences in the genetic make-up of different genotypes.

5.4.5 Effect of moisture stress on yield and yield parameters.

Drought stress causes a decrease in number seeds per pod, pod length and number of pods per plant. The results from the study showed that number of seeds per pod, pod length and number of pods per plant did not show response to moisture stress condtition (Table 11). Abayomi and Abidoye (2009) showed that there was no significant effect of moisture stress on branching. Moisture status exerted a significant influence on grain yield and dry pod weight. In the present study, moisture stress reduced dry pod weight and grain yield relative to well-watered treatment. This result agrees with Abayomi and Aderoru (2000) who reported that drought stress condition significantly reduced grain yield and growth at any stage in cowpea. Pod length, number of seeds per pod, number of pods per plant, biomass did not show any significant effect to moisture stress. Grain yield had a significant response to moisture stress condition.

5.4.6 Interaction of moisture status and genotype on 100 seed weight

Under water stress conditions, cowpea genotype Oloyin produced increased seed weight. Cowpea genotypes (Tvu 15143 and 16408) reduced seed weight under deficient soil moisture (Table 12). The results agree with Addo-Quaye *et al*. (2011) who reported that seed weight was significant reduced when cowpea plants were under water stress. But the results showed that water stress had a little effect on cowpea vegetative development. Similarly, several researchers reported that water stress had no or little effect on vegetative attributes of cowpea (Turk and Hall, 1980; Suliman, 2000). In the current study, the seed yield of cowpea was significantly reduced under water stress treatments. Kamara (1976) reported that drought stress significantly reduced seed weight of cowpea plants. Drought stress is the main factor to decrease seed weight and decreasing the length of the seed filling stage in sunflower (Cantagallo *et al.,* 1997). Higher seed weight recorded under stress conditions by Oloyin, suggest that it maintains better water status within the water deficit period by extracting deep soil moisture or reduce transpiration. Despite the fact that water stress was a major factor causing reduction in plant height and yield, Oloyin managed to tolerate drought stress. The results suggests that Oloyin tolerated the drought or may have avoided the drought as reported by Mitra (2001) that drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil-moisture. Although cowpea is referred to as a drought resistant crop, limited irrigation or rainfall is a frequent cause of yield reduction (Watanabe *et al*., 1997).

5.4.7 Effect of moisture stress on cowpea fresh and dry immature pods

Phosphorus level and moisture stress condition did not show any significant respond on fresh immature pods and dry matter percentage. While dry immature pods show significant differences under moisture stress (Table 11). Dry matter percentage showed a significant response among eight cowpea genotypes. Application of water regime to the cowpea varieties had an effect on immature green pods. Drought stress caused reduction on fresh weight of immature pods and dry weight of immature pods in all the cowpea genotypes tested. Cowpea is very sensitive to drought stress during pod filling. Decrease in number of pods per plant may also contribute toward low yield in crop production. Turk *et al.* (1980) indicated that drought stress during flowering and pod-filing stages had a major effect on grain production. Abayomi and Abidoye (2009) showed that drought stress significantly reduced pod weight which resulted in significant decrease in yield components.

5.4.8 Effect of cowpea genotype, P level and moisture stress on grain yield

Phosphorus is the most important element for cowpea grain yield because it promotes growth and initiate nodule development. Drought stress cause a serious drop in crop grain yield and reduces the quality of the crop. P level did not show any significant difference on different cowpea genotypes. Lack of P to respond to plant maybe was due to the fixation in the soil by calcium or magnesium (Table 1). Cowpea grain yield was significantly not affected by P application. Cowpea genotype showed significant difference in grain yield. Cowpea genotype Tvu 16408 obtained maximum grain yield as compared to IT00K1217. The results contradict with Singh *et al*. (2011) who reported that cowpea variety had no significant difference on the grain yield. The results agreed with Nkaa *et al*. (2014) who found significant effect between three cowpea varieties tested. There was no significant difference between cowpea genotype and P level, moisture stress and cowpea genotype and P level and moisture stress and cowpea genotype interactions. The results contradict with study by (Magani and Kuchinda, 2009), who found significant interaction between cowpea varieties and P level on cowpea grain yield in two years. But results agrees with study from Atakora *et al*. (2014) who reported that P application did not significantly increased cowpea grain yield. Moisture regimes respond toward grain yield. Cowpea grain yield benefited from water stress condition than well-watered condition. These results disagreed with study by Abayomi (2008) who found that moisture stress reduce yield component and yield in soybean. Soriano *et al.* (1994) concluded that the seed yield of sunflower was sensitive to water stress after anthesis. He also added that there is need of irrigation management under limited water supply, especially during the reproductive period. Cowpea seed yield decreased during water stress and increased during the supplementation of water. Drought stress reduced flower formation and decreased number of pod per plant. Cowpea is most sensitive to drought stress during pod-filling and flowering which later they will contribute towards seed yield. Cowpea genotype Tvu16408 had higher grain yield (3240 kg ha^{-1}), while the lowest grain yield was obtained IT00K1217 (1256 kg ha^{-1}). Grain yield showed a significant response toward moisture stress condition. The results agree with Abayomi and Abidoye (2009) who reported that drought stress decrease grain yield in cowpea and but contradict with study conducted by Nahar and Ullah (2011) who found that high yielding under water stress relative to well-watered condition in tomato. A highly significant correlation was observed between cowpea nodulation and grain yield (R^2=0.0326). The results agree with Sarkodie-Addo (1991) who observed positive correlation between grain yield and N fixation in several legumes, including cowpea.

5.4.9 Effect of cowpea genotype, P level and moisture stress on biomass production

Increase in the level of P applied also increased biomass. The increased in number of leaves and plant height in cowpea genotypes contributed toward increase in total biomass. Biomass showed a significant difference across different cowpea genotypes. Cowpea genotype Tvu 4632 obtained maximum plant biomass as compared to IT00K1217 (Table 11). Drought stress did not have influence on biomass. The results contradict with Hayatu and Mukhtar (2010) who reported that drought stress significantly reduce plant above ground biomass in cowpea genotypes. The mean total biomass at 40 mg kg^{-1}soil P was significantly higher than at 8 mg kg^{-1}in the soil. High soil P (35 mg kg^{-1}) soil increased by 19% while the lower soil P decreased by 24% of P. Okeleye and Okelana (1997) found significantly increased grain yield and total dry matter for cowpea genotypes in response to P application. Adequate amount of P promotes plant biomass, plant height and leaf area. Furthermore, high amount of P increased plant biomass which can be used in livestock feeding as silage and fodder and can also be used in cropping systems to improve soil fertility. A highly positive significant correlation was obtained between nodulation and biomass (R^2=0.1572). The results agree with Zhao *et al*. (1997) who reported a significant positive correlation between nodulation and cowpea biomass. There was no interaction effect between cowpea genotype and P rates. There was no interaction effect between cowpea genotype and moisture status level. There was no interaction effect between P rate, moisture status level and cowpea genotype.

5.5 Nutrient content of cowpea grain

5.5.1 Effect of Phosphorous (P) level on cowpea grain

Total P content and uptake increased with P application. Total P content and uptake showed a significant difference across cowpea genotypes. Cowpea genotype IT00K1217 obtained maximum total P content then Tvu 16408 while Tvu 16408 obtained maximum P uptake than IT00K1217 (Table 15). Total P content in cowpea grain increased with P application in the soil. The P uptake at 40 kg ha^{-1} P was higher than P uptake for 8 mg kg^{-1}P. Total N did not show a significant response to P rate increase. The results on total N contradicts with the results by Ankomah *et al*. (1995) and Asuming-Brempong *et al*. (2013) who reported increase in N content with increasing P rates. The P uptake increased with increase in P application. The findings agree with Asuming-Brempong *et al*. (2013) who reported that P uptake generally increased with increase in P application among treatment. Total P during high P (40 mg kg^{-1}) was higher than P uptake in low soil P (8 mg kg^{-1}). Phosphorus application stimulated the content of others nutrients in the leaves (Muleba and Ezumah, 1985), seed and green pods. Furthermore, P is also having multiples effects on nutrition. P rates affected the amount of P and P uptake in the cowpea grain. Thus adequacy of P promotes grain quality in cowpea.

5.5.2 Effect of moisture status on cowpea grain

Drought stress can tamper nutrient uptake in crops. The P uptake increased under well-watered conditions relative to low soil moisture conditions. P uptake under well-watered condition increased by 35% on Tvu15445 while Oloyin decreased by 55% under well-watered condition (Table 15). Drought stress has adverse effect on P uptake. The results are line with Samar Raza *et al*. (2013) who reported that P uptake decreased with decreasing soil moisture in wheat genotypes. Drought stress is a major constraint to both growth and yield in crop production. When there is lack of soil water, the rate of photosynthesis, respiration, ion uptake, carbohydrates, and nutrient metabolism decrease and plant growth is also affected (Jaleel *et al.,* 2009).

5.5.3 Effect of cowpea variety, P level and moisture stress on grain

Cowpea genotypes differed in nutrient content of grain. Total P content, P uptake, Total N content and N uptake showed significance difference among cowpea genotype (Table 15). Total P and N content increased in cowpea genotype IT00K1217 (35 P kg^{-1}) while in cowpea genotype Tvu 16408 total P and N content decreased with P application (8 mg kg^{-1}). P uptake increased in cowpea genotype Tvu 16408 while it decreased on cowpea genotype Tvu 4632. N uptake increased in Tvu16408 and it was decreased in IT00K1217. Differences that occur in different genotypes during nutrient uptake are important determinants of nutrient use efficiency (Oladiran, 2012). The difference in N uptake may be caused by the ability of cowpea genotypes to nodulate and fix more N thereby making it more obtainable for absorption (Mbagwu and Osuigwe, 1985). Differences in root system and root proliferation cause different cowpea genotype to absorb nutrient elements differently. There was no interaction effect between P rate and cowpea genotype. There was no interaction effect between moisture status and cowpea genotype. There was no interaction effect on P rate, moisture status level and cowpea genotype.

5.5.4 Interaction of P level and cowpea genotypes on phosphorus

Phosphorus uptake showed a significant ($P \leq 0.01$) effect on P level and cowpea genotype. The homogeneous group format cannot be used because of the pattern of significant differences (Table 15).

5.6 Nutrient content of cowpea pods

5.6.1 Effect of phosphorus rates of cowpea immature pods

Low soil P condition increased P uptake in cowpea immature green pods. The results showed that high P rate increased total P content and N uptake in cowpea immature pods and low soil reduced P content and N uptake (Table 17). Similar results were reported by Oladiran (2012) that application of P fertilisers significantly increased N uptake. This maybe due to increase in P application increased N uptake in this study. Phosphorus fertiliser application might have contributed to the higher values of available

P in the soil because of immobility of P in the soil. The difference in P uptake varies among various P rates. Paul and Giller (2002) observed varietal differences in the ability of legumes to extract soil P. Different cowpea genotypes differently toward P applications. Phosphorus rates affect both P and N uptake on cowpea pods. In soybean, Cauş et *al.* (2012) reported that a combination of stress factors, such as water stress and P deficiency, decreased P uptake more than N uptake in soybean.

5.6.2 Effect of moisture status of cowpea immature pods

Water-stress increased N uptake in cowpea immature pods while well-watered conditions increased the total P content in the cowpea immature pods (Table 18). Drought stress did not have an effect on P uptake. The results agree with Samar Raza *et al.* (2013) who observed no effect of water stress on P uptake. N uptake increased with drought stress. When soil moisture increased it increased the total P. Drought stress tampers some of nutrients during uptake. Bationo and Kumar (2002), response of cowpea genotypes to P levels is affected by environmental factors including drought stress. Water stress reduced P absorption and use of P in the pods. During drought stress, N and K uptake was limited in cotton (McWilliams, 2003). Moisture stress limits availability, uptake and metabolism of nutrients. Transpiration rate and nutrient absorption were reduced by water stress. Also drought stress reduces the efficiency with which nutrients are being absorbed by the roots.

5.6.3 Cowpea variety

There are significant differences between cowpea genotypes in absorption and use of P. During P deficiency, legumes vary greatly in their ability to take and use P. Total N, N uptake, total P and P uptake differed across the eight (8) cowpea genotypes (Table 17). Variation between total P content, P uptake, total N and N-uptake was observed in cowpea genotypes. The increase in P level increased total N content and N-uptake of cowpea genotypes Tvu 9848 and Tvu 15143. Low P level increased P uptake of cowpea genotype Tvu15445 and high P rate increased total P content of cowpea pods.

5.6.4 Interaction of phosphorus and cowpea genotypes on cowpea grain N content

Cowpea genotype Tvu 9848 obtained maximum total N under high P condition than in low soil P while the lowest total N was obtained by Tvu 15445 under low soil P then in high soil P (Table 19). Total N content increased with increase in P level and low soil P reduced total N content. This result agreed with the findings of Ankomah *et al*. (1995) and Asuming-Brempong *et al.* (2013) who reported an increase in N content with the increase in P levels in cowpea. Under low soil P, cowpea genotype Oloyin increased total N while in high soil P it reduced total N content. Phosphorus significantly increases total N in cowpea pods. Physiological characteristics are vital for P uptake and are affected by low soil P.

5.6.5 Interaction of moisture status and cowpea genotypes on immature green pods

The interaction between cowpea genotype and moisture status exerted a significant effect on N and P uptake of immature green pods but not on total N and P content (Table 18). Cowpea genotype Tvu 15445 obtained maximum P and N uptake in well-watered condition then in water stress condition while the lowest P and N uptake was obtained by Oloyin in well-watered condition then water-stress condition (Table 18). Under water stressed condition Oloyin managed to maintain maximum P and N uptake. Moisture status and cowpea genotype interaction reduced both P and N uptake in cowpea immature pods. Phosphorus and N uptake increased with an increased in soil moisture condition. These results contradict with the study a conducted by Samar Raza *et al*. (2013) who reported that higher P uptake in wheat plants was recorded under water stress. During well-watered conditions both P and N uptake benefited from water condition as compared to the water stress. Water stress limits P and N uptake on pods. Phosphorus absorptions and P concentration were limited by drought stress in soybean (Gutierrez-Boem and Thomas, 1999).

5.7 Root architecture

5.7.1 Effect of P level on root characterstics

Nodule score per plant did not show significance different to P level (Table 20). Nodule are important because they fixing atmospheric N. P level did not show any significance differences on root characterstics of different cowpea genotypes (Table 20). Phosphorus level did not have an influence on nodule score. The result contradict with Nkaa *et al.* (2014) and Oladira, (2012) who found that P fertilizer application enhanced number of nodules and weight of cowpea cultivar. The results agree with Singleton *et al*. (1985) who reported that P level does not show any significance difference on nodules. Phosphorus is important for root development but despite its importance in the soil, it did not show any influence on cowpea root traits. The applied P fertilizer was fixed and became unavailable to the crops. The amount of P level in the soil decrease with depth since P is immobile in the topsoil. The selection of crops with high P efficiency will increase the utilization of soil P. Cowpea genotypes varied significantly in their adaptation to P availability because many cowpea genotypes differed in uptake of P. P acquisition by crops depends on the soil, plant properties, crop and fertiliser management and environmental conditions. The use of genotypes with improved root traits that are able to unlock and absorb P from soil P resources may be important for increasing the efficiency or utilization of applied P fertilisers (Abelson, 1999). Tap root diameter at 15 cm increased with P while low soil P reduced tap root diameter at 15 cm.

5.7.2 Effect of moisture status on nodulation

Water stress condition reduced number of nodules per plant in the study it shows that nodules are sensitive toward drought stress condition (Table 20). Water stress condition decreased nodulation by 22 % while well-watered condition increased nodulation by 28 %. Cowpea genotype under well-watered condition produced maximum number of nodules than water stress condition. This shows that water play important role in nodulation and under limiting water condition it will results in decrease in root nodule. Nodules and tap root diameter increased with soil moisture condition while low soil moisture reduced nodule and tap diameter at 20 cm. Cowpea is a hardy crop, but still suffer considerable damage from abiotic and biotic conditions. Abiotic stress such as drought stress and low P availability affect nodule development and activity. The results reported by many authors showed that N fixation is highly sensitive towards toward drought stress in many countries. The finding by Scholz *et al*. (2002) reported under water limiting condition plant roots grow long than those in rain-fed. The results contradict with the annual report of the Science Daily (2008) reported that plants growing under drought stress condition grow taller in effort to ascent for nutrients around the growth environment. Drought tolerance in common bean has been associated with increased rooting depth (Sponchiado *et al.,* 1989).

5.7.3 Effect of P level, moisture stress and cowpea genotype on number of basal roots of different cowpea genotypes

Number of basal roots per plant in response to P applications and moisture stress conditions showed insignificant differences. Number of basal roots per plant showed significant differences among eight cowpea genotypes. Cowpea genotype Tvu 6365 showed to be more efficient in P acquisition while local check IT00K1217 showed to be less efficient in P acquisition (Table 20). Cowpea genotype Tvu 6365 produced higher number of basal roots which are responsible for acquisition of P in the soil while cowpea genotype IT00K 1217 had the lowest number of basal roots. The growth of the basal roots determines whether plant roots move or fall down rapidly to the subsoil or stay in the top soil (Lynch and Brown, 2001). Basal roots are a different class of roots arising near the basal end of the hypocotyl (Zobel, 1996), which form the structural frame upon which the majority of the bean root system develops (Liao *et al.,* 2004). According to Ge *et al.* (2000), geometric simulation modelling suggested that genotypes with shallow basal roots are more effective in P acquisition than genotypes with deeper roots, especially in stratified soils with heterogeneous P distribution. Highly positive and significant correlation was obtained between basal roots and branching density at 5 cm, shallow scores, deep score, nodule score, diseases and 3rd branching density. Highly positive and significant correlation (R^2=0.654) was obtained between number of basal roots and branching density at 10 cm, 1.5 branching density at 5 cm (R^2=0.062) and grain yield (R^2=0.053). The study conducted by Vieira *et al*. (2008) found a significant correlation between seed weight and number of whorl or number of basal roots in the common bean. Higher number of basal roots are desirable for a greater soil foraging. Highly positive and significant correlation was obtained between basal roots and branching density at 15 cm. Miller *et al*. (2003) reported that under low soil P adventitious roots were less affected as to compared basal roots in bean genotypes.

5.7.4 Effect of cowpea genotype, moisture stress and P level on nodule score

Nodules score per plant showed significant differences between eight cowpea genotypes. Cowpea genotype Tvu 6365 produced high number of nodules per plant as compared to the IT00K1217 (Table 20). The cowpea genotypes evaluated in the study showed variation in nodulation. Nodule score per plant in response to moisture (well-watered and water stress) was significant. Nodule score per plant did not show any significant response on P application. These results contradict with those of Nkaa *et al*. (2014) that P application significantly enhanced number and weight of nodules in cowpea. Cowpea genotype which received adequate amount of water in this study showed to have more number of nodules of plant. There was no interaction between cowpea variety x P level, moisture stress x cowpea genotype and P level x moisture stress x cowpea genotypes. The results agree with the study of Girma *et al.* (2014) who found that number of nodules was significantly affected by cowpea variety and also contradict the results that they found significant response to P level x bean interaction. Cowpea genotype Tvu 6365 had many nodules which are good for N-fixation. Nodules are limited by environmental conditions such as drought and nutrient stress in the soil. Nodule activities are affected by drought stress which limits N-fixation. The number of nodule increased with increase in soil moisture. Lawn and Bush (1982) also reported that nodule fresh weight was a good indicator for effects of different roots on N_2 fixation than was either specific or total nodule activity. Stoffella (1991) reported that nodules appear more on secondary roots of cowpea than on primary root (taproot). More nodules are found on the basal roots and laterals roots than on taproot diameters. Highly positive and significant correlation (R^2=0.366) was obtained between nodule scores and 3rd order branching density. Highly positive and significant correlation was obtained between nodules scores and disease. Positive and significant correlation was obtained between nodule scores and taproot diameter at 20 cm (R^2=0.0315) and cowpea grain yield (R^2=0.041). This pattern of nodulation may reflect the physical distribution of the root system (Kahn and Stoffella, 1991).

5.7.5 Effect of cowpea genotype, P level and moisture status on taproot diameter

Taproot diameters per plant at 5, 10, 15 and 20 cm did not show any significant difference to P applications at different depths (Table 21). Taproot diameter at 5 and 10 cm did not show significant difference to water regimes. Taproot diameter at 15 and 20 cm showed significance response to water regimes. Taproot diameter per plant at 15 cm showed significant effect on water regimes across eight cowpea genotypes. Tvu 4632 has long taproot diameter which will be good for extracting of water from the deeper depth in the soil as compared to Tvu 15445 which is having thinner taproot diameter. Cowpea genotype Tvu 4632 had strong thick and long taproot is are good for acquisition of water in water-limiting conditions. Miller *et al*. (2003) reported that under low soil P bean genotype had long taproot diameter. The taproot root size varies with depth in the soil. The taproot is single structure growing in essentially one plane (Kahn and Stoffella, 1991) which is having branching roots on it. Statistical analysis showed that taproot diameter at 5, 10 and 15 cm showed significant differences among genotypes, but taproot diameter at 20 cm depth did not show any significance differences. Highly positive and significant correlation was obtained on between on taproot diameter at 10 cm (R^2=0.510), number of basal roots (R^2=0.094), branching densities at 5 cm (R^2=0.086), 10 cm (R^2=0.104), 15 cm (R^2=0.1743), shallow scores (R^2=0.033), nodule scores (R^2=0.6900), 3rd order branching density (R^2=0.1735) and taproot diameter at 20 cm (R^2=0.1077). Highly positive and significant correlation was obtained between taproot diameter at 10 cm and angle of adventitious roots (R^2=0.065) and cowpea grain yield (R^2=0.060). The results obtained by Liu *et al*. (2014) showed that root diameter was positively and significantly correlated with grain yield in rice cultivars. Long taproot is good for acquisition of water in the soil since availability of water increases with increasing in soil depth. Cowpea genotypes with deep roots survive long under water limiting conditions because deep roots are good for acquisition of water from the soil during drought stress as compared to the shallow roots. Highly positive and significant correlation (R^2=0.054) was obtained between taproot diameter at 15 cm and number of basal roots. Taproot grows vertically downward with or without nutrient availability in deep layers. Highly positive and significant correlation was obtained between taproot diameter at 15 cm and branching density at 5 cm (R^2=0.0435), 1.5 branching density at 5 cm (R^2=0.0354) and 10 cm (R^2=0.0904), disease (R^2=0.048) and grain yield (R^2=0.031). Highly positive and significant correlation was obtained between stem diameter and branching density at 15 cm (R^2=0.053) and grain yield of cowpea (R^2=0.060). The results are in line with Icoz and Kara (2009) who found positive relationship between forage yield and stem diameter in maize, and Sallam *et al.* (2014) also found positive correlation between stem diameter and grain yield in wheat, but disagreed with the study conducted by Carpici and Celik (2010) who found negative relationship between yield and stem diameter in forage maize.

5.7.6 Effect of cowpea genotype, P level and moisture status on lateral root branching

Lateral root branching at 5 and 10 cm did not respond to P application and moisture stress condition. Postman *et al*. (2014) found that with insufficient P in the soil plants grew better with high lateral root branching density which was favoured for P acquisition. Fenta, (2012) reported that moisture stress enhanced branching density of tap and lateral roots in three common bean cultivars. Lateral root branching at 5, 10 cm, 1.5 mm lateral roots branching at 5 cm and 10 cm per plant showed significant differences among eight cowpea genotypes (Table 20). Lateral roots are found in the top soil layer which are good for acquisition of nutrients such as P. Cowpea genotype Tvu 6365 had more lateral root branching at branching depth of 5 cm among cowpea genotypes which will favour P acquisition since it is immobile in the soil. Improved lateral root branching density is an advantage for P acquisition in the plants. Cowpea genotype Tvu 15143 had more lateral branching roots at 10 cm depth while IT00K 1217 had less lateral roots branching. Lateral branching roots play an essential role in searching for nutrient availability in the soil (Lynch and Brown, 2001). Lateral roots are important for P acquisition since they are found at top soil layer and is an also immobile nutrient in the soil surface layers. Thus, the optimization of water and P acquisition by individual plants can be achieved by altering root shallowness when soil resources are limited and localized at different depths in the soil profile (Ho *et al.,* 2004). Highly significant and positive correlation was obtained between 1.5 mm branching density at 5 cm and 1.5 mm branching density at 10 cm (R^2=0.1127), shallow scores (R^2=0.24344), deep scores (R^2=0.1444), disease (R^2=0.1550). Highly significant positive correlation (R^2=0.0807) was obtained between 1.5 mm branching density at 5 cm and 3rd order branching density. Liao *et al.* (2001) emphasized that the efficiency of P acquisition is correlated with the shallowness of basal roots. Highly positive and significant correlation was obtained between branching density at 5 cm and taproot diameter at 20 cm (R^2=0.032). There was no significant correlation obtained branching density at 5 cm and grain yield. Drew and Saker (1978) showed that lateral branching roots increase in response to high availability of N and P. In common bean, P availability in the soil has shown to control various characteristics of root architecture such as branching, basal root length and adventitious roots in the topsoil (Ma *et al.,* 2003). Highly positive and significant correlations were obtained between angle of basal root and taproot diameter at 10 cm (R^2=0.0347), number of basal roots (R^2=0.0358), and nodule score (R^2=0.0390). The results disagree with the study by Vieira *et al*. (2008) who found no correlation between basal root growth angle and numbers of basal roots. There was no significant correlation between angle of angle of basal roots and cowpea grain yield. Fenta (2012) found in common bean that whorl angles, number of basal roots and adventitious root branching density were positively significantly related to seed yield

5.7.7 Effect of cowpea genotype, P level and moisture status on deep score

Deep score per plant in response to P fertilizer and moisture stress did not show any significant. Deep score per plant showed significant differences among eight cowpea genotype. Tvu 4632 performed well in water-limiting condition since is having long root which can extract water from the deep depth. Cowpea genotype Tvu 4632 it had thick and long roots which are good for water acquisition in water-limiting conditions while cowpea genotype Tvu 6365 had shallower roots. Some cowpea genotypes had deep roots, while some genotypes had less developed root systems. Cowpea genotypes with deep roots will be adapted to terminal drought stress conditions because they have capacity to absorb water from deeper soil. Sinclair and Muchow (2001) reported that maize enhanced absorption of water due to deep rooting capability, while in rice Li *et al.* (2005) reported that deeper rooting plants provide better enhanced drought tolerance. Highly positive and significant correlation was obtained between deep scores and taproot diameter at 20 cm (R^2=0.0733) and cowpea grain yield (R^2=0.0629).

5.7.8 Effect of cowpea genotype, P level and moisture status on shallow score

Shallow score per plant in response to both P level and moisture stress condition at different rates were found not be significant. Shallow scores per plant showed significant differences among eight cowpea genotypes. The shallowness of the roots in cowpea genotype plays the critical role in efficient P acquisitions. Cowpea genotype Tvu 6365 showed to be shallow in roots which show that it can be more efficient in P acquisition while Oloyin shows to the less efficient in P acquisition. Pronounced shallowness of the roots are great for nutrient acquisition in the topsoil. The adventitious roots enhance P acquisition because they have shallow root angles. Lateral roots are important for P acquisition since it is found at top soil layer and is an also immobile nutrient in the soil surface. As reported by Miller *et al.* (2003), the presence of adventitious roots enhance P acquisition since they have shallow growth angles and explore soil at less metabolic cost per unit length than other root types. Shallow roots genotypes had a better P acquisition in low soil P (Lynch and Brown, 2001). They added that root gravitropism is a potentially beneficial trait for P efficiency. Highly positive and significant correlation was obtained between angle of adventitious roots and taproot diameter at 15 cm (R^2=0.0237)) and shallow scores (R^2=0.0479). The effectiveness of shallowness of the roots may rely on interacting factors in addition to P availability (Liao *et al*., 2004). There was no significant correlation between shallow scores and cowpea grain yield.

Shallow score did not show any significant response to drought stress condition. High shallow roots score is not good for moisture stressed situation since the soil surface drier first and deeper soil layers will hold moisture for long time in the soil. Shallow roots during drought stress crop will show symptom deficiency and experience water stress earlier than long taproot crop. Shallow roots are good for acquisition P since it is immobile in the soil and is found in large amount on top soil layer.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The results revealed that growth parameters did not respond to moisture stress conditions. Phosphorus level influence plant height, number of branches and number of leaves on different cowpea genotypes. Moisture stress condition did not show any influence on plant height, number of branches and number of leaves on different cowpea genotypes. Growth parameters were enhanced by P application in the study. Phosphorus at the 40 kg ha^{-1} had the best performance in number of leaves and plant height. Cowpea genotype Tvu 15143 can be recommended to smallholder farmers since it was having more number of leaves under water stress and most of the smallholder farmers consume the eat leaves. However, more research should be conducted under multi-locations to evaluate these cowpea genotypes for better leaf yield production and check if the leaves are palatable by smallholder farmers.

Cowpea genotype differed widely in their response to moisture stress condition for photosynthetic parameters and grain yield. Cowpea genotype Tvu 9848 obtained more intercellular CO_2. Photosynthetic parameters did not respond to P level. Water stress condition lowered photosynthetic rate, water conductance, transpiration rate, RH while it increased vapour pressure deficit and CO_2. Water, sunlight and CO_2 play an important toward photosynthetic parameters because limiting of one the factor can limit photosynthesis despite other factors being availability. Cowpea genotypes Tvu 9848 resulted in increased intercellular CO_2 concentration. Oloyin perfomed well under moisture stress on photosynthetic rate, water conductance, transpiration rate, RH sample, and H_2O samples. Under moisture stress contion Tvu 9848 obtained high vapour pressure deficit while it was low under well-watered condition.

Total N and uptake did not respond to P level and moisture stress condition. Total P and uptake responded to application of P level and moisture stress condition on cowpea grains. Total P and uptake were enhanced by P applications. Phosphorus at the 40 kg ha^{-1} had the best performance as compared to 8 mg kg^{-1}. Total P and N uptake were enhanced by P level and water stress condition in cowpea immature green pods.

Phosphorus level and cowpea variety interaction significantly observed highest of P and N uptake to immature green pods.

The cowpea genotypes differed widely in their P requirement for growth parameters, pod length and dried biomass. The study showed that HSW, number of seeds per pod, number of pods per plant and fresh weight immature pods did not respond to P level and moisture stress condition. Phoshorus level did not influence cowpea grain yield in this study. Higher P level enhanced biomass and pod length. Cowpea grain yield and dry weight of immature were reduced by water stress condition in most cowpea genotypes tested. Cowpea genotype Tvu 16408 can be recommended to be planted by smallholder farmers in Limpopo Province since it give the highest yield and Limpopo Province is experienced low erratic rainfall condition. Tvu 16408 was the best yielding among cowpea genotypes tested.

The study showed that nodule score, taproot diameter at 15 cm and 20 cm show significant response to P level. Taproot at 15 cm and 20 cm respond well to water stress condition. Branching density at 5 cm, 10 cm, 15 cm, 1.5 branching density at 5 cm, 10 cm, 3rd order branching density, deep score, shallow score, taproot diameter at 5 cm, and 10 cm did not show any response to water stress condition and P level. Cowpea genotype Tvu 6365 showed to have more shallow roots which can have greater P efficiency. Cowpea genotype Tvu 4632 showed to have more deep roots which are good for acquisition of water during drought stress condition. Studies on showed be conducted on multi-locations on genotypes Tvu 6365, Tvu 16408, Oloyin, IT00K1217, Tvu 4632 and Tvu 6365 could serve as a breeding lines to improve yield under low soil P and water stress condition. There is need of selecting root traits, phototosynthetic parameres and yield parameters which can do well under low soil P and moisture stress condition.

There is a need to conduct future studies on different locations and environmental conditions to assess the response of P requirement and moisture stress conditions on root architecture, photosynthetic parameters and yield as to breed more P uptake efficiency genotypes. Such studies should be conducted under greenhouse or rain shelter to avoid rainfall.

There is need to assess cowpea genotypes that can have proper root distribution under low soil P and water stress condition which can be good for P acquisition and drought stress.

Nodule play an important role by N-fixing. Phosphorus level did not show any significant response on nodule score while moisture stress condition resulted in decrease in nodule score. Nodule score showed a significant response among eight cowpea genotypes.

Root characterstics such as stem diameter, taproot diameter at 5, 10, 15, number of basal roots, deep and nodule score had influences on cowpea grain yield.

CHAPTER 7

REFERENCES

Abayomi, Y. A. 2008. Comparative growth and grain yield responses of early and late soybean maturity groups to induced soil moisture stress at different growth stages. *World Journal Agricultural Sciences* 4: 71-78.

Abayomi, Y.A. and M.A. Aderoru. 2000. Effects of water stress at different stages on growth, grain yield and seed quality of cowpea genotypes. *Nigerian Society for Experimental Biology 1: 87-97.*

Abayomi, Y.A. and T. O. Abidoye. 2009. Evaluation of cowpea genotypes for soil moisture stress tolerance under screen house conditions. *African Journal of Plant Science* 3: 229-237.

Abelson, P.H. 1999. A potential phosphate crisis. *Science,* 283: 2015- 2015.

Addo-Quaye, A. A. Darkwa, A. A. and M. K. P. Ampiah. 2011. Performance of three cowpea (*Vigna unguiculata* (l) Walp) varieties in two agro-ecological zones of the central region of Ghana II: grain yield and its components. *Journal of Agricultural and Biological Science* 6: 1-9.

Aderolu, A.M. 2000. The effect of water stress at different growth stages on yield and seed quality of cowpea varieties. B. Agriculture Project University of Ilorin. p. 68.

Agbicodo, E.M. Fatokun, C.A. Muranaka, S. Visser, R.G.F. and C.G. Van Der Linden. 2009. Breeding drought tolerant cowpea: constraints, accomplishments and future prospects. *Euphytica* 167: 353-370.

Ali, B. Izge, A.U. Odo, P.E and D. Aminu. 2009. “Varietal Performance of Dual Purpose Dry Season Cowpea (*Vigna unguiculata* L. Walp) under Varying Plant Spacing in the Fadama in North Eastern Nigeria”. *American-Eurasian Journal of Sustainable Agriculture* 3: 13-18.

Amba, A.A. Agbo, E.B. and A. Garba. 2013. Effect of nitrogen and phosphorus fertilizers on nodulation of some selected grain legumes at Bauchi, Northern Guinea Savanna of Nigeria. *International Journal of Biosciences* 3: 1-7.

Ankomah, A.B. Zapata, F. Hardason, G. and S.K.O. Danso. 1995. Yield, Nodulation, and N_2 Fixation by Cowpea Cultivars at different Phosphorus levels. *Biology and Fertility of Soil* 22: 10-15.

Aquilar, A.S. and A. Van Diest. 1981. Rock P mobilization induced by the alkaline uptake pattern of legumes utilizing symbiotically fixed N. *Plant and Soil* 61: 27-42.

Ashley, J. 1993. Drought and crop adaptation. In: Rowland J.R.J (ed.), Dryland Farming in Africa. Macmillan Press Ltd, UK, pp. 46-67.

Asiwe, J.A.N. Belane, A. and F.D. Dakora. 2009. Evaluation of cowpea breeding lines for nitrogen fixation at ARC-Grain Crops Institute, Potchefstroom, South Africa. Paper presented at the 16th International Congress on Biological Nitrogen Fixation, Montana, USA, 14-19.

Asuming-Brempong, S. Wiafe, Y. and K. Aggrey Martin. 2013. Nodulation of cowpea (*Vigna unguiculata* [L]walp) at different levels of phosphorus in a Typic Kandiustalf. *Agricultural Science Research Journal* 3: 387- 394.

Atakora, W.K. Oppon, W.K.E. Mahama, R. Tuffour,H.O. and S. AduGyamfi. 2014. Cowpea Yield as Affected by Level and Time of Mineral Phosphorus Fertilizer Application in the Guinea Savanna Agro-Ecological Zone of Ghana. *Global Journal of Science Frontier Research: Agriculture and Veterinary* 14:13-17.

Atemkeng, M.F. Muki, T.J. Park, J.W. and J. Jifon. 2011. Integrating molecular tools with conventional breeding strategies for improving phosphorus acquisition by legume crops in acid soils sub—Sahara Africa. *Biotechnology and Molecular Biology Review* 6: 142-154.

Atkinson, D. 1991. “Influence of root system morphology and development on the need for fertilizers and the efficiency of use”, Plant roots: The Hidden Half. In: Waisel Y., Eshel A., Kafkaki U., (eds.), Marcel Dekker Inc., New York: 411–451.

Ayub, M. Nadeem, M.A. Sharar. M.S. and N. Mahmood. 2002. Response of maize (*Zea mays* L.) fodder to different levels of nitrogen and phosphorus. *Asian Journal of Plant Science* 1: 352-354.

Azad, M.S. Mondol, S. and A. Matin. 2013. Functional relationships of nodulation response and biomass production at nursery stages of two fast-growing, leguminous multipurpose tree species in Bangladesh: *Albizia saman* and *Leucaena leucocephala*. *Forest Science Practice* 15: 274–285.

Barrett, R.P. Simon, J.E. and J. Janick. 1997. Legume species as leaf vegetables. Advances in New Crops. Timber Press, Portland, pp. 391-396.

Bationo, A. and K. Kumar. 2002. Phosphorus use efficiency as related to sources of P-fertilisers, rainfall, soil, crop management and genotypes in the West African semi-arid tropics. In: J J Adu-Gyamfi (ed.), food security in nutrient stressed environment: Exploiting plant's genetic capabilities, pp. 145-154.

Bayuelo-Jimenez, J.S. Hernandez-Bravo, N. Magdaleno-Armas, M.L. Perez-Decelis, V.A. Gallardo-Valdez, M. Paredes-Gutierrez, L. C. and J.P. Lynch. 2013. Contribution of root traits to phosphorus acquisition efficiency by maize landraces in acid soils of the highlands in central Mexico. International Atomic Energy Agency, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Soil and Water Management and Crop Nutrition Section, Vienna (Austria); pp. 25-54

Blum, A.1995. Drought resistance, water-use efficiency, and yield potential-are they compatible, dissonant, or mutually exclusive. *Australian Journal of Agriculture Research* 56: 1159-1168.

Bremner, J.M. and C.S. Mulvaney. 1982. Nitrogen-Total. In: A.L. Page, R.H. Miller (Eds). Methods of Soil Analysis. Part 2. 2nd ed. Agronomy Monograph. 9. ASA and SSSA, Madison, WI, pp. 595-624.

Bubenheim, D.L. Mitchel, C.A. and S.S. Nielsen. 1990. Utility of cowpea foliage in a crop production system for space. In: J. Janick and J.E. Simon (eds.), Advances in new crops. Timber Press, Portland, pp. 535-538.

Cantagallo, J.E. Chimenti, C.A. and A.J. Hall. 1997. Number of seeds per unit area in sunflower correlates well with a photothermal quotient. *Crop Science* 37: 1780-1786.

Carpici, E. B. and N.Celik.2010. determining Possible Relationships between Yield and Yield-Related Components in Forage Maize (*Zea mays* L.) Using Correlation and Path Analyses. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 38: 280-285

Castro, J. Hodar, J. A. and J.M. Gomez. 2006. Seed size. In Handbook of Seed Science and Technology (Ed. Basra A. S.), New York: Food Products Press. pp. 397–427.

Cauş, M. Brand, C. and B. Eichler-Loebermann. 2012. Combined effects of drought and phosphorous deficiency on physiological and biochemical indices of soybean plants. Institute of Genetics and Plant Physiology, Moldovan Academy of Sciences, Chisinau, Moldova Rostock University, Faculty of Agricultural and Environmental Sciences, Rostock, Germany

Cayon, M.G. El-Sharkawy, M.A. and L.F. Cadavid. 1997. Leaf gas exchange of cassava as affected by quality of planting material and water stress. *Photosynthetica* 34: 409-418.

Chimenti,C.A. Marcantonio, M. and A.J.Hall. 2006. Divergent selection for osmotic adjustment results in improved drought tolerance in maize (*Zea mays* L.) in both early growth and flowering phases. *Field Crops Research* 95: 305-315.

Chiulele, R.M. Mwangi, G. Tongoona, P. Ehlers, J.D. and A.D. Ndeve. 2011. Assessment of cowpea genotypes for variability to drought tolerance. *African Crop Science Conference Proceedings* 10: 531-537.

Cobbinah, F. A. Addo-Quaye, A. A. and I. K. Asante. 2011. Characterization, evaluation and selection of cowpea (*Vigna unguiculata* (L.) Walp) accessions with desirable traits from eight regions of Ghana. *Journal of Agricultural and Biological Science* 6: 21-32.

Costa, R.C. and A.K. Lobato. 2011. ABA-mediated proline synthesis in Cowpea leaves exposed to water deficiency and rehydration. *Turkish Journal of Agriculture and Forestry* 35: 309-317.

Costa, R.C.L. 1999. Nitrogen assimilation and osmotic adjustment in nodulated plants of bean [*Vigna unguiculata* (L.) Walp] under water stress, PhD Thesis. Universidade Federal do Ceará, Brasil.

Costa, R.C.L. Lobato, A.K.S. Oliveira Neto, C.F. Maia, P.S.P. Alves, G.A.R. and H.D. Laughinghouse. 2008. Biochemical and physiological responses in two *Vigna unguiculata* (L.) Walp. cultivars under water stress. *Journal of Agronomy* 7: 98-101.

Davis, D.W. Oelke, E.A. Oplinger, E.S. Doll, J.D. Hanson.C.V. and D.H. Putnam. 1991. Alternative plant and animal products: Programs in information exchange and research. In: Alternative Field Crops Manual. Janick and J.E. Simon (eds.). New crops. John Wiley and Sons, New York, pp. 133-143.

Department of Agriculture Fishery and Forestry. 2011. Production of guidelines for cowpea. Available online at http://www.nda.agric.za/. Accessed: 2013-06-25.

Department of Agriculture Forestry and Fisheries. 2011. Food security. By Directorate Economic Servives Production Economics Units. Accessed from www.daff.gov.za. [Accessed: 2014-06-19)

Drew, M.C. and L.R. Saker. 1978. Nutrient supply and the growth of the seminal root system in barley. *Journal of Experimental Botany* 29: 435–451.

EI-Juhany, I. and M.I. Aref. 2005. Growth and dry matter partitioning of *Leuceana leucocephala* trees as affected by water stress. *Alexandria Journal Agricultural Research* 44: 237-259.

Elawad, H.O.A. and A.E. Hall. 1987. Influences of early and late nitrogen fertilization on yield and nitrogen fixation of cowpea under well-watered and dry field conditions. *Field Crops Research* 15: 229–244.

El-Shaikh, K.A.A. El-Dakkak A.A.A. and H.A. Obiadalla-Ali. 2010. maximizing productiviyt of some garden pea cultivars and minimising chemical phosphorus fertilizer via VA-Mycorrhizal Inoculants. *Journal of Horticultural Science and Ornamental Plants* 2:114-122.

Fan, M. Zhu, J. Richard, C. Brown, K.M. and J.P. Lynch. 2003. Physiological roles for aerenchyma in phosphorus-stressed roots. *Functional Plant Biology* 30: 493-506.

FAOSTAT. 2004. (Food and Agriculture Organization Statistical Database). http://apps.fao.org/faostat/collections. Accessed: 2012-11-20.

FAOSTAT. 2013. (Food and Agriculture Organization Statistical Database). http://apps.fao.org/faostat/collections. Accessed on 31 December 2014.

Farooq, M. A. Wahid, N. Kobayashi, D. and S.M.A. Basra. 2009. Plant drought stress, effects, mechanisms and management. *Agronomy for Sustainable Development* 29: 185–212.

Farquhar, G.D. and T.D. Sharkey. 1982. Stomatal conductance and photosynthesis. *Annual Review Plant Physiology* 33: 317-345.

Fenta, B.A. 2012. Investigation of the physiological responses in soybean and common bean to water deficit. PhD thesis of University of Pretoria, South Africa. pp 118-128.

Fery, R. L. 1990. The cowpea: production, utilization, and research in the United States. *Horticultural Review* 12: 197-222.

Fery, R.L. 1985. The genetics of cowpeas: A review of the world literature. In: Singh, S.R. and Rachie, K.O. (Eds). Cowpea Research, Production and Utilization. Chichester: John Wiley and Sons. pp. 25-62.

Ge, Z. Rubio, G. and J.P. Lynch. 2000. The importance of the root gravitropism for inter-root competition and phosphorus acquisition efficiency: results from a geometric simulation model. *Plant and Science* 218: 159-171.

Ghannoum, O. and J.P. Conroy. 2007. Phosphorus deficiency inhibits growth in parallel with photosynthesis in a C3 (*Panicum laxum*) but not two C4 (*P. coloratum* and *cenchrusciliaris*) grasses. *Functional Plant Biology* 34: 72–81.

Girma,A. Demelash, A. and T. Ayele. 2014. The response of haricot bean varieties to different rates of phosphorus at Arba Minch, southern Ethiopia. *ARPN Journal of Agricultural and Biological Science* 9:344-350.

Goldstein, A.H. Baertlein, D.A. and R.G. Mcdaniel. 1988. Phosphate starvation inducible metabolism in *Lycopersicon esculentum*. I. Excretion of acid phosphatase by tomato plants and suspension cultured cells. *Plant Physiology* 87: 711–715.

Grant, C. A. Flaten, D. N. Tomasiewicz, D. J. and S.C. Sheppard. 2001. The importance of early season P nutrition. *Canadian Journal Plant Science* 81: 211–224.

Gunderson, C. A. Sholtis, J. D. Wullschleger, S. D. Tissue, D. T. Hanson, P. J. and R. J. Norby. 2002. Environmental and stomatal control of photosynthetic enhancement in the canopy of a sweetgum (*Liquidambar styraciflua* L.) plantation during 3 years of CO_2 enrichment. *Plant, Cell and Environment* 25: 379–393.

Gutierrez-Boem, F. H. and G.W. Thomas. 1999. Phosphorus nutrition and water deficits in field-grown soybeans. *Plant and Soil* 207: 87–96.

Gwathmey, C.O. Hall, A.E. and M.A. Madore.1992. Adaptive attributes of cowpea genotypes with delayed monocarpic leaf senescence. *Crop Science* 32: 765–772.

Hall, A.E. 2004. Breeding for adaptation to drought and heat in cowpea. *European Journal of Agronomy* 21:447–454.

Hall, A.E. Cisse, N. Thiaw, S. Elawad, H.O.A. Ehlers, J.D. Ismail, A.M. Fery, R. Roberts, P.A. Kitch, L.W. Murdock, L.L. Boukar, O. Phillips, R.D. and K.H.Mcwatter. 2003. Development of cowpea cultivars and germplasm by the Bean/Cowpea CRSP. *Field Crops Research* 82: 103–134.

Hall, A.E. Singh, B.B. and J.D. Ehlers. 1997. Cowpea breeding. *Plant Breeding Review* 15: 215–274.

Hapton, R. Thottappily, G. and H. Rossel. 1997. Viral diseases of cowpea and legumes under storage conditions. *Annals of Agricultural and Biological Research* 9: 63-65.

Hayatu, M. and F.B. Mukhtar. 2010. Physiological responses of some drought resistant cowpea genotypes (*Vigna unguiculata* (l.) walp) to water stress. *Bayero Journal of Pure and Applied Sciences* 3: 69 –75

Ho, M.D. 2004. Effects of root architecture, plasticity, and tradeoffs on water and phosphorus acquisition in heterogeneous environments.PhD Thesis.Pennsylvania State University. Accessed: 29/04/2013.

Hussain, M. Malik, M.A.Farooq, M. Khan, M.B. Akram, M. and M.F. Saleema. 2009. Exogenous glycinebetaine and salicylic acid application improves water relation, allometry and quality of hybrid sunflower under water deficit conditions. *Journal of Agronomy and Crop Science* 195: 98-109.

Icoz, M. and S. M. Kara. 2009. Effect of plant density on yield and yield component relationships in silage corn. VIII. Field Crops Congress in Turkey.

International Institute of Tropical Agriculture (IITA) (2004). Available at http://www.iita.org/crop/cowpea.htm. Accessed: 2013-05-28.

Ismail, A.M. and A. E. Hall. 2000. Semi-dwarf and standard-height cowpea responses to row spacing in different environments. *Crop Science* 40: 1618–1623.

Jaleel, C.A. Manivannan, P. Wahid, A. Farooq, M. Somasundaram, R. and R. Panneerselvam. 2009. Drought stress in plants: a review on morphological characteristics and pigments composition. *International Journal of Agricultural Biology* 11: 100–105.

Jana, S. M.G. Som and N.D Das.1983. Correlation and path analysis of vegetable pod yield components in cowpea (*Vigna unguiculata var. sesquipedalis*). *Haryana Journal Horticulture Science* 12: 224-227.

Jensen. E.S. 1991. Evaluation of automated analysis of 15n and total N in plant material and soil. *Plant and Soil* 133: 83-92.

Jin, J. Tang, C.X. Armstrong, R. and P. Sale. 2012. Phosphorus supply enhances the response of legumes to elevated CO_2 (FACE) in a phosphorus-deficient Vertisol. *Plant and Soil* 358: 86–99.

Kafua, E.L. 2010. Fumonisin production by and biological control of *Furarium species* associated with cowpea seed. Submitted in partial fulfilment of the requirements for the degree of Magister Scientia: plant science. In the Faculty of Natural and Agricultural Science department of the Plant Science University of Pretoria

Kahn, .B.A. and P.J. Stoffella. 1991. Nodule Distribution among Root Morphological Components of Field-grown Cowpeas. *Journal of the American Society for Horticultural Science* 116: 655-658.

Kamara, C.S. 1976. The effects of excess and deficient soil moisture on growth and yield of cowpea. Tropical Grain Legume Bulletin pp. 4-8.

Karamanos, A.S. 1980. Water stress and leaf growth of field beans (*Vicia faba*) in the field: Leaf number and total area. *Annual Botany* 42: 1393-1402.

Karasu, A. and M. Oz. 2010. A study on coefficient analysis and association between agronomical characters in dry bean (*Phaseolus vulgaris* L.). *Bulgarian Journal of Agricultural Science* 16: 203-211.

Karkanis, A. Bilalis, D. and A.Efthimiadou. 2011. Architectural plasticity, photosynthesis and growth responses of velvet leaf (*Abutilon theophrasti Medicus*) plants to water stress in a semi-arid environment. *Australian Journal Crop Science* 5: 369-374.

Kawooya, R. 2014. Influence of plant density and intercropping on the performance of elite cowpea varieties in eastern Uganda. A thesis submitted to the directorate of research and graduate training in partial fulfilment of the requirements for the award of the degree of Master of Science in crop science (Agronomy) of Makerere University.

Kgonyane, M.C. I.K. Mariga and J.P. Dimes. 2013. Low rates of nitrogen and phosphorus as fertilizer options for maize production by smallholding farmers in drier regions of South Africa. *Research on Crops* 14: 444-454.

Khan, A. Bari, A. Khan, S. Shah, N.H. and I. Zada. 2010. Performance of cowpea genotypes at higher altitude of NWFP. *Pakistan Journal Botany* 42: 2291-2296.

Khan, M.A. Han, Y. Zhao, Y.F. Troggio, M. and S.S. Korban. 2012. A multipopulation consensus genetic map reveals inconsistent marker order among maps likely attributed to structural variations in the apple genome. *PLoS ONE* 7: 1-12.

Kiani, S.P. Talia, P. Maury, P. Grieu, P. Heinz, R. Perrault, A. Nishianakamasu, V. Hopp, E. Gentz bittel, L. Paniego, N and A. Sarrafi. 2007. Genetic analysis of plant water status and osmotic adjustment in recombinant inbred lines of sunflower under two water treatment. *Plant Science* 172: 773-787.

Kimiti, J.M. 2011. Influence of integrated soil nutrient management on cowpea root growth in the semi-arid eastern Kenya. *African Journal of Agricultural Research* 6: 3084-3091.

Kitch, L.W. Boukar, O. Endondo, C. and I. Murdock. 1998. Farmer acceptability criteria in breeding cowpea. Cambridge University press, UK, pp. 24-31.

Kugblenu, Y.O. Kumaga, F.K. Ofori, K and J. J. Adu-Gyamfi. 2014. Evaluation of cowpea genotypes for phosphorus use efficiency. *Journal of Agricultural and Crop Research* 2: 202-210.

Kumar, N. Nandwal, A.S. Devi, S. Sharma, K.D. Yadav, A. and R.S. Waldia. 2010. Root characteristics, plant water status and CO_2 exchange in relation to drought tolerance in chickpea. *Journal of SAT Agricultural Research* 8: 1-5.

Kumari, R.U. Usharani, K.S. Suguna, R. and C.R. Anandakumar. 2010. Relationship between the yield contributing characters in cowpea for grain purpose [*Vigna unguiculata* (l). Walp]. *Electronic Journal of Plant Breeding* 1: 882-884.

Kuznetsov, V.V. and N.I. Shevyakova.1997. Stress responses of tobacco cells to high temperature and salinity. Proline accumulation and phosphorylation of polypeptides. *Physiology Plant* 100: 320- 326.

Kwapata, M.B. and A.E. Hall. 1985. Effects of moisture regime and phosphorus on mycorrhizal infection, nutrient uptake, and growth of cowpea (*Vigna unguiculata* (L.) Walp.). *Field Crops Research* 12: 241-250.

Langyintuo, A.S. Lowenbergdeboer, J. Faye, M. Lambert, D. Ibro, G. Moussa, B. Kergna, A. Kushwaha, S. Musa, S. and G. Ntoukam. 2003. Cowpea supply and demand in west and central Africa. *Field Crops Research* 82: 215-231.

Lawn, R.J. and H.V.A. Bushby. 1982. Effect of root, shoot and Rhizobium strain on nitrogen fixation in four Asiatic *Vigna species*. *New Phytologist* 92: 425-434.

Li, Z. Mu, P L. I, Czhang, H. Li, Z. Gao, Y. and X. Wng. 2005. QTL mapping of the root traits in a doubled haploid population from a cross between upland and lowland japonica rice in three environments. *TAG Theoretical and Applied Genetics* 110: 1244-1252.

Liao, H, X Y. Rubio, G. Beebe, S.E. Blair, W.M. and J.P. Lynch. 2004. Genetic mapping of basal root gravitropism and phosphorus acquisition efficiency in common bean. *Functional Plant Biology* 31: 959-970.

Liao, H. Yan, X. Rubio, G. Beebe, S. E. Blair, M.W. and J.P. Lynch. 2001. Genetic mapping of basal root gravitropism and phosphorus acquisition efficiency in common bean. *Functional Plant Biology* 31: 959-970.

Liu, L. Zhang, H. Ju, C. Xiong, Y. Bian, J. Zhao, B. and J. Yang. 2014. Changes in Grain Yield and Root Morphology and Physiology of Mid-Season Rice in the Yangtze River Basin of China during the Last 60 Years. *Journal of Agricultural Science* 6: 9752-9760.

Lobato, A.K.S. Oliveira Neto, C.F. Costa, R.C.L. Santos Filho, B.G. Cruz, F.J.R. and H.D. Laughinghouse. 2008. Biochemical and physiological behaviour of *Vigna unquiculata* (L) Walp, under water stress during the vegetative phase. *Asian Journal of Plant Science* 7: 44-49.

Lobell, D.B. Burke, M.B. Tebaldi, C. Mastrandrea, M.D. Falcon, W.P. and R.L. Naylor. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science* 319: 607-610.

Lynch, J.P. 1995. Root architecture and nutrient acquisition. In Nutrient acquisition by plants: an ecological perspective. *Ecological Studies* 181:147-184.

Lynch, J.P. 1998. The role of nutrient-efficient crops in modern agriculture. *Journal of Crop Production* 1: 241-264.

Lynch, J.P. 2005. Root architecture and nutrient acquisition. pp. 147-184. In: Nutrient acquisition by plants: P, an ecological perspective (H. BassiriRad ed.). *Ecological studies* 181.

Lynch, J.P. and K.M. Brown. 2001. Topsoil foraging-an architectural adaptation of plants to low phosphorus availability. *Plant Soil* 237: 225–237.

Lynch, J.P. and K.M. Brown. 2008. Root strategies for phosphorus acquisition. *Plant Ecophysiology* 7: 83–116.

Ma, Z. Bielenberg, D. Brown, K.M. and J.P. Lynch. 2001. Regulation of root hair density in Arabidopsis by phosphorus availability. *Plant Cell and Environment* 24: 459-467.

Mafakheri, A. Siosemardeh, A. Bahramnejad, B. Struik, P.C. and Y. Sohrabi. 2010. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. *Australian Journal of Crop Science* 4: 580-585.

Magani, I.E. and C. Kuchinda. 2009. Effect of phosphorus fertilizer on growth, yield and crude protein content of cowpea (*Vigna unguiculata* [L.] Walp) in Nigeria. *Journal of Applied Biosciences* 23: 1387 - 1393

Magashi, A.I. Musa, S.F. and I. Muhammad. 2014. Evaluation of Cowpea Genotypes (*Vigna unguiculata* (L.) Walp) for some Yield and Root Parameters and their Usage in Breeding Programme for Drought Tolerance. *International Journal of Advances in Agricultural and Environmental Engineering (IJAAEE)* 1: 2349-1531.

Magloire, N. 2005. The genetic, morphological and physiological evaluation of African cowpea genotypes. Magister Scientiae Agriculturae dissertation submitted at the Faculty of Natural and Agricultural Sciences, Department of Plant Sciences (Plant Breeding) at the University of the Free State.

Marino, D. Frendo, P. Ladrera, R. Zabalza, A. Puppo, A. Arrese-Igor, C. and E.M. González. 2007. Nitrogen fixation control under drought stress. Localized or systemic? *Plant Physiology* 143: 1968–1974.

Marschner, H. 2002. Mineral Nutrition of Higher Plants", Second edition, Academic Press, Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego San Francisco, Singapore, Sydney, Tokyo.

Martinez-Ballesta, M.C., Martinez, V. and M. Carvajal. 2004. Osmotic adjustment, water relations and gas exchange in pepper plants grown under NaCl or KCl. *Environmental and Experimental Botany* 52: 161-174.

Matenge, S.T.P. van der Merwe, D. De Beer, H. Bosman, M.J.C. and A. Kruger. 2012. Consumers' beliefs on indigenous and traditional foods and acceptance of products made with cowpea leaves. *African Journal of Agricultural Research* 7: 2243-2254.

Mbagwu J. S. C. and J. O. Osuigwe. 1985. Effects of varying levels and frequencies of irrigation on growth, yield, nutrient uptake and water use efficiency of maize and cowpeas on a sandy loam ultisol. *Plant and Soil* 84: 181-192.

Mcwilliams, D. 2003. Drought Strategies for Cotton, Cooperative Extension Service Circular 582, College of Agriculture and Home Economics, New Mexico State University, USA.

Miller, C.R. Ochoa, I. Nielsen, K. Beck, D. and J.L. Lynch. 2003. Genetic variation for adventitious rooting in response to low phosphorus availability: potential utility for phosphorus acquisition from stratified soils. *Functional Plant Biology* 30: 973-985.

Mitchell, H. L. 1972. Micro-determination of nitrogen in plant tissues. *Journal Association of Analytical Chemis*t 55: 1-3.

Mitra, J. 2001. Genetics and genetic improvement of drought resistance of crop plants. *Current Science* 80: 758-763.

Muleba, N. and H.C. Ezumah. 1985. Optimizing cultural practices for cowpea in Africa. In: Singh, S.R. and Rachie, K.O., Eds., Cowpea Research, Production, and Utilization, John Wiley and Sons Ltd, Chichester, pp. 289- 295.

Murphy, J. and H.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica. Acta* 27:31-36.

Mustapha, Y. Biwe, E.R. and A. Salem. 2014. Effects of Moisture Stress on the Growth Parameters of Soybean Genotypes. *Discourse Journal of Agriculture and Food Sciences* 2: 142-148.

Nahar, K. and S.M. Ullah. 2011. Effect of Water Stress on Moisture Content Distribution in Soil and Morphological Characters of Two Tomato (*Lycopersicon esculentum* Mill) Cultivars. *Journal of Scientific Research* 3: 677-682.

Nakawuka, C.K. and E. Adipala.1999. A path coefficient analysis of some yield component interactions in cowpea. *African Crop Science Journal* 7: 327-331.

National Department of Agriculture. 2009. Production guidelines for Cowpeas. http:// www.nda.agic.za/docs/Infopark-cowpea booklet.pdf.(Accessed 2012 07 23).

Nduguru, B. J. Ntare B. R. Williams, J. H. and D.C. Greenberg. 1995. Assessment of groundnut cultivars for end-of-season drought tolerance in a Sahelian environment. *Journal of Agricultural Science* 125: 19-25.

Ng, N.Q. and R. Marechal. 1985. Cowpea taxonomy, origin and germplasm. In: Singh SR, Rachie KO (eds) Cowpea research, production and utilization. Wiley, New York, pp. 11–21.

Niu,Y.F. Chai,F.R. Jin,G.L. Wang, H.Tang, C.X. and Y. S. Zhang. 2012. Review: part of a special issue on matching roots to their environment Responses of root architecture development to low phosphorus availability: a review. *Annals of Botany* 10: 1 – 18.

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

Ohashi, Y. Nakayama, N. Saneoka, H. and K. Fujita. 2006. Effects of drought stress on photosynthetic gas exchange, chlorophyll fluorescence and stem diameter of soybean plants. *Biologia Plantarum* 50: 138-141.

Okeleye, K.A. and M.A.O. Okelana. 1997. Effect of Phosphorus Fertilisers on Nodulation, growth, and yield of Cowpea (*Vigna unguiculata*) varieties. *Indian Journal of Agricultural Science* 67: 10 –12.

Oladiran, O. 2012. Phosphorus Response Efficiency in Cowpea Genotypes. *Journal of Agricultural Science* 4: 81 – 90.

Paul C. S. and K.E. Giller. 2002. Appropriate Farm Management Practices for Alleviating N and P Deficiencies in Low-nutrient Soils of the Tropics In: J. J. Adu-Gyamfi (Ed.) Food Security in nutrient-stressed environments: exploiting plant genetic capabilities: Khiver Academic Publishers. pp. 277-288.

Pellerin, S. Mollier, A. and D. Plénet. 2000. Phosphorus deficiency affects the rate of emergence and number of maize adventitious nodal roots. *Agronomy Journal* 92: 690-697.

Pérez-Pérez, J.G., Robles, J.M., Tovar, J.C., and P. Botía. 2009. Response to drought and salt stress of lemon 'Fino 49' under field conditions: water relations, osmotic adjustment and gas exchange. *Horticultural Science* 122: 83-90.

Phillips, R.D. Kay, H. Mcwatters, M.S. Chinnam, Y.N. Larry, R. Beuchat, S.S. Sakyi-Dawson, E. Ngoddy, P. Nnayelugo, D. Enwerej, J. Komey, N.S. Liu, K. Mensa-Wilmot, Y. Nnanna, I.A. Okere, C. Prinyawiwatkul, W. and F.K. Saalia. 2003. Utilization of cowpea for human consumption. *Field Crops Research* 82: 193-213.

Quan, L. Cheng, X. Yan, M.M. and H. Liao. 2010. QTL analysis of root traits as related to phosphorus efficiency in soybean. *Annual Botany* 106: 223–234.

Quin, F.M. 1997. Introduction. In: Advances in Cowpea Research. Singh, B.B., D.R. Mohan Raj, K.E. Dashiel and L.E.N. Jackai (eds.), IITA, Ibadan, Nigeria, pp. IX-XV.

Raghothama, K. G. 1999. Phosphate acquisition. *Annual Review of Plant Physiology and Plant Molecular Biology* 50: 665–693.

Ramaekers, L. Remans R. Rao, I.M. Blair, M.W. and J. Vanderlevden. 2010. Strategies for improving phosphorus acquisition efficiency of crop plants. *Field Crops Research* 117: 169–176.

Reamaekers, R.H. 2001. Crop production tropical Africa. DGIC, Belgium, pp. 334-34.

Richard P.F. Heutte, N. Bouchart, V. and D. Garon. 2009. Evaluation contamination and mycotoxin production in maize silage. *Animal Feed Science and Technology* 148: 309-320.

Rogerio, M.C. 2003. Morphological and physiological responses of cowpea cultivars to induced water stress and phosphorus. Master of Agricultural Science dissertation, University of Stellenbosch.

Sairam, R. K. Tomer, P. S. and T. K. Gauguly. 1984. Growth, nitrogen uptake and forage yield of cowpea as affected by phosphorus application and inoculation. *Agricultural Science Digest* 4: 83-86.

Sallam, A. Hamed, E. Hashad, M. and M. Omara. 2014. Inheritance of stem diameter and its relationship to heat and drought tolerance in wheat (*Triticum aestivum* L.). *Journal of Plant Breeding and Crop Science* 6:11-23.

Samar Raza, M. A. Farrukh Saleem, M. Mustafa Shah, G. Jamil M. and I. Haider Khan. 2013. Potassium applied under drought improves physiological and nutrient uptake performances of wheat (*Triticum Aestivum* L.) *Journal Soil Science and Plant Nutrition* 13: 175-185.

Sanchez, P.A. 1976. Properties and Management of Soils in the Tropics. Wiley, New York.

Sanchez, P.A. 2010. Tripling crop yields in tropical Africa. *Nature Geoscience* 3: 299-300.

Santos, A.L. 2000.Some biotic and abiotic factors affecting the production of cowpea (*Vigna unguiculata* (L.) Walp) in Mozambique. Undergraduate Thesis, College of Agriculture and Forestry, Maputo.

Sarker, B.C. and M.Hara. 2011. Effects of elevated CO_2 and water stress on the adaptation of stomata and gas exchange in leaves of eggplants (*Solanum melongena* L.). *Bangladesh Journal of Botany* 40: 1-8.

Sarkodie-Addo, J. 1991. Evaluation of *Bradyrhizobium japonicum* isolates from ontario soybean fields. Msc Thesis, University of Guelph, pp. 130.

Schakel, K.A. and A.E. Hall. 1979. Reversible leaflet movements in relation to drought adaptation of cowpeas, *Vigna unquiculata* (L.) Walp. *Australian Journal Plant Physiology* 6: 265–276.

Scholz, F. G. Bucci, S. J. Goldsteem, G. Meinzer, F. C. and A.C. Tranco. 2002. Hydraulic redistribution of soil water by neotrpical Savanna tress. *Tree Physiology* 22: 603- 612.

Science Daily. 2008. Nitrogen fixation process in plants to combat drought in various species of legumes. Science Daily (September 27, 2013). Available online at http://www.scienedaily.com/. Accessed: 2013-09-27.

Sebetha, E.T. Ayodele, V.I. Kutu, F.R. and I.K. Mariga. 2010. Yields and Protein content of two cowpea varieties grown under different production practices in Limpopo province. *African Journal of Biotechnology* 9: 628-634.

Serraj, R. 2003. Effects of drought stress on legume symbiotic nitrogen fixation: physiological mechanisms. *Indian Journal of Experimental Biology* 41: 1136-1141.

Siddique, K.H.M., Regan, K.L., Tennant, D., and B.D. Thomson. 2001. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. *European Journal of Agronomy* 15: 267-280.

Sinclair, T.R. and R.C. Muchow. 2001. System analysis of plant traits to increase grain yield on limited water supplies. *Agronomy Journal* 93: 263-270.

Sinclair, T.R. Muchow, R.C. Ludlow, M.M. Leach, G.J. Lawn, R.J. and M.A. Foale. 1987. Field and model analysis of the effect of water deficits on carbon and nitrogen accumulation by soybean, cowpea and black gram. *Field Crops Research* 17: 121–140.

Singh, A. Baoule, A.L. Ahmed, H.G. Aliyu, U. Sokoto, M.B. Alhassan, J. Musa, M. and B. Haliru. 2011. Influence of phosphorus on the performance of cowpea (*Vigna unguiculata* (L.) Walp.) varieties in the Sudan Savanna of Nigeria. *Journal of Agricultural Science* 2: 313-317.

Singh, A. Muhammad, A. Sokoto, M.B. Singh, R.B. Kilgori, M.J.S. and N.D. Ibrahim. 2009. Response of cowpea [*Vigna unguiculata* (L.) Walp.] to phosphorus application in Dundaye area of Sokoto State, Nigeria. In: I. Muhammed, U.B. Kyiogwom, W.A. Hassan, A. L. Ala, A. Singh and S.D. Dogondaji (eds.), Sustainable Agricultural Growth to Meet National Economic Development. Proceedings of the 23rd Annual Conference. Farm Management Society of Nigeria, 14 - 17th December, 2009, pp. 381-385

Singh, B.B. and B. Sharma. 1996. Restructuring cowpea for higher yield. *Indian Journal Genetics* 56: 389 – 390.

Singh, B.B. Chambliss, O.L. and B. Sharma. 1997. Recent advances in cowpea breeding. In: Singh, B.B., Mohan Raj, D.R., Dashiell, K.E., Jackai, L.E.N (eds.). Advances in Cowpea Research. Sayce Publishing, Devon, UK, pp. 375.

Singh, B.B. Ehlers, J.D. Sharma, B. and F.R. FreireFilho. 2002. Recent progress in cowpea breeding. In: Fatokum CA, Tarawali SA, Singh BB, Kormara PM, Tamo M (eds.), Challenges and opportunities for enhancing sustainable cowpea production. Proceedings of the World Cowpea and opportunities at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 4-8 September 2000. IITA, Ibadan, Nigeria, pp. 22-40.

Singleton, P. AbdelMagid, H. and J.Tavares. 1985. Effect of Phosphorus on the Effectiveness of Strains of *Rhizobium japonicum*. *Soil Science Society of America Journal* 49: 613-616.

Smit, A.L. Groenwold, J. and J. Vos.1994.The Wageningen rhizolab—a facility to study soil–root–shoot–atmosphere interactions in crops. II. *Methods of root observations. Plant Soil* 161: 289-298.

Smith, S.E. and D.J. Read. 2008. Mycorrhizal Symbiosis, Third Edition. Academic Press and Elsevier London.

Soldatini, G. F. Rammieri, A. and O. Gerini. 1990. Water balance and photosynthesis in Zea mays L. seedlings exposed to drought and flooding stress. *Biochem Physiologist Pflanzen* 186: 145 – 152.

Soriano, M.A. Villalobos, F.J. Fereres, E. Orgaz, F. Borin, M. and M. Sattin.1994. Response of sunflower grain yield to water stress applied during different phenological stages, Abano-Padovo, Italy, pp. 18-22.

Souza, R.P. Machado, E.C. Silva, J.A.B. Lagoa, A.M.M.A. and J.A.G. Silveira. 2003. Photosynthetic gas exchange, chlorophyll fluorescence and some associated metabolic changes in cowpea (*Vigna unquiculata*) during water stress and recovery. *Environmental and Experimental Botany* 51:45-56.

Sponchiado, B.N. White, J.W. Castillo, J.A. and P.G. Jones. 1989. Root growth of four common bean cultivars in relation to drought tolerance in environments with constrasting soil types. *Experimental Agriculture* 25: 249-257.

Stoffella, P.J.1991. Nodule distribution among root morphological components of field-grown cowpeas. *Journal of the American Society for Horticultural Science 116*: 655-658.

Suliman, A.H. 2000. Effect of water stress at different stages of growth on the performance of cowpea (*Vigna unguiculata* [L] Walp) cultivars. M.Sc. (Thesis), University of Khartoum, Sudan

Suriyagoda, L.D.D. Ryan, M.H. Renton, M. and H. Lambers. 2010. Multiple adaptive responses of Australian native perennial legumes with pasture potential to grow in phosphorus- and moisture-limited environments. *Annals of Botany* 105: 755–767.

Taiz, L. and E. Zieger. 1998. Stress Physiology. In: Plant Physiology, 2nd edition. Sinauer Associates, Inc., Sunderland, M.A. (ed.). pp. 725-757.

Tanaka, Y. Sugano, S.S. Shimada, T and I.Hara-Nishimura. 2013. Enhancement of leaf photosynthetic capacity through increased stomatal density in Arabidopsis. *New Phytologist* 198: 757-64.

Thiyagarajan, K. and S. Rajasekaran. 1993. Metro graph analysis in cowpea. *Indian Journal of Pulses Research* 6: 145-148.

Timko, M.P. Ehlers, J.D. and P.A. Roberts. 2007. Cowpea. In: Kole C (Ed) Genome Mapping and Molecular Breeding in Plants, Vol 3, Pulses, Sugar and Tuber Crops, Springer Verlag, Berlin Heidelberg, pp. 49–67.

Tshuma, M. C. 2012. A review of the poverty and food security issues in South Africa: Is agriculture the solution? *African Journal of Agricultural Research* 7: 4010-4020.

Turk, K.J. and A.E. Hall. 1980. Drought adaptation of cowpea III. Influence of drought on plant growth and relation with seed yield. *Agronomy Journal* 72: 428-433.

Turner, N.C. Wright, G.C. and K.H.M. Siddique.2001. Adaptation of grain legumes (pulses) to water limited environments. *Advances in Agronomy* 14:193–231.

Van Wyk, B.E. and N. Gericke. 2000. People‘s plants: A guide to Useful Plants in Southern Africa. Briza Publication, Pretoria, pp. 192.

Vieira, R. F. Carneiro, J.E.S. and .J. P. Lynch. 2008. Root traits of common bean genotypes used in breeding programs for disease resistance. *Pesquisa Agropecuária Brasileira* 43: 707-712.

Vorster, H. J. Stevens, J. B. and G.J. Steyn. 2008. Production systems of traditional leafy vegetables: Challenges for research and extension. *South African Journal of Agricultural Extension* 37: 85–96.

Walker, T.S. Bais, H.P. Grotewold, E. and J.M. Vivanco. 2003. Root exudation and rhizosphere biology. *Plant Physiology* 132: 44–51.

Watanabe, N.C. Hakoyama, T. T. and B.B. Singh. 1997. Evaluation methods for drought tolerance of cowpea. In: Advances in cowpea research. Singh, B.B., D.R. Mohan Raj, K.E. Dashiell and L.E.N. Jackai (eds). Copublication of the International Institute of Tropical Agriculture (IITA) and Japan International Research Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria, pp. 141-146.

Wery, J. Silim, S.N. Knight, E.J. Malhotra, R.S. and R. Cousion. 1994. Screening techniques and sources of tolerance to extremes of moisture and air temperature in cool season food legumes. *Euphytica* 73: 73-83.

Yada G.L. 2011. Establishing optimum plant populations and water use of an ultra-fast maize hybrid (*Zea mays* l.) under irrigation. PhD thesis University of Free State, South Africa, pp. 30-33.

Yan, H.X. Fang, L.B and D. Z. Huang. 2011. Effects of drought stress on the biomass distribution and photosynthetic characteristics of cluster mulberry. *Ying Yong Sheng Tai Xue Bao* 22:3365-70.

Zhang, S.Q. and W.H. Outlaw. 2001. The guard-cell apoplast as a site of abscisic acid accumulation in Vicia faba L. *Plant Cell and Environment* 24: 347-355.

Zhao, Y. H. Fonji, C. F. Nwaga, D. M. and Li, W. G. 1997. Effect of Bradyrhizobiumsp. Inoculation on biomass and nodulation of cowpea. *Pedosphere* 7: 43-48.

Zhou, G. S. Liu, F. Cao Jin, H. Yue, B. and L. Xiong. 2011. Detecting quantitative trait loci for water use efficiency in rice using a recombinant inbred line population. *Crop Genetics* 56: 1481-1487.

Zhu, J.M. and J.P. LYNCH. 2004. The contribution of lateral rooting to phosphorus acquisition efficiency in maize (*Zea mays*) seedlings. *Functional Plant Biology* 31: 949–958.

Zimmermann, M.J., Rocha, M. and T. Yolanda. 1988. Bean Crop: Factors Affecting Productivity. Brazilian Association for the Presence of Potash and Phosphate, Piracicaba, Brazil, pp. 31-40.

Zobel, R.W. 1996. Genetic control of the roots systems, In plant roots: the hidden half (eds., Waisel, A. and U. Kafkafi) Marcel Dekker, Inc. New York, pp. 21-30.

APPENDICES

Summary of Analysis of Variance (ANOVA) tables on the effect of moisture status, phosphorus and genotype on selected cowpea lines

Appendix 1: MS values for measured parameters

Source	DF	Phosphorus	P uptake	Nitrogen	N uptake
P level (b)	1	0.0350*	0.0030**	0.6032ns	0.2232ns
Moistate (c)	1	0.5296ns	0.0322*	0.1218ns	0.1451ns
B*C	1	0.3212ns	0.1328ns	0.3304ns	0.2593ns
Genotypes(d)	7	0.0015**	0.0335*	0.0354*	0.0242*
B*D interaction	7	0.0070**	0.7414ns	0.0564ns	0.6343ns
C*d interaction	7	0.3967ns	0.7450ns	0.1950ns	0.7060ns
B*C*D interaction	7	0.6416ns	0.4799ns	0.5438ns	0.5145ns

Appendix 2: Analysis of Variance for nutrient content cowpea pods

Source	DF	Phosphorus	P uptake	Nitrogen	N uptake
Plevel(b)	1	0.0179*	0.0093**	0.1275ns	0.0203*
Moistate(c)	1	0.0327*	0.3234ns	0.1011ns	0.0286*
B*C	1	0.8409ns	0.8585ns	0.1705ns	0.9846ns
Genotypes(d)	7	0.0000**	0.0000***	0.0000***	0.0000***
B*D	7	0.2159ns	0.0029**	0.0245*	0.0347*
C*D	7	0.0920ns	0.0199*	0.7652ns	0.0251*
B*C*D	7	0.1199ns	0.4340ns	0.6201ns	0.1583ns

Appendix 3: Analysis of Variance table for plant height

Source	DF	Plant Height 4WAP	Plant Height 6WAP	Plant Height 8WAP	Plant Height 10WAP
Plevel(b)	1	0.7448ns	0.3840ns	0.3248ns	0.3312ns
Moistate(c)	1	0.0067**	0.0188*	0.0095**	0.0146*
B*C	1	0.6279ns	0.6774ns	0.6276ns	0.5226ns
Genotypes(d)	7	0.0000***	0.0021**	0.0000***	0.0000***
B*D	7	0.2044ns	0.1321ns	0.2399ns	0.1367ns
C*D	7	0.0861*	0.5566ns	0.0053**	0.0552*
B*C*D	7	0.9923ns	0.6691ns	0.5881ns	0.3254ns

Appendix 4: Analysis of Variance table for 50 % physiological maturity and fresh and dry biomass

Source	DF	50% pm	Fresh Biomass(kg)	Dry biomass
Plevel(b)	1	0.1411ns	0.0002***	0.0007***
Moistate(c)	1	0.7796ns	0.4225ns	0.4656ns
B*C	1	0.7796ns	0.2672ns	0.3815ns
Genotypes(d)	7	0.0000***	0.0003***	0.0010**
B*D	7	0.0260*	0.9395ns	0.9267ns
C*D	7	0.1094ns	0.3286ns	0.2605ns
B*C*D	7	0.7042ns	0.1672ns	0.5435ns

Appendix 5: Analysis of Variance Table for yield attributes and Corrected grain yield kg ha^{-1}

Source	DF	Corrected yield	Pod fresh weight	Pod dry weight
Plevel(b)	1	0.0210*	0.5516ns	0.0917ns
Moistate(c)	1	0.4613ns	0.7174ns	0.0326*
B*C	1	0.4872ns	0.1727ns	0.2899ns
Genotypes(d)	7	0.0145*	0.0000***	0.0000***
B*D	7	0.7696ns	0.2112ns	0.0023**
C*D	7	0.6321ns	0.0332*	0.0321*
B*C*D	7	0.4203ns	0.1319ns	0.0209*

Appendix 6: Analysis of Variance table for branching densities

Source	DF	BD 5	1.5BD5	BD10	1.5BD10	BD15	3RD BD
Plevel(b)	1	0.4580ns	0.1154ns	0.9141ns	0.5627ns	0.5931ns	0.1972ns
Moistate(c)	1	0.7885ns	0.2529ns	0.8459ns	0.5222ns	0.0768ns	0.3336ns
B*C	1	0.3386ns	0.2347ns	0.7275ns	0.6665ns	0.4912ns	0.0652ns
Genotypes(d)	7	0.0000***	0.0244*	0.0008***	0.0001***	0.1070ns	0.0003***
B*D	7	0.0210*	0.0885ns	0.0347*	0.3664ns	0.7984ns	0.1720ns
C*D	7	0.5086ns	0.1024ns	0.5288ns	0.8273ns	0.9221ns	0.2300ns
B*C*D	7	0.1364ns	0.2675ns	0.7077ns	0.9493ns	0.3950ns	0.7608ns

Appendix 7: Analysis of Variance table for taproot diameters

Source	Td5	Td10	Td15	Td20	Ds	Ss	Ns	#basal roots
P level (b)	0.0817ns	0.0740ns	0.0468*	0.1940ns	0.1299ns	ns	0.0915ns	0.6183ns
Moistate(c)	0.8655ns	0.7963ns	0.0238*	0.0325*	0.5168ns	0.5050ns	0.0154*	0.8059ns
B*C	0.7291ns	0.9215ns	0.8927ns	0.5054ns	0.3985ns	0.8919ns	0.1111ns	0.3668ns
Genotypes (d)	0.016*	0.001**	0.0444*	0.1636ns	0.0091**	0.0094**	0.0000**	0.0000***
B*D interaction	0.932ns	0.7556ns	0.9566ns	0.4011ns	0.7340ns	0.6304ns	0.1444ns	0.0926ns
C*D interaction	0.754ns	0.2313ns	0.5532ns	0.1636ns	0.7103ns	0.7907ns	0.4974ns	0.6435ns
B*C*D interaction	0.709ns	0.4303ns	0.3817ns	0.4011ns	0.0862ns	0.3191na	s0.3010ns	0.2102ns

TD= Taproot diameters, Ds= Deep score, SS= Shallow score, Ns= Nodule scores

Appendix 8: Analysis of Variance table for number of leaves

Source	DF	Number of leaves 4	Number of leaves 5	Number of leaves 6	Number of leaves 7	Number of leaves 8
Plevel(b)	1	0.0201*	0.0088**	0.0395*	0.0468*	0.0475*
Moistate(c)	1	0.4959ns	0.8914ns	0.3696ns	0.3327ns	0.1332ns
B*C	1	0.5826ns	0.3928ns	0.9586ns	0.9324ns	0.5568ns
Genotypes(d)	7	0.0000***	0.0000***	0.0000***	0.0000***	0.0000***
B*D	7	0.0455*	0.0355*	0.7119ns	0.7283ns	0.6797ns
C*D	7	0.0396*	0.6087ns	0.1619ns	0.3457ns	0.0442*
B*C*D	7	0.2328ns	0.6604ns	0.8990ns	0.9475ns	0.9953ns

Appendix 9: Analysis of Variance Table for photosynthesis parameters

Source	DF	Ci	Cond	Photo	Trmmol
Plevel(b)	1	0.8290	0.7423ns	0.5632ns	0.7338
Moistate(c)	1	0.7763	0.0001***	0.0004***	0.0005***
B*C	1	0.6782	0.8817ns	0.7576ns	0.7390ns
Genotypes(d)	3	0.0909	0.0000***	0.0000***	0.0000***
B*D	3	0.2159ns	0.6187ns	0.4830ns	0.1861
C*D	3	0.0071**	0.8877ns	0.0665ns	0.2305
B*C*D	3	0.7428ns	0.9312ns	0.9156ns	0.9729ns

Ci= Intercellular CO_2, Cond= Conductance to water, Photo= Photosynthetic rate,Trmmol= Transpirate rate

Appendix 10: Analysis of Variance Table for photosynthetic parameters

Source	DF	CO_2S	Vpdl	H_2OS	RHS
Plevel(b)	1	0.6947ns	0.8211ns	0.6842ns	0.5748ns
Moistate(c)	1	0.0002***	0.0001***	0.0013**	0.0010**
B*C	1	0.6792ns	0.2199ns	0.8565ns	0.8806ns
Genotypes(d)	3	0.0000***	0.0043***	0.0000***	0.0000***
B*D	3	0.4211ns	0.7549ns	0.2278ns	0.2657ns
C*D	3	0.1808ns	0.6549ns	0.2414ns	0.1622ns
B*C*D	3	0.9081ns	0.4573 ns	0.9720ns	0.9357ns

$C0_2S$ = Sample cell CO_2, Vpdl= Vapour pressure based on leaf temp, H_2OS= Sample cell H_2O, RHS= Relative huminidy in the cell

Appendix 11: Accepted abstract for oral presentation at the January 2014 Combined Congress

RESPONSE OF COWPEA ROOT CHARACTERISTICS AND YIELD ATTRIBUTES TO VARIABLE PHOSPHORUS AND MOISTURE STRESS CONDITIONS AT UKULIMA FARM, LIMPOPO PROVINCE

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INTRODUCTION

The problems of low soil phosphorus (P) and drought stress constitute abiotic stresses that threaten crop production, and hence, global food security. Root architecture, spatial configuration of the root system, exerts significant influence on the underground nutrient and water acquisition by plants (Lynch, 1995). This study aimed to assess the potential adaptation of eight cowpea (*Vigna unquiculata* L. Walp) lines to low soil P and moisture stress under field conditions.

MATERIALS AND METHODS

A field experiment was planted at Ukulima farm near Modimolle, Limpopo Province during 2012/13-summer growing season. Treatments comprised of two levels each of soil P (low and high) and moisture (water stress and well-watered); and eight cowpea genotypes comprising of seven imported lines (Tvu4632, Tvu6365, Tvu9848, Tvu15445, Tvu16408, Tvu15143 and Oloyin) and one locally registered new line (IT00K-1217). The cowpea root traits measured included number of basal roots, tap root diameter at 5, 10, 15 and 20 cm; lateral root branching density at depths of 5, 10 and 15 cm, nodule score, and 1.5 branching density at 5 and 10 cm depths. Yield attributes measured included number of pods per plant, number of seeds per pod, grain weight, and hundred seed weight (HSW). All treatment factors were combined as split-split plot arrangement and fitted into a randomized complete block design with four replicates. Data were subjected to analysis of variance using Statistix 8.1 software and treatment means were separated using Tukey's HSD-test at 5% probability level.

RESULTS AND DISCUSSION

Results indicate that branching density at 5 and 15 cm differed significantly ($p=0.05$) across the different genotypes. A significant Moisture status x genotype interaction effect on 1.5 branching density at 5 and 10 cm depths, taproot diameter at 10, 15 and 20 cm depths and nodule score were observed. A significant P rate x genotype interaction effect on taproot diameter was also observed at 10 cm depth. Phosphorus level and genotype variation exerted significant ($P\leq0.01$) effects on pod length. The differences in mean number of pods per plant, pod weight and number of seeds per pod among cowpea genotypes were highly significant ($P=0.01$). Moisture state and genotype variation exerted significant ($P\leq0.05$) effects on grain yield and HSW.

CONCLUSIONS

The results of this study revealed that root architecture exerted significant effects on water and P acquisition, as well as the nodule information of the various cowpea genotypes including the South African newly registered line; and consequently, cowpea productivity.

REFERENCES

LYNCH, J.P. 1995. Root architecture and nutrient acquisition. In: H Bassiri-Rad (ed.), Nutrient acquisition by plants: P an ecological perspective. Ecological studies 181: 147-184.

Keywords: Cowpea genotypes; P fertilisation; moisture stress; root traits; grain yield