EFFECT OF GENOTYPE AND PHOSPHORUS FERTILIZER RATES ON WATER USE AND YIELD OF CHICKPEA

BY

THENDO MADZIVHANDILA

STUDENT NO: 11511824

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SUPERVISOR: Prof. J.B.O Ogola

CO-SUPERVISOR: Prof. J.J.O Odhiambo

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ABSTRACT

Production of chickpea in South Africa is currently insignificant but local demand is high. There are no recommendations on suitable genotypes of chickpea and agronomic practices at present. This study aimed at evaluating the effect of genotype and phosphorus (P) fertilizer rates on water use and yield of four chickpea genotypes. A field experiment was undertaken, in winter 2009 and summer 2010, using a factorial arrangement of 3 P fertilizer rates (0, 45 and 90 kg P ha^{-1}) and 4 chickpea genotypes (ICCV92944, ICCV3110, ICCV4306 and ICCV7307) laid in a randomized complete block design and replicated 3 times. Total crop biomass was determined at vegetative, 50% flowering, and harvest maturity (HM) stages and number of pods per plant, seeds per pod, 100 seed weight, grain yield and harvest index (HI) were determined at harvest maturity. Water use (ET) was determined by measuring soil moisture content at week intervals. Neutron probe was used to measure soil moisture content every week after emergence until physiological maturity. Soil moisture value was used to determine crop water use. Water use efficiency was determined as the ratio of crop biomass or grain yield to water use (ET). Genotype and P fertilizer rates affected the crop biomass at vegetative and 50% flowering stage in season I and season II. Desi genotypes had greater crop biomass compared with kabuli genotypes in winter and summer season. Genotype did not affect crop biomass at harvest maturity in both winter and summer season but the application of phosphorus fertilizer rate significantly ($P<0.01$) affected crop biomass at harvest maturity in summer season. Genotype significantly affected grain yield in winter ($P<0.05$) and summer ($P<0.01$) se ason. The desi types significantly had greater grain yield (1464 and 979 kg ha^{-1}) compared with kabuli types (680 and 274 kg ha^{-1}) in season I.

In contrast, the kabuli types significantly had greater grain yield (1538 and 1396 kg ha^{-1}) compared with desi types (1196 and 983 kg ha^{-1}) in season II. Application of phosphorus fertilizer rates did not affect grain yield in season I probably due to water deficits in winter season. In contrast, P fertilizer application rates significantly ($P<0.01$) af fected grain yield in season II. Phosphoru s fertilizer at the rate of 90 kg P ha^{-1} produced significantly greater grain yield (1585.0 kg ha^{-1}) followed by 45 kg P ha^{-1} (1313.0 kg ha^{-1}) and 0 kg P ha^{-1} (935.0 kg ha^{-1}) in season II. Genotype and did not affect water use (ET) in season I (average 221.3 mm) and season II (average 314.2 mm). Phosphorus application also did not affect water use (ET) in season I (average 221.3 mm) and season II (average 314.2 mm). The desi types significantly had greater water use efficiency of grain yield (WUE_g) (6.36 and 4.41 kg ha^{-1} mm^{-1}) compared with kabuli types (2.69 and 1.33 kg ha^{-1} mm^{-1}) in season I. In contrast, the kabuli types significantly had greater water use efficiency of grain yield (WUE_g) (4.90 and 4.40 kg ha^{-1} mm^{-1}) compared with desi types (3.41 and 3.12 kg ha^{-1} mm^{-1}) in season II. Application of phosphorus fertilizer rates significantly ($P<0.05$) affected water use efficiency of grain yield (WUE_g) in season I and season II. Application of phosphorus fertilizer at the rate of 90 kg P ha^{-1} produced significantly greater water use efficiency of grain yield (WUE_g) compared with 45, 0 kg P ha^{-1}. Therefore desi genotypes may be more favourable in winter season. In contrast, kabuli appears to be more suitable in summer season while 45 and 90 kg P ha^{-1} phosphorus fertilizer rates may increase chickpea yield for the site of current study in both season and season II.

1. INTRODUCTION

1.1. Background Information

Chickpea (*Cicer arietinum*) is an ancient annual grain legume crop grown mainly for human consumption. Chickpea is the second most important pulse crop in the world, grown in at least 33 countries in South Asia, West Asia, North Africa, East Africa, Southern Europe, North and South America, and Australia (Jodha and Subbarao, 1987; Maiti, 2001). This crop is believed to have originated in Southeastern Turkey and the adjoining parts of Syria. Chickpea is cultivated across a wide range of environments, from the subtropics to arid and semi-arid Mediterranean regions. Chickpea requires an annual rainfall of 60-100 mm and temperatures ranging from 21/18-29/26^{0}C (day/night) (Duke, 1981; Smithson *et al.*, 1985; Muehlbauer and Singh, 1987). Earlier, Gupta and Agrawal (1976) indicated that chickpea requires 247-290 mm of moisture during the growing period depending on the water balance in the root zone and genotypes.

Chickpea is used for various purposes, e.g. as a human food, animal feed, for medication and industrial purposes. Chickpea plays a vital role in human nutrition as a source of protein, energy, fibre, vitamins and minerals for large population sectors in the world and is considered a healthy food in many developed countries (Abbo *et al.*, 2003). Hulse (1991) reported that chickpea seeds have high protein content of about 25.3-28.9% after being dehulled. The protein quality of chickpea is better than that of crops such as pigeon pea, black gram and green gram (Singh *et al.*, 2005).

Chickpea grains can be eaten fresh, dried, fried, boiled or roasted. Sprouted seeds can be consumed as vegetables or added to salads. Chickpea seeds can also be consumed as "dhal". The cooked seeds are used in soups and salads or ground into flour.

Van Rheenen and Singh (1997) reported that some chickpea seed having high quality protein (of about 20%) can be fed to animals, such as pigs (Mexico), and cattle and horses (India). Dry leaves mixed with straw/fodder are sour in taste and fed to the animals. Mathews *et al.* (2005) reported that chickpea vegetative biomass may be used as fodder in drought-prone areas where grazing vegetation is not sufficient, especially during winter.

Chickpea seeds can also be utilized for several medicinal purposes. For example, in Chile, a cooked chickpea-milk (4:1) mixture was found to effectively control diarrhoea in infants (Mathews *et al.*, 2005). Chickpea can also be used for industrial purposes; chickpea grains with 21% of starch are suitable for textile sizing which gives a light finish to silk, wool, and cotton cloth. Besides being used as source of human and animal food or medicine, the crop can also maintain soil fertility, particularly in dry areas due to its ability to fix nitrogen from the atmosphere (Saxena *et al.*, 1990) and special mechanisms for phosphorus uptake from the soil (Ae *et al.*, 1991).

Chickpea can also be used in rotational cropping systems. Many studies reported that cereals produce more grains when grown after a legume or fallow than after a non-legume (Rego and Seeling, 1996).

Dalal *et al*. (1998) observed that wheat yields were significantly higher in the chickpea-wheat rotation than in the wheat - wheat rotation. This could be due to improved soil water holding capacity, nutrient content, nutrient balance, friability and pH. Therefore, chickpea has the potential of increasing the productivity of cereal-based cropping systems especially in the dry environments like Limpopo Province.

Some studies do show that most smallholder farmers in Limpopo province grow maize as the main crop. However, the average grain yield of maize realized are quite low (<500 kg ha^{-1}) due mainly to inadequate rainfall, poor soils and low external inputs. Indeed, Ogola and Ngobeni (2005) reported that poor soils and inadequate water are the major physical constraints limiting maize yields for smallholder farmers in Vhembe District, Limpopo province. The low productivity of these largely maize-based cropping systems lead to increased levels of poverty amongst the smallholder farmers of this region. Improving the productivity of these cropping systems may thus, partially contribute to poverty alleviation in this region. Therefore, incorporation of chickpea into these largely maize-based cropping systems may help in improving their productivity. This is because chickpea is a dual-purpose legume crop that is tolerant to drought due its ability to extract water deep down in the soil where some other crops cannot reach (Miller *et al*., 2002). Furthermore, chickpea has great potential of improving soil fertility through fixing atmospheric nitrogen (Saxena *et al*., 1990) and solubilizing unavailable soil phosphorus (Ae *et al*., 1991). Chickpea can be easily incorporated into the existing maize-based cropping systems through either intercropping or rotational cropping systems. It can be grown as a rotational crop during winter which is unsuitable for most common grain legumes.

Moreover, Aulakh *et al.* (2003) reported that low native soil phosphorus availability and poor utilization efficiency of added P is a major constraint limiting the productivity of most grain legumes. Therefore, chickpea productivity in this region may be increased partly through the use of external fertilizer inputs. However, the use of inorganic fertilizer P is limited by its high cost, while organic inputs generally do not provide sufficient P for optimum crop growth due to their low P concentration. Thus, the optimal use of phosphorus fertilizers leading to increased P use efficiency should be encouraged.

The effect of P fertilizer on the growth and yield of chickpea is well documented in a number of traditional chickpea growing areas (Khourgami and Farnia, 2009; Saini *et al.*, 2004). However, chickpea production in this region in particular, and South Africa in general is currently insignificant. Moreover, there are no agronomic recommendations (such as fertilizer rates, suitable genotypes, planting density, planting time etc) for chickpea in this region. Indeed, there is hardly any evidence in literature on the effect of P fertilizer rates on chickpea growth and production in South Africa. The hypothesis tested in this study was that genotype and phosphorus fertilizer rates affect the productivity of chickpea in a dry environment in Limpopo Province. The overall objective of this study was to evaluate the effect of phosphorus fertilizer rates on the productivity of four chickpea genotypes. The specific objectives were:

- To assess the effect of phosphorus fertilizer rates on growth and yield of chickpea in Vhembe district.
- To evaluate the growth and yield of different chickpea genotypes in Vhembe district.
- To evaluate the effect of genotype and phosphorus on water use and water use efficiency.

2. LITERATURE REVIEW

2.1. Chickpea production

Chickpea (*Cicer arietinum L*) is regarded as a food, feed and fodder crop. It is an important grain legume in the world ranking third behind dry beans (*Phaseolus vulgaris*) and field pea (*Pisum sativum*), with total global annual production of 9.77 million tonnes from about 11.08 million hectares (FAOSTAT, 2010). India is the leading producer accounting for about 60% of the global production followed by Turkey, Pakistan and Mexico (Kassie *et al*., 2009). In South Africa, chickpea production is currently insignificant but the demand is increasing.

2.2. Chickpea types

The chickpea plant is erect with primary and secondary branching, resembling a small bush. There are two leaf types, the fern leaf with multiple leaflets attached to a leaf stem, and the single or unifoliate leaf that is present on some kabuli varieties. The plant flowers profusely and has an indeterminate growth habit, continuing to flower and set pods as long as climatic conditions are favourable. The lowest seed pods are typically 0.12 to 0.18 m from the soil surface under dry land conditions (Wang *et al*., 2006). There are two types of chickpea: the small-seeded desi and large seeded kabuli chickpeas. The desi type is mainly grown in the semi-arid tropics while the kabuli type is mainly grown in temperate regions (Muehlbauer and Singh, 1987; Malhotra *et al*., 1987). The seeds of the different chickpea types differ in various aspects such as colour, size and shape.

The seed coat for desi chickpea is dark with rough seed coat whereas the seed coat for kabuli is light with smoother seed coat. In terms of seed weight, kabuli chickpea has large seeds which vary from 270 to 550 mg (Kumar and Abbo, 2001; Siddique *et al*., 2002). In contrast, the seed weight for desi varies from 170 to 320 mg, depending on cultivar (Anonymous, 2002). Desi and kabuli chickpea cultivars can be easily identified by flower colour, with desi types having purple flowers and kabuli types having white flowers, corresponding with the presence or absence of pigmentation in their respective seed coats (Miller *et al*., 2002). Plant height typically ranges from 30 to 70 cm, with kabuli types often slightly taller than desi types (Muehlbauer and Singh, 1987).

2.3. Production constraints of chickpea

The major constraints to chickpea production include both biotic (especially diseases and insect pests) and abiotic (e.g. drought, temperatures, soil type, etc.) factors.

2.3.1. Biotic factors

Chickpea is susceptible to a number of diseases and insect pests. Ascochyta blight, a disease caused by *Ascochyta rabie* (pass.) *Labrouse* is the major constraint limiting chickpea productivity worldwide. The disease occurs in the major chickpea growing areas of the world (Chongo *et al*., 2003). This disease reduces chickpea seed yield and quality significantly, and in some circumstances yield losses for susceptible cultivars are as high as 100% (Reddy and Singh, 1990). Insect pests also play a role in reducing chickpea yield.

Smithson *et al.* (1985) reported that pod borer (*Helicoverpa armigera*) is one of the most important pests that feed on the leaves and developing seeds and can cause 100% yield loss.

2.3.2. Abiotic factors

Low temperature at flowering and podding stage is one of the major abiotic factors leading to unstable yield in many current production areas. Pod setting can be inhibited if the crops are exposed to low temperatures of -1.5 to 1.5 ^{o}C, especially at flowering stage (Lawlor *et al.*, 1998; Srinivasan *et al.*, 1999). High temperatures of more than 40 ^{o}C is also a major constraint limiting productivity of chickpea as it causes flower abortion which may result into seed yield reduction (Leport *et al.*, 1999). Also, drought affects chickpea productivity, particularly at the critical stages of growth, such as flowering stage. Leport *et al.* (1999) reported that severe drought or heat stress during reproductive stage can cause significant pod abortion, particularly after pod setting starts. Poor soil fertility, especially P deficiency, also limits the production of chickpea in the tropics. Tenebe *et al.* (1995), and Okeleye and Okelana (1997) observed that phosphorus deficiency is the main limiting factor affecting most grain legumes under tropical conditions.

2.4. The effect of phosphorus on the growth and yield of chickpea

Several studies (e.g. Malik *et al.*, 2006) have reported that P is one of the most important macro nutrients for grain formation and root establishment in most legumes. Mansur *et al.* (2006) reported that P is an essential element required by most pulses for better root development. Effect of phosphorus fertilizer on chickpea yield depends on the application rate amongst other factors.

For example, Tawaha *et al.* (2005) reported that application of phosphorus produced greater grain yield at 70 kg P ha^{-1} (1311.5 kg ha^{-1}) compared with 35 kg P ha^{-1} (1069.0 kg ha^{-1}) and 0 kg P ha^{-1} (955.0 kg ha^{-1}). Similarly, Khourgami and Farnia (2009) reported that application of phosphorus at 130 kg ha^{-1} increased chickpea 100 seed weight and seed yield compared with control treatment. Phosphorus fertilizer rates have also been shown to affect the yields of other grain legumes. For example, application of phosphorus at the rate of 90 kg P ha^{-1} and 120 kg P ha^{-1} increased 100-seed weight of mung bean significantly compared with control treatment (Singh and Hiremath, 1990; Kar *et al.*, 1989; Chauhan *et al.*, 1992 and Anchal *et al.*, 1997). Reddy and Singh (1990) reported that soybean yield increased by 36, 60, and 68% after application of P fertilizer at the rate of 11, 22 and 44 kg P ha^{-1}, respectively.

The effect of P on yield has been attributed to better growth and increased assimilate partitioning to grains (Jakson and Miler, 2003). Yahiya *et al.* (1995) found that chickpea leaf area index increased with phosphorus fertilizer application. Increase in leaf area index tends to lead to yield increases. This is because the plant will trap more radiation which may be converted into assimilates and then partitioned to the different plant parts.

Moreover, phosphorus fertilization affects leaf area, above-ground biomass, root dry matter biomass, nodulation (number and mass), and yield in a number of grain legumes (Mafongoya *et al.*, 2000; Kasturikrishna and Ahlawat, 1999). Increase in nodulation and nitrogenase activity and yield with application of P have been reported in pea and summer mung bean (Kasturi, 1995; Sarkar and Banik, 1991).

Also, Valverde *et al.* (2002) found that phosphorus fertilizer increases nitrogen fixation capacity in most legumes through stimulating the host plant growth rather than by exerting specific effects on rhizobial growth or nodule formation and function. Therefore, it is clear that the effect of phosphorus fertilizer on growth and yield of chickpea will vary from region to region. Moreover, there is a dearth of information on the effects of phosphorus on productivity of chickpea in the region of the current study. Furthermore, the effects of P on growth and yield of other grain legume crops in this region have been quite varied, but largely insignificant (Odhiambo and Thovhogi, 2004; Mabapa *et al.*, 2010). Therefore, there is need to assess the response of chickpea to fertilizer phosphorus rates at a representative site of the dry environments of Limpopo Province.

2.5. Effect of genotype on the growth and yield of chickpea

Several studies show that growth and yield of chickpea and other crops vary with genotype. This variation can be attributed to factors such as adaptation to various environments, plant density, fertilizers, spatial arrangement, etc. In Mediterranean-type of environment, desi type called sona has been selected due to its high yield potential (Khan and Siddique, 2000). In Northern Iraq, chickpea genotypes were significantly different in number of days to 50% flowering, number of days to 90% maturation, number of pods per plants, plant height, seeds per pod and seed yield (Hammed and Al-Badrany, 2007). Variations in characteristics such as plant height, stem diameter, stem shoot dry weight etc have also been reported in maize genotypes grown in Egypt (Sadek *et al.*, 2006).

Sadek *et al.* (2006) also speculated that the differences between the studied genotypes on growth might be due to the photosynthetic activity of leaves (i.e. internal factor) and/or to the differences in climatic factors, e.g. light distribution on leaf surface of the crop canopy resulting from differences in chlorophyll content and enzymes activity and to the differences in the stomatal conductance. Thangwana and Ogola (2012) found that desi gave greater yield in winter than kabuli while the converse was true in summer at the site of the current study.

Also, Leport *et al.* (1999) reported lower yield and pod number per plant in kabuli types compared with the desi types under terminal drought. Other studies have reported significant genotypic differences in number of days to 50% flowering, number of days to 90% maturation, number of pods per plants, plant height, seeds per pod and seed yield in chickpea (Hammed and Al-Badrany, 2007). Moreover, Shamsi *et al.* (2010) reported that Arman and Hashem genotypes gave significantly higher number of pods per plant than that of genotype ILC-482.

Effect of genotype on the growth and development of chickpea depend on their adaptation to various environment conditions, resistance to different diseases, resistance to salinity, yield potential and ultimately yield. Genotypes adaptation to an environment can only be determined by their growth and yield compared to other genotypes under study. The adaptability of a genotype over a diverse environment is usually tested by the degree of interaction with different environments under which it is grown. Therefore, it is necessary to assess the response of chickpea genotypes in the current study region.

2.6. Effect of genotype and phosphorus on water use and water use efficiency

The effect of genotype on the water use of chickpea and other crops varies with several factors such as environment, soil moisture content, management practices and growth stage. The differences in ET due to genotype could also be attributed to differences in canopy development and size. Ogola *et al.* (2009) reported that differences in WUE among the genotypes could be attributed to differences in crop biomass and grain yield. Earlier studies show that kabuli genotype uses more water and have high stomatal conductance than desi genotypes mainly due to its high aboveground biomass (Raschke, 1975).

Cooper *et al.* (1988) defined water use efficiency as the ratio of grain yield to water consumed expressed as either evapotranspiration or total water input to the system in a defined season or the cumulative carbon gain versus cumulative transpiration of a crop canopy (Steduto and Albrizio, 2005).

Water use efficiency tends to remain linear under both well- watered and water deficit conditions (Hsiao, 1993), or relatively insensitive to variation in soil nutrients status (Stanhill, 1986) or may vary with climatic conditions (Tanner and Sinclair, 1983). Increase canopy cover affects water use and it's partitioning between transpiration and soil evaporation and subsequent water use efficiency (Gregory *et al.*, 2000). Lewis and Thurling (1994) found that water use efficiency (WUE) was greater when evaporation comprised small proportion of evapotranspiration in three oil seed brassica species.

Similarly Ogola *et al.* (2005; 2002) found that WUE was high where evaporation was reduced and transpiration increased as a result of larger crop leaf canopy in maize crop. Gregory *et al.* (1997) reported that increasing the total amount of water available to a crop e.g. through irrigation, may not only increase crop yield but also increase water use efficiency if transpiration is increased proportionately more than direct evaporation from the soil (Es), deep drainage (D) and runoff (R). Cooper *et al.* (1988) reported that evaporation account for a larger percentage of seasonal rainfall received in dry environments. Therefore, water use efficiency in these environments can be enhanced by manipulating the balance between transpiration and direct evaporation from soil.

Increasing planting density leads to greater partitioning of water use into transpirational loss rather than soil evaporation which may as a result increase water use efficiency. Similar results were reported by Gan *et al.* (2009) where water use efficiency of desi and kabuli chickpea genotypes increased from low (20 plants m^{-2}) to medium (30-40 plants^{-2}) planting density. Furthermore, report by Gan *et al.* (2009) found high water use efficiency at high planting density (50 plants m^{-2}) when grown on stabble (except for desi chickpea). In contrast, Ogola *et al.* (2005) reported that increased planting density reduced water use efficiency of maize grain yield due to decreased harvest index. The use of nitrogen can also increase canopy cover which may as result a reduce the loss of water through evaporation. In current study, different P fertilizer rates and genotypes were used to evaluate their influence on water use efficiency.

Variation among genotypes has also been shown to affect the WU and WUE of chickpea and other crops; these variation are in turn affected by factors such as environment and management practices. For example, kabuli genotypes had lower WUE (6.6 kg ha^{-1} mm^{-1}) than desi genotypes (7.3 kg ha^{-1} mm^{-1}) when grown on fallow and stubble soils (Gan *et al.*, 2009). Biederbeck and Bouman (1994) found that chickpea, pea and chickling vetch had greater WUE than black lentil and tangler flat pea. Rowland (2004) reported that environment as a factor influenced the groundnut genotype's response to water use. Environment and management practices also play a significant role in the genetic expression of genotype's trait. For example, Gan *et al.* (2009) reported that early maturing cultivars of dry pea escaped later season drought, hence increasing WUE in the semi-arid Canadian prairie. Therefore, it is necessary to document the effect of genotype on WU and WUE of chickpea in the region of current study.

Phosphorus fertilizer influences the water use of chickpea and other crops. Phosphorus fertility level exerts an effect on stomata response to water stress. For example, Radin (1984) found that P influences the water use by causing stomata of cotton to begin closing at higher leaf water potentials compared with plants grown on soils with more typical P levels without any P application. Increase in leaf area index leads to increase in water use or loss. However, Gholipoor (2007) reported that application of P at the rate of 120 kg P ha^{-1} did not affect evapotranspiration of chickpea grown under rainfed conditions. It is clear that the effect of P fertilizer rates on water use will vary from region to region. Therefore, there is a need to assess the effect of P fertilizer rates on chickpea water use in this region.

3. MATERIALS AND METHODS

3.1. Experimental site

Field studies were carried out at the University of Venda's experimental farm situated in Thohoyandou (longitude and latitude of $30^0$26.411'E and $22^0$58.081'S, respectively, and altitude 595 metres), Limpopo Province, Republic of South Africa. The annual rainfall is about 500 mm and falls predominantly in the summer. The average maximum and minimum temperatures are 31°C and 18°C, respectively (Tadross, *et al.*, 2005). The site is characterized by deep, well-drained clay soil (Soil Classification Workgroup, 1991). Some of the pre-sowing soil physical and chemical properties at this experimental site are presented in Table 3.1.The pH of the soil is slightly acidic. The soil has a low CEC value, and the organic content and available P levels are low. Exchangeable cation levels of the soil are also low (Table 3.1).

Table 3.1: Some physical and chemical properties of the soil (0-20 cm depth) at the experimental site

Parameter measured	Value
pH (H_20)	6.12
Particle size (%)	
Clay	70.0
Silt	20.3
Sand	9.7
CEC (cmol kg^{-1})	17.60
Carbon (%)	1.71
Phosphorus (mg kg^{-1})	2.03
Exchangeable cations (cmol kg^{-1})	
Na	0.02
K	0.18
Ca	3.94
Mg	2.15

3.2. Experimental design

The experiments consisted of a factorial combination of P fertilizer rates (0, 45 and 90 kg P ha^{-1}) and four chickpea genotypes (kabuli types-ICCV4306, ICCV7307 and desi types-ICCV92944 and ICCV3110). The treatments were laid out in a randomized complete block design and replicated three times. Each experimental unit measured 1m x 1.2 m. Trials were undertaken in two seasons (winter and summer). The winter and summer trials were planted on 24 May 2009 and 05 December 2009, respectively. Field layouts for the different experiments are given in Figure 3.1.

Genotypes included:

1. ICCV7307 = V1
2. ICCV92944 = V2
3. ICCV4306 = V3
4. ICCV3110 = V4

Phosphorus fertilizer rates were:

1. 0 kg P ha^{-1}= P1
2. 45 kg P ha^{-1}=P2
3. 90 kg P ha^{-1}=P3

Figure 3.1: Field layout of 4 chickpea genotypes planted with three phosphorus fertilizer rates in both season I (winter 2009) and season II (summer 2009/2010) trial.

BLOCK I

V4P1	V1P2	V4P3	V2P2	V1P3	V2P1	V4P2	V1P1	V3P2	V2P3	V3P1	V3P3

BLOCK II

V4P3	V2P1	V3P2	V1P3	V3P1	V1P2	V1P1	V2P3	V4P2	V3P3	V4P1	V2P2

BLOCK III

V2P2	V3P3	V1P1	V4P2	V3P2	V4P1	V2P3	V3P1	V1P3	V4P3	V1P2	V2P1

3.3. Cultural practices

Land preparation was done using a tractor by ploughing and disking the land prior to plot demarcation and planting. In all trials, catch cans were installed in every plot to measure amount of irrigation-water applied. Irrigation was done in both trials immediately after planting to promote uniform germination and crop establishment. Supplemental irrigation was also applied at different occasions in both experiments whenever necessary; total irrigation water applied was 28.7 mm and 10.1 mm in Experiment I (winter) and II (summer), respectively.

Two seeds were sown per hole, with intra-row spacing of 10 cm and inter-row spacing of 40 cm. Phosphorus was band applied at planting as Super grow (20.3% P) at the rate of 0, 45, and 90 kg P ha^{-1} as per the treatments. Nitrogen was band applied as Limestone ammonium nitrate (28% N) at the rate of 40 kg N ha^{-1} at planting to all the plots. In both experiments, plots were kept weed-free throughout the growing season. A net was used to cover the whole trial at 50% flowering in order to prevent bird damage. The net was removed immediately after physiological maturity.

3.4. Measurements

3.4.1. Weather

Daily weather data (mean temperature; total rainfall; total evaporation; solar radiation, mean Vapour Pressure Deficits) was obtained from an automatic weather station that is located approximately 140 m away from the experimental site (Table 3.2).

Table 3.2: Summary of weather data at Thohoyandou (Univen), during the winter (2009) and summer (2009/2010) cropping season.

Year/ Month	Mean Temp (^{0} C)	Total Rainfall (mm)	Total E_{pan} (mm)	Solar Radiation (MJ m^{-2} d^{-1})	Mean VPD (kpa)
EXP I (2009)					
May	23.0	6.1	90.4	15.0	1.0
June	18.0	17.8	80.1	13.7	1.1
July	15.5	19.1	85.4	14.0	0.8
August	18.2	2.8	104.0	16.9	1.2
September	21.0	14.0	102.9	15.3	1.4
October	24.0	24.6	126.5	18.1	1.5
Mean/Total	**20.0**	**84.4**	**589.3**	**15.5**	**1.2**
EXP II (2009/2010)					
December	26.0	207.5	129.0	21.3	1.1
January	24.5	119.9	131.7	19.9	1.0
February	24.5	179.1	108.2	17.9	1.0
March	26.0	59.2	81.1*	18.8	1.0
Mean/Total	**25.3**	**565.7**	**450.1**	**19.5**	**1.0**

3.4.2. Biomass accumulation

Biomass was determined at vegetative, 50% flowering stage and harvest maturity. Plants were sampled from the two inner rows from an area measuring 0.2 m^2 at vegetative (27 and 31 DAE, for kabuli and desi types, respectively, for winter trial; 21 and 23 DAE, for kabuli and desi types, respectively, for summer trial) and at 50% flowering stages (41 and 59 DAE, for kabuli and desi types, respectively, for winter trial; 31 and 32 DAE, for kabuli and desi types, respectively, for summer trial). Biomass at harvest maturity (126 and 132 DAE, for kabuli and desi types, respectively, for winter trial; and 95 and 98 DAE, for kabuli and desi types, respectively, for summer trial) was determined from an area of 0.4 m^2 of the two inner-most rows in all trials. The pods were removed from the plants. The samples were then oven-dried at 65-70^{0}C for 48 hours in order to determine biomass yield.

3.4.3. Soil moisture content

Immediately after crop emergence, access tubes were installed to a depth of 110 cm in between the rows for all experimental plots. Neutron probe was used to measure soil moisture content every week by lowering the probe in each access tube and taking 16-second count readings at 30, 60 and 90 cm depths. The count readings were converted to soil moisture content using the moisture calibration equation developed by Thangwana (Personal Communication, 2011). Standard count was taken before taking any soil moisture readings. Count ratios (x) were calculated as actual readings/standard count. The volumetric water content (Qv) was calculated at different depth using the calibration equations 1-3 (Thangwana Personal Communication, 2011).

0.30 m: $Qv = 0.0818x + 0.0268$ 1

0.60 m: $Qv = 0.3227x - 0.2733$ 2

0.90: $Qv = 0.3736x - 0.3297$ 3

3.4.4. Crop water use and water use efficiency

The standard water balance equation (equation 4) was used to estimate the total crop water use.

$$ET = -\Delta S + P - D - R \quad (4)$$

Where ΔS stands for change in storage which is the difference in volumetric water content of the entire profile between the first and last neutron probe readings, P is rainfall, D the drainage and R the runoff. Drainage and runoff were assumed to be negligible. Water use efficiency (WUE) was determined for total biomass and grain yield, respectively, as shown in equations 5 and 6.

$$WUE_b = \frac{Biomass}{ET} \quad (5)$$

$$WUE_g = \frac{Grain\ yield}{ET} \quad (6)$$

3.4.5. Chickpea grain yield

Chickpea grain yield was determined from the same plants used for biomass at harvest maturity. All the harvested plants were separated into shoots and pods. Shoots were oven-dried at 65-70^{0}C for 48 hours then weighed to determine biomass yield. Pods per plant as well as seeds per pod were counted. Pods were weighed and threshed manually. The seeds were dried by sunlight until realizing a constant weight, to determine grain yield. Harvest index was determined by calculating the ratio of grain yield to aboveground biomass.

3.5. Data analysis

Genstat (version 7) statistical package (Genstat, 2003) was used to analyse the data. Effect of genotype and phosphorus (P) fertilizer rates on the water use, growth and yield of chickpea was assessed using Analysis of variance (ANOVA) at $P \leq 0.05$ level of testing. Mean separation was done using the standard error of differences of the means (SED).

4. RESULTS

4.1. Effect of genotype and phosphorus fertilizer rates on above ground biomass at vegetative stage

The effect of genotype on above ground biomass at vegetative stage was significant in season I ($P<0.05$) and season II ($P<0.01$) (Table 4.1). Above ground biomass ranged from 383 kg ha^{-1} (ICCV4306) to 682 kg ha^{-1} (ICCV3110) in season I. The desi types significantly had greater above ground biomass (682 and 644 kg ha^{-1}) compared with kabuli types (427 and 383 kg ha^{-1}) at vegetative stage (Table 4.1). Above ground biomass ranged from 756 kg ha^{-1} (ICCV4306) to 2066 kg ha^{-1} (ICCV92944) in season II. The desi types significantly had greater above ground biomass (2066 and 1753 kg ha^{-1}) compared with kabuli types (1046 and 756 kg ha^{-1}) at vegetative stage (Table 4.1). Above ground biomass produced by kabuli types were significantly different from each other.

The effect of phosphorus fertilizer rates on above ground biomass at vegetative stage was significant in season I ($P<0.05$) and season II ($P<0.01$) (Table 4.1). Application of phosphorus fertilizer at the rate of 90 kg P ha^{-1} produced the highest above ground biomass (731 kg ha^{-1}) followed by 45 kg P ha^{-1} (532 kg ha^{-1}) and 0 kg P ha^{-1} (338 kg ha^{-1}) in season I. Similarly, application of phosphorus fertilizer at the rate of 90 kg P ha^{-1} produced the highest above ground biomass (1659 kg ha^{-1}) followed by 45 kg P ha^{-1} (1420 kg ha^{-1}) and 0 kg P ha^{-1} (1136 kg ha^{-1}) in season II (Table 4.1). The interaction between genotype and phosphorus fertilizer rates did not affect above ground biomass in season I and season II (Table 4.1).

Table 4.1: Effect of genotype and phosphorus fertilizer rates on above ground biomass (kg ha^{-1}) at vegetative stage in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	Above ground biomass (kg ha^{-1})	
	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	644a	2066a
ICCV3110	682a	1753b
Kabuli types		
ICCV7307	427b	1046c
ICCV4306	383b	756d
SED	79.0	136.1
P rate (kg ha^{-1})		
0	338c	1136c
45	532b	1420b
90	731a	1659a
SED	68.4	117.9
F-test probabilities		
Genotype	p<0.05	p<0.01
P rate	p<0.05	p<0.01
Genotype X P rates	ns	ns
CV%	4.3	7.9

Means followed by different letters within each column are significantly different

4.2. Effect of genotype and phosphorus fertilizer rates on above ground biomass at 50% flowering

Genotype significantly ($P<0.01$) affected above ground biomass at 50% flowering in season I and season II (Table 4.2). Above ground biomass at 50% flowering ranged from 1311 kg ha^{-1} (ICCV7303) to 2206 kg ha^{-1} (ICCV3110) in season I. The desi types significantly had greater biomass (2188 and 2206 kg ha^{-1}) compared with kabuli types (1726 and 1311 kg ha^{-1}) in season I (Table 4.2). Above ground biomass ranged from 1764 kg ha^{-1} (ICCV7307) to 2672 kg ha^{-1} (ICCV92944) in season II. The desi types significantly had greater biomass (2672 and 2163 kg ha^{-1}) compared with kabuli types (1772 and 1764 kg ha^{-1}) (Table 4.2). On average, above ground biomass was lower in season I (mean of 1858 kg ha^{-1}) compared with season II (mean of 2093 kg ha^{-1}).

The effect of phosphorus fertilizer rates on above ground biomass at 50% flowering was significant in season I ($P<0.01$) and season II ($P<0.05$) (Table 4.2). Application of 90 kg P ha^{-1} produced greater above ground biomass (2320 kg ha^{-1}) than 45 kg P ha^{-1} (1914 kg ha^{-1}) and 0 kg P ha^{-1} (1339 kg ha^{-1}) in season I. In season II, application 90 kg P ha^{-1} produced greater above ground biomass (2294 kg ha^{-1}) than 0 kg P ha^{-1} (1754 kg ha^{-1}). However, above ground biomass at 90 kg P ha^{-1} and 45 kg P ha^{-1} were not significantly different. The interaction between genotype and phosphorus fertilizer rates did not affect above ground biomass in both seasons I and II (Table 4.2).

Table 4.2: Effect of genotype and phosphorus fertilizer rates on above ground biomass (kg ha^{-1}) at 50% flowering stage in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	Above ground biomass (kg ha^{-1})	
	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	2188a	2672a
ICCV3110	2206a	2163b
Kabuli types		
ICCV7307	1311c	1764c
ICCV4306	1726b	1772c
SED	176.9	159.4
P rate (kg ha^{-1})		
0	1339c	1754b
45	1914b	2230a
90	2320a	2294a
SED	153.2	138.0
F-test probabilities		
Genotype	p<0.01	p<0.01
P rate	p<0.01	p<0.05
Genotype X P rates	ns	ns
CV%	13.7	5.7

Means followed by different letters within each column are significantly different

4.3. Effect of genotype and phosphorus fertilizer rates on above ground biomass at harvest maturity

Genotype and phosphorus fertilizer rates did not affect above ground biomass at harvest maturity in season I (Table 4.3). In contrast, genotype did not affect above ground biomass at harvest maturity but the effect of phosphorus fertilizer application rate was significant ($P<0.01$) in season II (Table 4.3). Application of 90 kg P ha^{-1} produced greater above ground biomass (7114 kg ha^{-1}) compared with 45 kg P ha^{-1} (6364 kg ha^{-1}) and 0 kg P ha^{-1}(4637 kg ha^{-1}). The interaction between genotype and phosphorus fertilizer rates did not affect above ground biomass in both seasons (Table 4.3). Average above ground biomass was lower in season I (5300 kg ha^{-1}) compared with season II (6038 kg ha^{-1}).

Table 4.3: Effect of genotype and phosphorus fertilizer rates on above ground biomass (kg ha^{-1}) at harvest maturity in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	Above ground biomass (kg ha^{-1})	
	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	5678	5681
ICCV3110	5409	6823
Kabuli types		
ICCV7307	5363	5618
ICCV4306	4750	6031
SED	633.3	479.8
P rate (kg ha^{-1})		
0	5184	4637c
45	5466	6364b
90	5250	7114a
SED	548.4	415.5
F-test probabilities		
Genotype	ns	ns
P rate	ns	p<0.01
Genotype X P rates	ns	ns
CV%	6.4	7.2

Means followed by different letters within each column are significantly different

4.4. Effect of genotype and phosphorus fertilizer rates on yield components

Genotype significantly ($P<0.05$) affected number of pods per plant in season I but not in season II; number of pods per plant ranged from 4.3 (ICCV4306) to 12.3 (ICCV92944) in season I (Table 4.4). The desi types had significantly greater number of pods per plant (12.3 and 12.2) compared with kabuli types (4.5 and 4.3) (Table 4.4). The interaction between genotype and phosphorus fertilizer rates did not affect number of pods per plant in both seasons (Table 4.4). The average number of pods per plant in season II was 11.87 g.

Genotype significantly ($P<0.05$) affected number of seeds per pod in season I, but not in season II (Table 4.4). The average number of seeds per pod in season II was 1.3 g. Number of seeds per pod ranged from 1.1 (ICCV3110; ICCV7307) to 1.2 (ICCV92944; ICCV4306) in season I (Table 4.4). Desi type (ICCV92944) and kabuli type (ICCV4306) produced number of seeds per pod that were significantly greater than the rest of the genotypes. On average, number of seeds per pod for desi genotypes (1.23) was greater compared with kabuli genotypes (1.17). The interaction between genotype and phosphorus fertilizer rates affected the number of seeds per pod in season I but not in season II (Table 4.4).

Genotype significantly ($P<0.01$) affected 100 seed weight in season I but the effect of phosphorus fertilizer rates was not significant in season I (Table 4.5). 100 seed weight ranged from 154.0 g (ICCV3110) to 340.0 g (ICCV4306). The kabuli types had significantly greater 100 seed weight (340.0 and 303.0 g) compared with desi types (230.0 and 154.0 g) in season I (Table 4.5).

Genotype and phosphorus fertilizer rates significantly ($P<0.01$) affected 100 seed weight in season II. The kabuli types had significantly greater 100 seed weight (317.4 and 314.3 g) compared with desi types (226.7 and 204.6 g) in season II (Table 4.5).

Application of 90 kg P ha^{-1} produced highest 100 seed weight (302.2 g) followed by 45 kg P ha^{-1} (274.0 g) and 0 kg P ha^{-1} (221.0 g) in season II. The interaction between genotype and phosphorus fertilizer rates did not affect 100 seed weight in season I and season II (Table 4.5). Average 100 seed weight was lower in season I (256.8g) compared with season II (265.8g).

Table 4.4: Effect of genotype and phosphorus fertilizer rates on yield components in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	Number of pods per plant		Number of seeds per pod	
	Season I (Winter 2009)	Season II (Summer 2009/2010)	Season I (Winter 2009)	Season II (Summer 2009/2010)
Genotype				
Desi types				
ICCV92944	12.3a	11.5	1.2a	1.3
ICCV3110	12.2a	13.8	1.1b	1.2
Kabuli types				
ICCV7307	4.5b	10.0	1.1b	1.3
ICCV4306	4.3b	12.3	1.2a	1.2
SED	2.50	2.06	0.05	0.14
P rate (kg ha^{-1})				
0	8.7	11.2	1.2	1.2
45	8.0	12.2	1.4	1.3
90	8.3	12.2	1.1	1.2
SED	2.17	1.79	0.04	0.12
F-test probabilities				
Genotype	$p<0.05$	ns	$p<0.05$	ns
P rate	ns	ns	ns	ns
Genotype X P rates	ns	ns	$p<0.05$	ns
CV%	7.0	23.2	3.8	4.2

Means followed by different letters within each column are significantly different

Table 4.5: Effect of genotype and phosphorus fertilizer rates on 100 seed weight (g) in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	100 seed weight (g)	
	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	230.0c	226.7d
ICCV3110	154.0d	204.6c
Kabuli types		
ICCV7307	303.0b	314.3a
ICCV4306	340.0a	317.4a
SED	37.70	18.37
P rate (kg ha^{-1})		
0	289.0	221.0c
45	243.0	274.0b
90	240.0	302.2a
SED	32.70	15.91
F-test probabilities		
Genotype	p<0.01	p<0.01
P rate	ns	p<0.01
Genotype X P rates	ns	ns
CV%	7.9	9.9

Means followed by different letters within each column are significantly different

4.6. Effect of genotype and phosphorus fertilizer rates on grain yield

Genotype significantly ($P<0.05$) affected grain yield in season I but the effect of phosphorus fertilizer rates was not significant (Table 4.6). Grain yield ranged from 274 kg ha^{-1} (ICCV4306) to 1464 kg ha^{-1} (ICCV92944). The desi types had significantly greater grain yield (1464 and 979 kg ha^{-1}) compared with kabuli types (680 and 274 kg ha^{-1}) in season I (Table 4.6). In season II, genotype and phosphorus fertilizer rates significantly ($P<0.01$) affected grain yield (Table 4.6). Grain yield ranged from 983 kg ha^{-1} (ICCV92944) to 1538 kg ha^{-1} (ICCV4306). The kabuli types had significantly greater grain yield (1538 and 1396 kg ha^{-1}) compared with desi types (1196 and 983 kg ha^{-1}) in season II (Table 4.6).

Application of phosphorus fertilizer at the rate of 90 kg P ha^{-1} produced highest grain yield (1585 kg ha^{-1}) followed by 45 kg P ha^{-1} (1313 kg ha^{-1}) and 0 kg P ha^{-1} (935 kg ha^{-1}) in season II. The interaction between genotype and phosphorus fertilizer rates did not affect grain yield in both seasons (Table 4.6). Average grain yield was lower in season I (849 kg ha^{-1}) compared with season II (1278 kg ha^{-1}).

Table 4.6: Effect of genotype and phosphorus fertilizer rates on grain yield (kg ha^{-1}) in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	Grain yield (kg ha^{-1})	
	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	1464a	983d
ICCV3110	979b	1196c
Kabuli types		
ICCV7307	680c	1396b
ICCV4306	274d	1538a
SED	272.5	121.1
P rate (kg ha^{-1})		
0	939	935c
45	821	1313b
90	786	1585a
SED	236.0	104.8
F-test probabilities		
Genotype	p<0.05	p<0.01
P rate	ns	p<0.01
Genotype X P rates	ns	ns
CV%	14.3	18.9

Means followed by different letters within each column are significantly different

4.7. Effect of genotype and phosphorus fertilizer rates on the harvest index

Genotype significantly ($P<0.05$) affected harvest index in season I and season II (Table 4.7). Harvest index ranged from 0.06 (ICCV4306) to 0.26 (ICCV92944) in season I. Desi type (ICCV92944) gave the highest harvest index (0.26) compared with the rest of the genotypes (Table 4.7). Harvest index ranged from 0.17 (ICCV92944) to 0.27 (ICCV7307) in season II. The kabuli types had greater harvest index (0.27 and 0.25) compared with desi types (0.18 and 0.17) in season II (Table 4.7). Phosphorus fertilizer rates did not affect harvest index in both seasons I and II (Table 4.7).

Table 4.7: Effect of genotype and phosphorus fertilizer rates on harvest index in season I (Winter 2009) and season II (Summer 2009/2010).

	Harvest index	
Treatment	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	0.26a	0.17b
ICCV3110	0.17b	0.18b
Kabuli types		
ICCV7307	0.14b	0.27a
ICCV4306	0.06c	0.25a
SED	0.049	0.034
P rate (kg ha^{-1})		
0	0.19	0.21
45	0.14	0.21
90	0.15	0.23
SED	0.042	0.029
F-test probabilities		
Genotype	p<0.05	p<0.05
P rate	ns	ns
Genotype X P rates	ns	ns
CV%	9.9	27.7

Means followed by different letters within each column are significantly different

4.8. Effect of genotype and phosphorus fertilizer rates on water use and water use efficiency of biomass and grain production of chickpea in season I (Winter 2009) and season II (Summer 2009/2010).

Genotype and phosphorus fertilizer rates did not affect water use of chickpea in season I and season II (Table 4.8). On average, water use was 221.1 and 314.4 mm for winter and summer seasons, respectively.

Genotype did not affect water use efficiency of biomass production (WUE_b) in season I and season II (Table 4.9). The average WUE_b was 24.4 and 19.2 kg ha^{-1} mm^{-1} for season I, and season II respectively. The effect of phosphorus fertilizer rates on water use efficiency of biomass production (WUE_b) was not significant in season I. In contrast, the effect of phosphorus fertilizer rates on WUE_b was significant ($P<0.01$) in season II (Table 4.9). Water use efficiency increased with application of phosphorus fertilizer rate from 14.9 kg ha^{-1} mm^{-1} (0 kg P ha^{-1}) to 22.5 kg ha^{-1} mm^{-1} (90 kg P ha^{-1}).

The effect of genotype on water use efficiency of grain yield (WUE_g) was significant in season I ($P<0.05$) and season II ($P<0.05$) (Table 4.9). WUE_g ranged from 1.3 kg ha^{-1} mm^{-1} (ICCV4306) to 6.4 kg ha^{-1} mm^{-1} (ICCV92944) and 3.1 to 4.9 kg ha^{-1} mm^{-1} in season I and season II, respectively (Table 4.9). WUE_g was significantly greater for desi types (6.4 and 4.4 kg ha^{-1} mm^{-1}) compared with kabuli types (2.7 and 1.3 kg ha^{-1} mm^{-1}) in season I (Table 4.9). In season II, in contrast, WUE_g was greater in kabuli (4.9 and 4.4 kg ha^{-1} mm^{-1}) compared with desi (3.4 and 3.1 kg ha^{-1} mm^{-1}) types (Table 4.9).

The effect of phosphorus fertilizer rates on water use efficiency of chickpea grain yield (WUE_g) was significant ($P<0.05$) in season II but not in season I (Table 4.9). WUE_g was greater at 90 kg P ha^{-1} (4.7 kg ha^{-1} mm^{-1}) compared with 45 kg P ha^{-1} (4.2 kg ha^{-1} mm^{-1}) and 0 kg P ha^{-1} (3.0 kg ha^{-1} mm^{-1}) in season II (Table 4.9). On average, WUE_b was lower in season II (19.23 kg ha^{-1} mm^{-1}) than in season I (24.45 kg ha^{-1} mm^{-1}). Also, WUE_g was lower in season I (3.8 kg ha^{-1} mm^{-1}) than in season II (4.0 kg ha^{-1} mm^{-1}).

Table 4.8: Effect of genotype and phosphorus fertilizer rates on water use (ET) in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	Water use (mm)	
	Season I (Winter 2009)	Season II (2009/2010)
Genotype		
Desi types		
ICCV92944	227.9	314.4
ICCV3110	219.4	312.4
Kabuli types		
ICCV7307	228.3	316.5
ICCV4306	209.6	313.5
SED	18.25	1.7
P rate (kg ha^{-1})		
0	221.3	312.5
45	213.5	313.8
90	229.2	316.3
SED	15.80	1.5
F-test probabilities		
Genotype	ns	ns
P rate	ns	ns
Genotype X P rates	ns	ns
CV%	4.2	0.4

Means followed by different letters within each column are significantly different

Table 4.9: Effect of genotype and phosphorus fertilizer rates on water use efficiency of biomass and grain yield of chickpea in season I (Winter 2009) and season II (Summer 2009/2010).

Treatment	WUE_b (kg ha^{-1} mm^{-1})		WUE_g (kg ha^{-1} mm^{-1})	
	Season I (Winter 2009)	Season II (Summer 2009/2010)	Season I (Winter 2009)	Season II (Summer 2009/2010)
Genotype				
Desi types				
ICCV92944	25.4	18.1	6.4a	3.1b
ICCV3110	24.7	21.8	4.4b	3.4b
Kabuli types				
ICCV7307	24.9	17.8	2.7c	4.4a
ICCV4306	22.8	19.2	1.3d	4.9a
SED	3.34	1.60	1.11	0.55
P rate (kg ha^{-1})				
0	23.6	14.9c	3.8	3.0c
45	25.7	20.3b	3.7	4.2b
90	24.1	22.5a	3.6	4.7a
SED	2.90	1.39	0.96	0.47
F-test probabilities				
Genotype	ns	ns	p<0.05	p<0.05
P rate	ns	p<0.01	ns	p<0.05
Genotype X P rates	ns	ns	ns	ns
CV%	7.5	17.7	8.5	29.3

Means followed by different letters within each column are significantly different

5. DISCUSSION

5.1. Above ground biomass

The effect of genotype on above ground biomass at vegetative and flowering stage was significant in season I ($P<0.05$) and season II ($P<0.01$) but not significant at harvest maturity stage. Desi types had greater above ground biomass compared with kabuli types at both vegetative and flowering stage. This could be due to variation in terms of genotype emergence e.g. desi types emerged two days earlier than kabuli types in both season I and season II. The ability of emerging early in desi chickpea might be due to their small seed size and the ability to grow fast after storage. These results are consistent with the findings of Hopper *et al.* (1979) who reported emergence rate differences in soybean cultivars grown in both soil-peat mixture and sand media.

Above ground biomass was lower in season I (mean of 1858.0 kg ha^{-1}) compared with season II (mean of 2093.0 kg ha^{-1}) at 50% flowering stage probably due to shortage of water during winter season. Lower above ground biomass in season I compared to season II could be due to lower amount of rainfall received at vegetative stage in season I (6.1 mm) compared with in season II (207.5 mm).

Phosphorus fertilizer application rate affected above ground biomass at vegetative and flowering stages in both season I and II. In contrast, the effect of phosphorus fertilizer application rate on biomass at harvest maturity was significant in season II but not significant in season I.

The increase in above ground biomass with increase in application of phosphorus fertilizer could be probably due to the effect of phosphorus on accumulation of high biomass (Singh and Ahuja, 1985). These results are in conformity with the findings of Das *et al.* (2008) who reported lowest above ground biomass produced by the plants cultivated without applied phosphorus. The results from this study were higher compared with 2880 kg ha^{-1} (40 kg P ha^{-1}), 2867 kg ha^{-1} (20 kg P ha^{-1}) and 2733 kg ha^{-1} (0 kg P ha^{-1}) reported at harvesting stage in Canada (Walley *et al.*, 2005). This could be attributed to low phosphorus levels of the test site (Table 3.1).

5.2. Yield and yield components

The number of pods per plant varied with genotypes as expected. The desi types had greater number of pods per plant than the kabuli types in both season I and season II, although in season II the differences were not statistically significant. Similar results have been reported elsewhere. For example, Leport *et al.* (1999), Siddique *et al.* (1999), Liu *et al.* (2003) and Upadhyaya *et al.* (2007) reported that desi types had greater number of pods per plant than kabuli types. However, the number of pods per plant found from this study for desi types was lower (12.34 and 12.17) compared to 61.9 and 45.6 reported by Leport *et al.* (2006) probably due to differences in genotypes used in current study.

Number of seeds per pod varied with genotypes as expected. The number of seeds per pod in this study ranged from 1.1 (ICCV3110) to 1.2 (ICCV92944). These results are consistent with the findings of Khan *et al.* (2004) who reported significant variation on the number of seeds per pod (varying from 1.1 to 1.9) between chickpea genotypes. Similar results were reported by Hammed and Al-Badrany (2007) who found the number of seeds per pod ranging from 1.1 to 1.3.

Wang *et al.* (2006) reported greater number of seeds per pod for desi genotype (1.3) compared to kabuli genotype 0.7.

Phosphorus fertilizer application rate did not affect number of pods per plant and number of seeds per pod in both seasons, probably due to poor P recovery. However, number of seeds per pod found from this study is comparable to the number of seeds per pod reported elsewhere (Wang *et al.*, 2006).

There was difference between season I and II in terms of number of pods per plant, probably due to higher temperature during the reproductive stage of growth in season II compared with season I. The higher temperature could have led to greater flower abortion in season II. Leport *et al.* (2006) also reported the increase in flower abortion and pod shedding at high temperatures.

Genotype affected 100 seed weight in season I and season II. Desi types had lower 100 seed weight in both season I and season II. 100 seed weight in season I and season II from this current study were higher than those reported by Upadhyaya *et al.* (2006), Gul *et al.* (2011).

Application of phosphorus fertilizer rates affected 100 seed weight only in season II. This could be attributed to response of grain yield to phosphorus rate in summer compared to winter season. Similarly, Singh and Hiremath (1990); Kar *et al.* (1989); Chauhan *et al.* (1992) and Anchal *et al.* (1997) reported greater 100-seed weight of mung bean when using 90 kg P ha^{-1} as compared to control treatment.

5.3. Chickpea grain yield

The effect of genotype on grain yield was significant in season I ($P<0.05$) and season II ($P<0.01$). Desi genotypes produced significantly greater yields compared with kabuli in season I, probably due to high above ground biomass at vegetative and flowering stage of growth and number of pods per plant. In contrast, kabuli produced greater yields than desi in season II. This could be due to better resistance of kabuli to high temperature at podding stage compared with desi genotypes (Leport *et al.*, 1999).

These results are in line with those found by Thangwana and Ogola (2012) who reported greater yield of desi and kabuli cultivars in the winter and summer sowings, respectively, at this site despite using different cultivars. Therefore, summer season appears to be more favourable for the kabuli types compared with desi types. Similarly, Kobraee *et al.* (2010) reported that Arman cultivar gave significant greater grain yield (1067.1 kg ha^{-1}) than ILC-482 (802.4 kg ha^{-1}).

The effect of genotype on grain yield was significant in season II ($P<0.01$). The kabuli types significantly had greater grain yield compared with desi types to season II. This was mainly attributed to significantly higher 100 seed weight and harvest index in season II. The greater yields of kabuli genotypes have also been reported elsewhere. For example, Kushwaha (1991) reported that ICCV-2 kabuli genotype had greater yield than desi.

Many previous studies have reported significant effect of genotype on grain yields for example, Hammed and Al-Badrany (2007) reported that rafidain genotype produced greater seed yield (1902.56 kg ha^{-1}) while the f97-25 gave the lowest seed yield (1287.75 kg ha^{-1}) in Iraq. The results of the current study were in accordance with those reported by Malhotra *et al.* (1997) and Khourgami and Rafiee (2009).

Grain yield increased with P fertilizer rates in season II. This could be attributed to increase in crop biomass at vegetative, and 50% flowering and 100 seeds weight with fertilizer application rate. Similarly, Tawaha *et al.* (2005) reported greater grain yield at 70 kg P ha^{-1} (1311.5 kg ha^{-1}) compared with 35 kg P ha^{-1} (1069.0 kg ha^{-1}) and 0 kg P ha^{-1} (955.0 kg ha^{-1}) in North Jordan. Similar results have been reported in soybean where Asghar *et al.* (2006) reported lowest seed yield in control treatment compared with 30, 60, 90,120 kg P ha^{-1}.

However, application of phosphorus fertilizer did not affect the grain yield in winter season; probably due to soil moisture deficit (Ogola *et al.*, 2007) and poor recovery of phosphorus (Upadhyaya *et al.*, 2007). Similar results have been reported elsewhere. For example, Wen *et al.* (2008) reported that moisture availability influenced response of chickpea crop to applied P fertilizer in Montana. Amount of rainfall received in the winter season (84.3 mm) was 86% lower than the summer (565.7 mm) season, while the converse was true for vapour pressure deficit, which was 20% greater in the winter compared with the summer season.

Lower precipitation (rainfall and irrigation) and greater vapour pressure deficits (VPD) in the winter season probably resulted into greater soil moisture deficits in winter compared to the summer season. Similarly, Ogola *et al.* (2007) attributed seasonal variation in soil moisture deficit in Machakos, Kenya, partly to variation in VPD; soil moisture deficit was greater in the season that experienced greater VPD.

Season II gave greater grain yield than season I. This could be due to the greater amount of water received (rainfall and irrigation) throughout growing periods in season II (387 mm) than season I (86.51 mm), as well as seasonal variation in mean temperatures. The grain yield found from this study is not comparable to the other study in this area (Thangwana and Ogola, 2012) probably due to differences in genotypes used in these studies.

5.4. Harvest Index

The effect of genotype on harvest index was significant ($P<0.01$) in both season I and season II. Only desi type ICCV92944 had greater harvest index compared to the rest of the genotypes in season I. The kabuli types had greater harvest index compared with desi in season II. The greatest harvest index reported from this study in both seasons I and II was much lower than 0.54 reported by Pacucci *et al.* (2006), and 0.29 to 0.54 reported by Khan *et al.* (2004).

Phosphorus application rate did not affect harvest index in season I probably due to insignificant effect of phosphorus fertilizer application rates on above ground biomass at harvest maturity.

The non-significant effect of phosphorus fertilizer application rates on harvest maturity in season II could probably be due to greater effect of phosphorus fertilizer application rates on grain yield (55%) than above ground biomass (45%) at harvest maturity in this season.

5.5. Water use and water use efficiency

The effect of genotype on water use (ET) of chickpea was not insignificant in season I and season II. Similarly, Gan *et al.* (2010) reported no significant differences in water use amongst chickpea genotypes grown in semi-arid environments in the northern hemisphere. However, these results are not comparable to other studies. For example, Ogola *et al.* (2009) in the area of current study found that genotype affected water use of chickpea. Similar results were reported by Gan *et al.* (2009) who found significant differences on water use amongst pulse crops in semiarid northern high latitude. The differences could be due to difference in seasons, genotypes and variation in the environmental factors.

Genotype did not affect water use efficiency of biomass production (WUE_b) in both season I and season II. The non-significant effect of genotypes on WUE_b in season I and season II could probably be due to the non-significant effect of genotypes on water use. In contrast, genotypes affected water use efficiency of grain yield (WUE_g) in both seasons. Desi genotypes gave greater WUE_g in season I than season II. This implies that desi is more suitable in winter than summer season. In contrast, kabuli is more favourable in summer season. The significant effect of genotype on WUE_g could be attributed to difference in grain yield. Genotypes with high grain yield had higher WUE_g in both season I and season II. Ogola *et al.* (2009) reported that genotypes with high above ground biomass and grain yield had higher WUE_g.

Similar results were reported by Anwar *et al.* (2003) who found that Sanford genotype had greatest WUE_g in New Zealand, which was 27% and 71% higher than in Dwelley and B-90 genotypes. Gan *et al.* (2009) reported that desi types had greater WUE_g (7.3 kg ha^{-1} mm^{-1}) than kabuli types (6.6 kg ha^{-1} mm^{-1}) when grown under fallow and stubble condition. Rowland *et al.* (2004) showed that environment influenced the response of groundnut genotype to water use. Combination of management practices and environment plays a significant role in the genetic expression of traits in genotype. In the semi-arid Canadian prairie, early maturing cultivars of dry pea escaped later season drought, hence increasing WUE_g (Gan *et al.*, 2009).

The effect of phosphorus fertilizer rates on WUE_b and WUE_g was not significant in season I but significant in season II, probably due to insufficient moisture availability in winter season. Application of phosphorus fertilizer rate influences the water use of chickpea and other crops. Radin (1984) reported that P influences the water use efficiency by causing stomata of cotton to begin closing at higher leaf water potentials compared with plants grown on more typical P levels without any P application.

The effect of genotype on water use efficiency was greater in season II than season I. These results are inconsistent with the findings of Ogola *et al.* (2009) who reported that genotype produced greater WUE_g in winter season compared with summer season.

7. CONCLUSIONS

This study has clearly shown the potential of genotype and phosphorus fertilizer rates in improving chickpea yield. Increase in phosphorus fertilizer application rates increased the yield of chickpea genotypes probably due a similar increase in shoot biomass and 100 seed weight. Desi genotypes had greater chickpea grain yield as compared to the kabuli genotypes. This implies that it could probably be the most suitable genotype for the winter season in the site of the current study. In contrast, kabuli appears to be more suitable in summer season. Phosphorus fertilizer application increased chickpea grain yield in summer but not in winter probably due to water stress. The results of this study have shown that, genotype and phosphorus fertilizer rates did not affect water use efficiency of biomass production in both season I and season II. Genotype and fertilizer rates affected water use efficiency of grain production in both season I and season II. Desi genotypes had greater water use efficiency of grain yield as compared to the kabuli genotypes. Application of P fertilizer rates significantly affected water use efficiency of biomass production in season II but insignificant in season I.

8. RECOMMENDATIONS

This study has shown that genotype and phosphorus fertilizer rates may be beneficial for the chickpea yield. However, since this study was for two seasons, it is recommended that further studies, over a number of seasons, should be conducted before any definite recommendation can be made.

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APPENDICES

Season I

Crop biomass at vegetative stage

Variate: TBM1

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	12568.	6284.	0.22	
Block.*Units* stratum					
Genotypes	3	611847.	203949.	7.27	0.001
P_rates	2	926343.	463172.	16.50	<.001
Genotypes.P rates	6	274501.	45750.	1.63	0.186
Residual	22(1)	617432.	28065.		
Total	35(1)	2442691.			

Crop biomass at 50% flowering stage

Variate: TBM2

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	84456.	42228.	0.56	
Block.*Units* stratum					
Genotypes	3	3872829.	1290943.	17.03	<.001
P_rates	2	119890.	59945.	0.79	0.466
Genotypes.P rates	6	440751.	73458.	0.97	0.470
Residual	21(1)	1591544.	75788.		
Total	34(1)	5897804.			

Crop biomass at harvest maturity stage

Variate: TBM3

Variate: Harvesting_biomas_kg_ha_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F
Block stratum	2	2759725.	1379863.	0.76	
Block.*Units* stratum					

Genotypes	3	4149927.	1383309.	0.77	0.525
P_rates	2	523921.	261961.	0.15	0.866
Genotypes.P_rates	6	3740370.	623395.	0.35	0.905
Residual	22	39701612.	1804619.		
Total	35	50875556.			

Number of pods per plant

Variate: No of pods per plant

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	8.15	4.08	0.14	
Block.*Units* stratum					
Genotypes	3	556.07	185.36	6.58	0.003
P_rates	2	2.94	1.47	0.05	0.949
Genotypes.P rates	6	187.16	31.19	1.11	0.392
Residual	21(1)	592.01	28.19		
Total	34(1)	1344.56			

Number of seeds per pod

Variate: No of seeds per plant

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.046309	0.023155	2.33	
Block.*Units* stratum					
Genotypes	3	0.126254	0.042085	4.23	0.017
P_rates	2	0.005647	0.002823	0.28	0.756
Genotypes.P rates	6	0.178682	0.029780	3.00	0.028
Residual	21(1)	0.208722	0.009939		
Total	34(1)	0.557429			

100 seed weight

Variate: %100 seed Wt

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	9938.	4969.	0.78	
Block.*Units* stratum					
Genotypes	3	182475.	60825.	9.50	<.001
P_rates	2	18211.	9105.	1.42	0.264

Genotypes.P rates	6	89896.	14983.	2.34	0.069
Residual	21(1)	134458.	6403.		
Total	34(1)	421655.			

Grain yield

Variate: Total seed Wt

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2	353185.	176592.	0.53	
Block.*Units* stratum					
Genotypes	3	6786881.	2262294.	6.77	0.002
P_rates	2	154051.	77026.	0.23	0.796
Genotypes.P rates	6	3337024.	556171.	1.66	0.177
Residual	21(1)	7349811.	334082		
Total	34(1)	179809521.			

Harvest Index

Variate: HI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.00598	0.00299	0.28	
Block.*Units* stratum					
Genotypes	3	0.18541	0.06180	5.80	0.004
P_rates	2	0.01320	0.00660	0.62	0.547
Genotypes.P_rates	6	0.12121	0.02020	1.89	0.127
Residual	22	0.23457	0.01066		
Total	35	0.56037			

Water use (ET)

Variate: ET

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2109.	1055.	0.70	
Block.*Units* stratum					
Genotypes	3	2088.	696.	0.46	<.001
P_rates	2	1463.	732.	0.49	<.001
Genotypes.P rates	6	10677.	1779.	1.19	0.625
Residual	22	32960.	1498.		

Total	35	49297.		

Water use efficiency (WUE_b)

Variate: WUE_b

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	81.18	40.59	0.81	
Block.*Units* stratum					
Genotypes	3	35.06	11.69	0.23	0.873
P_rates	2	29.18	14.59	0.29	0.751
Genotypes.P rates	6	198.76	33.13	0.66	0.683
Residual	22	1106.46	50.29		
Total	35	1450.64			

Water use efficiency (WUE_g)

Variate: WUE_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.356	1.178	0.21	
Block.*Units* stratum					
Genotypes	3	128.127	42.709	7.75	0.001
P_rates	2	0.427	0.213	0.04	0.962
Genotypes.P rates	6	56.690	9.448	1.71	0.165
Residual	22	121.261	5.512		
Total	35	308.8			

SEASON II

Crop biomass at vegetative stage

Variate: TBM1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	296089.	148044.	1.78	
Block.*Units* stratum					
Genotypes	3	9977369.	3325790.	39.90	<.001
P_rates	2	1642239.	821119.	9.85	<.001
Genotypes.P rates	6	368617.	61436.	0.74	0.625
Residual	22	1833961.	83362.		

Total	35	14118274.		

Crop biomass at 50% flowering stage

Variate: TBM2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	342817.	171408.	1.50	
Block.*Units* stratum					
Genotypes	3	4955841.	1651947.	14.45	<.001
P_rates	2	2089912.	1044956.	9.14	0.001
Genotypes.P rates	6	1183199.	197200.	1.73	0.162
Residual	22	2514650.	114302.		
Total	35	11086419.			

Crop biomass at harvest maturity stage

Variate: TBM3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4543670.	2271835.	2.19	
Block.*Units* stratum					
Genotypes	3	8280705.	2760235.	2.66	0.073
P_rates	2	38697012.	19348506.	18.68	<.001
Genotypes.P rates	6	4065088.	677515.	0.65	0.687
Residual	22	22789018.	1035864.		
Total	35	78375492.			

Number of pods per plant

Variate: Pods per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	182.35	91.18	4.77	
Block.*Units* stratum					
Genotypes	3	68.29	22.76	1.19	0.336
P_rates	2	9.03	4.52	0.24	0.791
Genotypes.P rates	6	12.12	2.02	0.11	0.995
Residual	22	420.48	19.1		
Total	35	692.28			

Number of seeds per pod

Variate: Seeds per pod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.06542	0.03271	0.36	
Block.*Units* stratum					
Genotypes	3	0.11910	0.03970	0.44	0.729
P_rates	2	0.15500	0.07750	0.85	0.440
Genotypes.P rates	6	0.51278	0.08546	0.94	0.487
Residual	22	1.99958	0.09089		
Total	35	2.85188			

100 seed weight

Variate: %100 seed Wt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	16745.	8373.	5.51	
Block.*Units* stratum					
Genotypes	3	92744.	30915.	20.35	<.001
P_rates	2	40834.	20417.	13.44	<.001
Genotypes.P rates	6	11285.	1881.	1.24	0.325
Residual	22	33415.	1519.		
Total	35	195025.			

Grain yield

Variate: Total seed Wt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1404472.	702236.	10.65	
Block.*Units* stratum					
Genotypes	3	1575603.	525201.	7.96	<.001
P_rates	2	2554329.	1277165.	19.36	<.001
Genotypes.P rates	6	349074.	58179.	0.88	0.524
Residual	22	1451003.	65955.		
Total	35	7334481.			

Harvest Index

Variate: HI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.088645	0.044322	8.74	
Block.*Units* stratum					
Genotypes	3	0.066275	0.022092	4.35	0.015
P_rates	2	0.003990	0.001995	0.39	0.680
Genotypes.P rates	6	0.013993	0.002332	0.46	0.830
Residual	22	0.111619	0.005074		
Total	35	0.284522			

Water use (ET)

Variate: ET2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	45.63	22.82	0.90	
Block.*Units* stratum					
Genotypes	3	81.66	27.22	1.07	0.381
P_rates	2	91.13	45.56	1.79	0.190
Genotypes.P rates	6	135.66	22.61	0.89	0.519
Residual	22	558.59	25.39		
Total	35	912.68			

Water use efficiency (WUE_b)

Variate: WUE_b

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2759725.	1379863.	0.76	
Block.*Units* stratum					
Genotypes	3	4149927.	1383309.	0.77	0.525
P_rates	2	523921.	261961.	0.15	0.866
Genotypes.P rates	6	3740370.	623395.	0.35	0.905
Residual	22	39701612.	1804619.		
Total	35	5087556.			

Water use efficiency (WUE_g)

Variate: WUE_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.356	1.178	0.21	
Block.*Units* stratum					
Genotypes	3	128.127	42.709	7.75	0.001
P_rates	2	0.427	0.213	0.04	0.962
Genotypes.P rates	6	56.690	9.448	1.71	
Residual	22	121.261	5.521		
Total	35	308.860.			