THE EFFECT OF PLANTING DENSITY ON WATER USE EFFICIENCY, GROWTH AND YIELD OF FOUR CHICKPEA (*Cicer arietinum* L.) GENOTYPES HAVING CONTRASTING GROWTH PATTERNS.

BY

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF AGRICULTURAL MANAGEMENT (Agronomy) IN THE FACULTY OF SCIENCE AND AGRICULTURE (SCHOOL OF AGRICULTURAL AND ENVIRONMENTAL SCIENCE AT THE UNIVERSITY OF LIMPOPO

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DEDICATIONS

I dedicate this research to my children Oratilwe and Joenior and their father Joseph Kutla who gave me support during the study. A big gratitude to my loving parents Mr and Mrs Leboho and also my siblings and their children. I also dedicate this work to the whole UNIVEN chickpea team and everyone who supported me.

DECLARATIONS

I, Terry Moraka Leboho, student number: [redacted] hereby declare that this Dissertation for Master of Agriculture Management (Agronomy) at the University of Limpopo has not been submitted previously for any degree at this or any another University. It is original in design and execution, and all references have been duly acknowledged.

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Signature Date

As the supervisor/co-supervisor of the candidate, we agree to the submission of this Dissertation.

Supervisor: Prof. I.K. Mariga _____ _____

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Signature Date

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ABSTRACT

Field experiments were conducted at two locations; University of Limpopo (Syferkuil) and University of Venda (Thohoyandou) during 2015 and 2016 winter cropping seasons. The objectives of this study were to determine; the effect of genotype (ACC# 1, 3, 4 and 7) and planting density (33, 25 and 20 plants/m^2) on four chickpea genotypes having contrasting growth patterns and also to determine the effect genotype and planting density on water use and water use efficiency of four chickpea genotypes having contrasting growth patterns. The experimental design was randomized complete block design in factorial arrangement with three replications. Plant height, number of primary and secondary branches, grain yield and yield components (number of pods per plant, number of seeds per pod, Harvest Index and 100 seed weight [100-SW] and above ground biomass, and were determined at different growth stages. Data obtained was subjected to analyses of variance using the general linear model of Genstat 17th edition. Significant differences between the treatments means were compared using the standard error of difference (LSD) of the means at 5% level. Correlation analyses were performed to assess the relationship between parameters.

Plant height varied with genotype from 41 cm (84 DAE) to 44 cm (118 cm) at Syferkuil and 41 (56 DAE) to 44 cm (63 DAE) at Thohoyandou. Primary branches was not significantly affected by genotype and planting density at both locations and seasons. Planting density had significant effect on number of secondary branches, greater number was recorded at low (32, 6) density at Syferkuil in 2016. Above ground biomass was significantly affected by planting density at Syferkuil during in 2015 (5344 kg ha^{-1}) and 2016 (3701 kg ha^{-1}) growing seasons. Genotype and planting density did not affect number of pods $plant^{-1}$, number of seeds $plant^{-1}$, 100 SW (100 seed weight), and Harvest index were not significant at both locations and seasons. Grain yield was significantly affected by planting density at Syferkuil in 2015 and Thohoyandou in 2016. Grain yield increased with the increase in planting density at both locations.

Two field experiments were conducted at University of Venda (Thohoyandou) during 2015 and 2016 winter cropping seasons. This study aimed at assessing the effect of genotype

and planting density on water use efficiency of four chickpea genotypes with contrasting growth patterns. Crop water use (WU) was determined by monitoring soil water content at 7-day intervals using a neutron probe and, water use efficiency (WUE) was determined as a ratio of crop biomass and grain yield to WU. Genotype and planting density had no significant effect on WU in 2015 and 2016. Genotype and planting density had no significant effect on biomass production (WUE_b) and grain yield production (WUE_g) in 2015. In contrast, WUE_b and WUE_g was significantly affected by planting density in 2016. WUE_b was 43.2% greater at high density compared to low density. Similarly, WUE_g was 39.3% greater at high density compared to low density. WUE_b and WUE_g increased with the increase with planting density. Therefore, manipulation of management practices such as planting density may increase chickpea production.

Keywords: Planting density, genotype, grain yield and yield components, water use efficiency.

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LIST OF ABBREVIATIONS

100-SW	Hundred seed weight
ABV	Aboveground biomass
DAE	Days after emergence
ET	Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
G	Gram
GY	Grain yield
HI	Harvest index
IPPC	Intergovernmental panel on climate change
KG	Kilogram
LI	Light Interception
P	Phosphorus
PD	Planting density
PM	Physiological maturity
Qv	Volumetric water content
RI	Intercepted radiation
RUE	Radiation use efficiency
WU	Water use
WUE	Water use efficienc

CHAPTER 1: INTRODUCTION

1.1. Background information

Chickpea [*Cicer arietinum* (L.)] is one of the most important widely grown pulse crops in the world which belongs to genus *Cicer,* tribe *Cicereae*, family *Fabaceae* and subfamily *Papilionaceae* (Saxena and Singh, 1987). It is the third largest produced food legume globally, after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.) (FAO, 2015). It is thought to have originated in Western Asia and spread to India and Europe and subsequently it spread to Africa, Latin and Central American Countries (Ladizinsky, 1975).

The world chickpea production was estimated to be about 9 million tons from an area of 11 million hectares of which developing countries contribute 95 and 93% of total cultivated area and production, respectively (FAO, 2016). India is the leading producer of chickpea accounting for approximately 65% of the world's production followed by Pakistan (7%) and Turkey and Iran at approximately 6% and 3%, respectively.

There are two types of chickpea, namely desi and kabuli. Both kabuli and desi types generally have yellow cotyledons. Kabuli chickpea has a thin transparent seed coat, whereas the desi type has a thick, reddish brown-coloured seed coat. Kabuli seeds are generally larger than desi seeds (Shiferaw *et al*., 2007). Chickpea is a herbaceous annual plant which branches from the base. It is almost a small bush with diffused and spreading branches though a few erect cultivars exist. The plant is mostly covered with glandular or non-glandular hairs but some genotypes do not possess hair (Singh and Diwakar, 1995).

Chickpea plays an important role in human nutrition as a source of protein, energy, fibre, vitamins and minerals for large population sectors in the developing world and is considered a healthy food in many developed countries. Being a legume,

chickpea improves physical, chemical and biological properties of soils and thus plays an important role in sustaining soil productivity. Under favourable conditions, symbiotic nitrogen (N) fixation can produce greater than 100 kg N ha^{-1} (Beck, 1992), and provide up to 85% of the N required by a chickpea crop thus reducing the need and cost for external inputs (Walley *et al*., 2005).

Despite its importance there is insignificant commercial chickpea production in South Africa. However, production has slowly started in Limpopo and Mpumalanga Provinces at research level. Preliminary findings have shown huge potential and high market demand. Early studies showed that poor management strategies such as crop water needs, genotypes and the correct plant density are amongst key challenges affecting yield. It has been reported in the same region that any management practices that increase the efficiency of water utilization may increase chickpea productivity (Ogola and Thangwana, 2013).

Chickpea is traditionally planted in winter and taking advantage of the residual moisture from the previous season. Therefore under rainfed conditions suitable density must be considered for more absorption of solar energy, and improved utilization of water and soil (ICARDA, 1990). Due to global warming there is a need to consider drought tolerant crops which are adopted to harsh conditions, with a pronounced warm-season growth habit such as chickpea (*Cicer arietinum* L.) in semi-arid regions (Gan et al., 2009). Introducing a new grain legume to South African cropping system would be also beneficial for reducing the substantial deficit of protein (Henseler et al., 2013).

Planting density is one such management practice that may improve water use efficiency. Different planting densities may result in different canopy cover and variation in water extraction and hence water use efficiency. In addition, variation in growth habit amongst chickpea genotypes may affect water extraction pattern and water use efficiency.

However, preliminary study has reported on the effect of planting density and genotype on water use efficiency but not on genotypes having contrasting growth patterns. Moreover, water use efficiency may vary with season owing to variation in

seasonal temperatures. However, information on the effect of planting season on chickpea water use efficiency is scanty. Therefore, this study aimed at determining the effect of planting density and genotype on yield components, yield, and water use and water use efficiency of chickpea crop.

In addition, the effect of planting density on chickpea growth parameters such as plant height and branches and their effects on water use and water use efficiency has hardly been reported. Literature o the effect of planting density on WUE of chickpea genotypes having contrasting growth patterns under local conditions in limited.

There is currently no commercial chickpea production in South Africa. Chickpea is a fairly drought tolerant crop, however if grown in areas of unreliable rainfall it subsequently suffers from terminal drought. Determination of optimum of planting density and suitable chickpea genotypes with high water use efficiency may increase yield while conserving moisture in semi-arid areas such as in Limpopo Province. The combination of high water use efficient genotypes of desirable growth duration with appropriate planting density during the correct planting season maximize water use and yield of chickpea.

1.2. Hypotheses

I. Genotype and planting density affect chickpea water use and water use efficiency.

II. Genotype and planting density affect growth, grain yield and yield components of chickpea.

1.3. Aim and objectives

The aim of the study was to determine the effect of genotype and planting density on water use and water use efficiency of four chickpea genotypes having contrasting growth patterns.

The specific objectives of the study were to determine;

I. The effect of genotype and planting density on chickpea water use and water use efficiency.

II. The effect of genotype and planting density on growth, grain yield, and yield components of chickpea.

CHAPTER 2: LITERATURE REVIEW

2.1. Origin and description of chickpea

Chickpea (*Cicer arietinum* L.) is said to have originated from southeastern Turkey and adjoining Syria where three wild annual species of *Cicer viz*, *Cicer bijigum* K.H. Rech, *Cicer aerhinosperum* P.H. Davis and *Cicer reticulatum* Lad are found (Saxena and Singh, 1987). Chickpea is a self-pollinated annual crop and it completes its life cycle in 90 to 180 days depending on the genotype and prevailing environmental conditions (Saxena and Singh, 1987).

The chickpea plant is erect with primary and secondary branching resembling a small bush and the plant height ranges from 30-70 cm. The plant flowers profusely and has an indeterminate growth habit, in which vegetative growth continues to set pods after the first flowering as long as climatic conditions are conducive. Flowers vary from with types; with desi types having purple flowers and Kabuli types having white flowers (Miller *et al*., 2002). Chickpea exhibits five growth habits and are classified erect, semi-erect, semi-spreading, spreading and prostrate.

2.2. Importance and production of chickpea

Chickpea (*Cicer arietinum* L) is the third most important pulse crop in the world, after dry bean and field pea (Parthasarathy *et al*., 2010). The world chickpea production was estimated to be about 9 million tons from an area of 11 million hectares of which developing countries contribute 95 and 93% of total cultivated area and production, respectively (FAO, 2016). India is the leading producer of chickpea accounting for approximately 65% of the world's production, Pakistan (7%) and by Turkey and Iran at approximately 6% and 3% respectively stands the second largest producer, producing approximately 7% of the world supply, followed by Turkey and Iran at approximately 6% and 3%, respectively (FAO, 2016). The geographic

distribution of chickpeas differs, Kabuli is mainly produced in the western Mediterranean and Desi in the eastern Mediterranean to central Asia and India subcontinent.

Africa chickpea is produced in Egypt, Sudan, Ethiopia, Kenya and Tanzania. Currently there is hardly any commercial chickpea production in South Africa despite the high and increasing domestic demand (Thangwana and Ogola, 2012). However, its production has slowly started in Limpopo and Mpumalanga Provinces at research level. In developing and developed countries chickpea is used as human and livestock feed due to its high protein (29%), carbohydrates (59%), vitamins, oil (5%), ash (4%) and fibre (3%) contents. Bhatnagar *et al*., 2015 reported that the green chickpea is used for vegetable purpose whereas, dry seed is consumed in the form of whole seed, dhal, and in the form of fried items from chickpea flour. Chickpea seeds provide food and nutritional security in rural areas and its lateral roots develops nodules which are capable of fixing atmospheric nitrogen (103 kg N). Therefore in cooperation of chickpea into the existing agricultural systems will improves soil fertility for smallholder farmers and hence increase source of income (Ojiem *et al*., 2007).

2.3. Productions constraints

Chickpea, like any other legume, is exposed to different biotic and abiotic constraints which reduces grain yield in arid and semi-arid regions. In these regions gram caterpillar or pod borer (*Helicorvepa amrigera* Hubner) is among the major biotic factors (Begum *et al*., 1992). On average, 30 to 40 % pods are damaged by pod borer resulting in about 400 kg/ha loss in grains yield (Rahman, 1990). Shengel and Ujagir (1990) found that under favourable conditions the pod damage may go up to 90-95 %. Seed beetle or bruchids *(Callosobruchus spp*) is the most important storage pest in chickpea. The main fungi that affect chickpea are *Fusarium oxysporum* (causes the plant to wilt) and *Ascochyta* blight which is caused by *Ascochyta rabiei*. Blight causes brown spots on leaves, stems, pods and seeds (Kaiser, 1992).

Chickpea faces various abiotic stresses during its life cycle such as drought, cold, terminal heat and salinity (Millan et al., 2006). Among other constrains faced in rainfed agriculture, drought is one of the major abiotic factor affecting chickpea production. This is mainly because soil moisture availability determines germination and development of the crop which is normally grown on residual moisture and it gets exposed to terminal drought (Johansen *et al*., 1994). Drought affects the upper soil layer which is responsible for early crop establishment and this lead to uneven germination and the decrease in plant growth and consequently in crop yield. Drought stress in agriculture worldwide contributing to about 50% of crop loss (Mohammad, 2013) due to water limitation and unreliable rainfall in semi-arid regions.

Chickpea being a cool season crop, is also susceptible to high temperatures (30-35ºC) for few days at flowering stage and can cause substantial yield loss (Jha et al., 2014). High temperatures hampers photosynthesis by damaging both structural and functional activity of chlorophyll and lowers the chlorophyll content. Furthermore, cold temperatures stress represent a major limiting factor in major producing countries (Jha et al., 2014). Low temperatures stress is becoming more prevalent in temperate region creating a serious threat to vegetative growth by several means like creating chlororis, necrosis of leaf tip and curling of whole leaf (Jha et al., 2014. Similarly during reproductive stage, this may cause damage on juvenile buds drops, aborted pods, reduced pollen viability and stigma receptivity, inhibited pollen tube growth and ultimately, deteriorated seed quality and seed yield (Kumar et al., 2007).

2.4. **Chickpea growth habits**

Growth habit is influenced by branching in chickpea and branching is a primary factor in determining the number and position of flowers and pods, and thus seed yield (Muehlbauer and Singh, 1987). Canopy structure therefore essentially affects crop functions such as light interception (LI) and evapotranspiration and eventual biomass accumulation and seed yield

production. In this research, canopy architecture elements evaluated are leaf type (i.e., leaf morphology or shape), growth habit (i.e., individual plant shape) and number of nodes on main stem as a proxy for number of primary branches (Vanderpuye 2010).

Growth habit in chickpea varies from erect, with primary branch angles of 0 to 15º from vertical; through semi-erect, with primary branch angles of 16 to 25º from vertical; semi-spreading (bushy) with primary branch angles 26 to 60º from vertical; to spreading, with primary branch angles of 61 to 80º from vertical and prostrate, with branches lying flat on the ground (Singh and Diwakar, 1995).

Two leaf types (fern and unifoliate) and three growth habits (bushy, erect and spreading) are exhibited by chickpea cultivars grown on the Canadian Prairies. The pinnate compound fern leaves are expected to have better seasonal radiation capture by allowing deeper penetration of radiation into the canopy than the simple unifoliate leaves. The more branched bushy and spreading growth habits may have earlier and greater canopy closure than the erect growth habit (Vanderpuye 2010). This may result in differences in PPD required for maximum yield by the contrasting leaf types 3 and growth habits. The rate of canopy development is a combination of leaf type, growth habit and PPD. Chickpea canopies with differing rates of canopy development may affect light interception (LI), cumulative intercepted radiation (RI) and radiation use efficiency (RUE) as well as WU and WUE.

2.5. Effect of genotype on growth and yield of chickpea

Genotypes play an important role in determining yield of chickpea. The yield potential of a certain genotype within its genetic limits depend on the suitability of a certain environment or location. Yield of chickpea genotypes may be enhanced by providing suitable environment and manipulation of agronomic practices. Variation among genotypes differs from growth

parameters to grain yield. Yield potential generally depend on many physiological processes which are controlled by genetic makeup and environment. Growth is generally a function of environmental factors (such as temperature, solar radiation, nutrients and moisture) and mineral nutrition, along with genotype and production practices (Alam and Haider, 2006).

Studies in chickpea have reported a significant genetic variation for number of secondary branches per plant, number of pods per plant, biomass yield, seed yield and harvest index (Malik *et al*., 2010), days to flowering, days to maturity, number of pods per plant and seed yield (Bakhsh *et al*., 2007). Qureshi *et al*., (2004) reported significant variation for growth habit, seed shape and seed coat colour and, plant height, number of primary and secondary branches per plant, pods per plant and biomass yield (Aslamshad *et al*., 2009). Goyal *et al*., 2010, indicated variability among Kabuli genotypes may be due to genetic characteristics for example growth patterns and growth duration. Genotype 'Phule G 95333' recorded significantly higher in various growth characters, yield attributing traits grain and straw yield as compared to genotype 'Phule G 0515.

Kumar *et al*. (2001) reported high genotypic variations for number of pods per plant and seed yield per plant. The highest phenotypic variances were found for number of pods per plant, biological yield per plant, plant height, grain yield per plant and 100-grain weight, while the lower phenotypic variances were found for days to 50% flowering, number of secondary branches per plant and number of primary branches per plant.

The main causes of yield components variability are genotypic, genotypes by environment interactions, climatic variability in terms of temperature regime and moisture availability and plant population (Verghis, 1996). Thangwana and Ogola (2012) reported that high variation in grain yield and yield components between two growing season could be due to differences in the length of the growing season between the two seasons. Singh *et al*. (1990) reported that growing season, location and planting time influence the quality of parameters of kabuli cultivars.

Moreover, environment has an effect on genotypes for example Jiayin *et al*. (2013) found out that seed yield varied greatly among genotypes grown at different locations varying in climate; ranging from 560 kg ha^{-1} to 1200 kg ha^{-1} in York, from 500 kg ha^{-1} to 1060 kg ha^{-1} in Bindi and from 890 kg ha^{-1} to 1780kg ha^{-1} in Cunderdin.

Genotypes respond differently to varying environments and this can be revealed through growth and yield percentage. In case of chickpea, under unfavourable climatic conditions, genotypes appear to show little variation in grain yield due to increased plant population density (Kumar, 1995). During growth, plants are usually exposed to different environmental stresses which limit their growth and productivity. Among these, drought affects every aspect of plant growth and metabolism. In drought condition, varieties with strong root growth are particularly important to avoid drought effects (Dhanda *et al*., 1995).

2.6. Effect of plant density on growth and yield of chickpea

Research has shown that growth of chickpea is affected by management strategies such as planting density and use of varieties (Biabani, 2011). Planting density is one the most important cultural practices in determining grain yield, as well as other agronomic attributes of a crop and can be used as a key component in optimizing the productivity of chickpea (Valimohammadi *et al.,* 2009). Generally, planting density is an area dependent factor because seeds yield of chickpea differ across a diverse sets of environment yet one planting density (33 plant m^2) has been recommended. High or low density affects grain yield; high density creates competition for natural resources (Light, soil moisture, space and nutrients) and low density facilitates aeration and light penetration in to plant canopy for optimizing rate of photosynthesis. Chapin, (1991) reported that where there is insufficient of resources; plants response by preferentially portioning growth to maximize the acquisition of most limiting resource.

High density initially provokes fast growth of canopy in per unit area which in turn ejects available stored water in soil through respiration and causes the plant to encounter drought stress during flowering and grain-filling stages; therefore, under rainfed conditions suitable seed density must be considered for more absorption of solar energy, and improved utilization of water and soil (ICARDA, 1990). It has been revealed that yield augmentation caused by increasing seed density has been achieved by planting the genotypes with dense plant form (Saxena, 1979). Gan *et al*. (2003) reported that high planting density increases grain yield in areas with a short growing season, however the yield increase depends on the environmental conditions.

According to Singh *et al*., (1988), more number of branches, pods per plant, 100 seed weight, biomass and grain yield were produced by dense and semi-extensive varieties. Cokkizgin (2012) reported that maximum plant height was recorded at optimum (50 plant m^{-2}) followed by high (60 plant m^{-2}) density with the lowest plant height at (40 plant m^{-2}) low densities.

Beech and Leach (1989) concluded that the number of plants per unit area influences plant size and yield components. In Iran, Shamsi (2009) conducted research on the effects of planting density on grain filling, yield and yield components of three chickpea varieties and found that the number of branches per plant were significantly affected by plant density. Barkry *et al*. (2011) reported that number of branches per plant decreased with the increase in density but Cokkizgin (2012) argued that number of branches increased with the decrease in plant density. The results are in agreement with Al-Suhaibani *et al*. (2013) found that a maximum number of braches per plant of faba bean under low plant population. .

Adaptation of a genotype to season, weather and environment is very crucial in chickpea production. Vanderpuye (2010) reported that height of lowest pod increased significantly with increase in plant density. Shad *et al*. (2010) found that high plant density decreased number of pods per plant in faba bean due to a reduction in the number of branches per plant. Beech and Leach (1989) also reported the same in chickpea and the decrease was presumed to be due to interplant completion for resources

Thangwana and Ogola (2012) reported that a significant effect of planting density and cultivar on number of pods per plant during winter, number of pods per plant was greater at the low compared with the medium and high planting density. Ayaz *et al*. (2000) planted chickpea at four different plant population densities (5000; 50, 000; 100,000 and 200,000 plants/ha) and reported that dry matters accumulated over time was affected by plant population densities. Felton *et al*. (2001) concluded that dry matter production was high at high plant populations (60 plant m^2) compared to low and medium.

Determination of optimum plant population continues to be a challenge for the dryland farmers. In pulses, optimum plant population density appears to differ with plant, type of cultivars and the environmental conditions (Kumar, 1995). Yigitoglu (2006) reported that highest seed yield of chickpea was obtained in early winter sowing at high plant density (45 plant m^2) and suggested that planting density depends to environmental conditions, seed size, genotype and way of sowing. Thangwana and Ogola (2012) found that grain yield was 108% greater at high planting density compared to lower planting density and 70% greater at the high planting density compared with the medium planting density. Also, Singh and Saxena. (1996) found that seed yield of chickpea increased with an increase in density from 33 to 50 plants m^2 in Northern Syria.

Optimum plant density of a crop variety at one location may not apply at other locations because of variation in water availability, adaptability and other environmental conditions. Also different genotypes may require different plant density to obtain its maximum yield. Therefore, there is a need to test genotypes and density at different sites.

2.7. Effect of planting density on water use (WU) and water use efficiency (WUE)

Water is the most important abiotic factor limiting crop productivity in the semiarid regions. Improvement in water use efficiency in agriculture is essential because irrigation sources are declining and energy costs make irrigation rather expensive for resource poor farmers to deliver. World demand for food and feed is increasing and production is being pushed into more arid environments. Moreover, currently in South Africa; Irrigation agriculture is the biggest consumer of

scarce water resources. As it is, South Africa is a semi-arid country whose water profile is rapidly moving from water scarce to water stressed (Singels *et al*., 2010). Therefore, research on water use efficiency in dry-land areas may provide a better understanding on efficient water use that can enhance chickpea production. Thus, the information will assist small-scale farmers to optimally utilize the water resources since is critically important.

Water use efficiency (WUE) has several definitions and they vary depending on scale, e.g., plant leaf or whole plant or time, e.g., short-time scale of minutes or longer-term up whole plant growth season (Bacon, 2004). Water use efficiency can be defined as a ratio of biomass accumulation, expressed as carbon dioxide assimilation, total crop biomass, or crop grain yield, to water consumed, expressed as transpiration, evapotranspiration (ET), or total water input to the system (Sinclair *et al*., 1986). For the plant leaf, WUE is defined as the ratio between instantaneous net CO_2 assimilation rate and transpiration (Sinclair *et al*., 1986). Water use efficiency is one of the most important challenges for crop improvement researches in the arid and semi-arid regions. It is well characterized by crop yield per unit of water used. This can be based either on water loss through evapotranspiration (ET) or transpiration from the crop. To minimize and redirect water through non-productive processes to plant use, agronomic practices such as planting density and use of suitable genotypes may be employed to improve the availability of moisture in the soil.

Plant density is very important to facilitate aeration and light penetration into plant canopy for optimizing rate of photosynthesis (Azizi and Kahrizi, 2008). Increasing plant population tended to increase WUE (Biabani, 2011). The increased water use efficiency, without improvement in water extraction and water consumption, indicates that efficiency of water use in pulses can be improved by using higher plant population to cover ground quickly, thus reducing fraction of evaporation in evapotranspiration. Also, the higher WUE under high plant density could be attributed to the effect of increased evapo-transpiration on yield.

Under low populations, moisture may be used rationally throughout the growing season which resulted in higher seed yield and WUE. Assimilations under water stress may also lead to a decrease in efficacy of other processes like photosynthesis and growth. In arid and semiarid environments, the increased seed yield with higher planting density is largely due to improved water use and WUE (Biabani, 2011). Ogola and Thangwana (2013) reported on the use of chickpea genotypes to improve water use and water use efficiency in the same study area. However, they did not use genotypes with contrasting growth patterns and the canopy structure have an influence on the partitioning of and pattern of water extraction, hence the water use and water use efficiency. Therefore, proper understanding of water extraction patterns in response under varying plant density in arid and semi-arid areas of Limpopo is required.

2.8. Effect of genotype on water use and water use efficiency

Crop production in South Africa is mainly affected by drought and decreased water availability due to unreliable rainfall. Water scarcity is one of the major factors that constraint crop production in arid and semi-arid areas, such as the north eastern part of South Africa (Ogola *et al*., 2013). Water use efficiency has important implications for crop productivity in dry environments that are characterized by low and unreliable rainfall. Water use efficiency relies on the soil's ability to capture and store water, the crop's ability to convert water into biomass and the crop's ability to convert biomass into grain (GRDC. 2009).

Variety selection is a cost-effective way of maximizing water use efficiency. Using varieties that are tolerant to a range of environmental stresses allows effective use of growing season rainfall. Varieties can potentially improve water use efficiency in a number of ways. The WUE of each genotype will vary because of phenology, root system, soil type, soil moisture,

intercepted radiation, temperatures and precipitation (Kalefetoglu *at el*., 2009, Gurbuz *et al.*, 2009). The pattern of water extraction/use is crucial for crops grown with a limited amount of water in the soil profile because crop reproductive success depends largely on a sustained water use into the reproductive growth stage (Merah, 2001; Kato *et al*., 2008). Indeed, water shortage during flower and pod production has a dramatic negative impact on final seed yield (Leport *et al*., 2006).

The limitation of soil water supply results in a sequence of plant responses that involve reductions in growth and in the rates of gas exchange (Pereira and Chaves 1993). So accurate estimation of water availability across the cropping cycle is an important tool for assessing crop performance, particularly in the post-rainy cropping systems where water supply is limited. In these systems, the amount of water available during the reproductive stage depends, for one part, on the way water was used by the plant earlier in the cropping cycle, i.e. on the capability of the plant to limit water use at the early stages to allow a significant amount of water to remain for the reproduction/pod-filling stage. Kholova *et al*., (2010) reported that lower canopy conductance in terminal drought tolerant near isogenic lines of pearl millet saves water under non stressed conditions, allowing plants to have water available to fill up grains.

CHAPTER 3: MATERIALS AND METHODS

3.1. Experimental sites

Field experiments were carried out at two research farms; University of Limpopo (UL) situated at Syferkuil (longitude and latitude of 29°42.44'E and 23°50.42'S, respectively, and altitude 1230 m) (Thabang *et al*., 2013), and University of Venda (UNIVEN) situated in Thohoyandou (latitude and longitude 30°26.411'E and 22°58.081'S, respectively, and altitude 595 m), both in Limpopo Province, Republic of South Africa. Thohoyandou receives an annual rainfall of about 500 mm which falls predominantly in summer. The average maximum and minimum temperatures are 31°C and 18°C in summer and winter, respectively (Tadross *et al*., 2006). The site is characterized by well drained clay soil (Soil Classification Workgroup, 1991). Syferkuil receives mean annual rainfall of about 500 mm with the average minimum and maximum 18°C and 30°C from October to March and 25°C or lower from April to September (Mpangane *et al.,* 2004). The farm has sandy loam soil, of the Hutton form, Glenrosa family, with pH ranging from 6.0-6.2 (Moshia, 2005).

3.2. Experimental design and treatments

The experiment consisted of a factorial combination of three planting density levels (20, 25 and 33 plants/m^2) and 4 chickpea genotypes (ACC# 1-erect, ACC# 3-prostrate, ACC#-4 erect and ACC#7-prostrate). Treatments were laid in a randomized complete block design and replicated three times (Figure 3.1). The trials were planted over two winter seasons on 05 May 2015 and 09 May 2016 at Thohoyandou and 02 May 2015 and 15 May 2016 at, Syferkuil. Individual experimental units

were 2m wide and 2m long, and for density of 20 plant m^2 the spacing was 50cm X 30cm, having a total of 4 rows. For 25 plant m^2 the spacing was 40 cm X 30 cm with 5 rows while for 33 plants m^2 the spacing was 30 cm X 30 cm with 6 rows per plot.

Figure 3.1. Field layout of 4 chickpea genotypes planted with three planting density levels over two winter season (2015/2016) trial for two sites.

REP 1

G1 PD3	G7 PD2	G3 PD1	G4 PD2	G1 PD2	G7 PD1	G3 PD3	G4 PD3	G1 PD1	G7 PD3	G3 PD2	G4 PD1

REP 2

G4 PD1	G3 PD3	G7 PD1	G1 PD2	G3 PD2	G7 PD3	G4 PD2	G1 PD1	G3 PD1	G4 PD3	G7 PD2	G1 PD3

REP 3

G7 PD3	G3 PD1	G4 PD2	G1 PD3	G4 PD1	G3 PD2	G7 PD2	G1 PD1	G3 PD3	G1 PD2	G4 PD3	G7 PD1

G= Genotype, G1= ACC# 1, G3= ACC# 3, G4= ACC# 4 and G7= ACC# 7

PD1=33, PD 2=25 and PD3= 20 plant m^2

3.3. Cultural and management practices

Land was prepared using a tractor by ploughing and discing a week prior to demarcation and planting of the experiments. Three rain gauges were installed in the experiment units to measure the amount of irrigation-water applied at Thohoyandou only. After planting, irrigation was applied in both experiments to enhance germination and good crop establishment. Supplementary irrigation was applied throughout the growing season when necessary. The irrigation schedule was dependent on the amount of rainfall received during the week of application.

Two seeds were sown per hole, with different levels of densities of 33, 25 and 20 plants m^{-2}. During planting phosphorus was applied at a rate of 90 kg P ha^{-1}. Weeding was done when necessary. Thinning was done 14 days after emergence to maintain the three designed densities. The pesticides (cypermethrin 200 EC (2mℓ/1ℓ) was applied during flowering as a control measure for pod borer at both sites.

3.4. Data collection of growth, yield components and yield.

3.4.1. Crop growth

Crop growth was assessed at both sites of the study. Three plants in each plot were randomly selected and tagged to determine plant height, and number of primary and secondary branches. The number of branches were determined by counting both primary and secondary branches from 21 days after emergence until physiological maturity at seven days intervals. Plant height measurements was also recorded from 21 days after emergence until physiological maturity. Heights of three tagged plants within an experimental unit were measured from the lower part of the stem to the highest leaflet using a tape measure and average height was calculated.

3.4.2. Grain yield and yields components.

Ten plants from the inner most rows from an area of 0.6 m, 0.8 m and 1m for 33, 25 and 20 plants/m^2, respectively were sampled in all experimental units for determination of grain yield of chickpea at harvest maturity. Plants were harvested at physiological maturity and pods were separated from the plant. To obtain number of pods per plant, total number of pods was divided by number of plants. Pods were counted and mass of the pods was determined. Pods were then shelled and weighed to determine number of seeds per pod by dividing number of seeds/number of pods. Seeds per plant was determined by calculating number of seeds/number of plants. 100 seed weight was obtained by counting three hundred seed weights from bulk of harvested seed and calculated and average was use.. Above ground biomass was determined at harvest maturity by sampling ten plants within each experimental unit. To determine aboveground dry biomass, plants harvested from the sample area were oven dried at 65℃ for 24 hours to constant weight and dry matter was measured using an electronic scale.

The grain yield was calculated by dividing grain seed weight/ harvested area. The mean grain yields was extrapolated to a hectare basis over the total cultivated area. Harvest index (HI) was calculated using the formula, HI = Grain yield/total aboveground biomass yield.

3.4.3. Soil moisture content

Immediately after crop emergence, access tubes were installed in the soil at depth of 110 cm in between the rows in each plot. Soil moisture was recorded from 14 days after emergence (DAE) until physiological maturity. A 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 depth. The standard count readings were taken and used to calculate the count ratio (count ration/standard count). Volumetric water content (Q_v) at each depth was calculated using equations 1-3 (Thangwana and Ogola, 2016).

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

Total crop evapotranspiration or crop water use (ET) was estimated using the standard water balance equation 1, (Howell et al., 1995).

ET=ΔS+R+I-D-R…… (4)

Where ET is the crop evaporation (mm), ΔS stands for change in soil moisture storage (mm), calculated as the difference in volumetric water content of the entire profile between the first and the last reading; P is precipitation/rainfall (mm), D the drainage and R the runoff. Drainage and runoff was assumed to be negligible (Ogola & Thangwana 2013; Ogola et al., 2013). WUE was determined for total biomass and grain yield by using equations 5 and 6, respectively.

Water use efficiency for biomass = WUE_b = $\frac{Biomass}{ET}$ …….. (5)

Water use efficiency for grain = WUE_{gy} =$\frac{Grainyield}{ET}$…… (6)

3.5. Weather data

Weather data for two sites were obtained, from automatic weather station located approximately 100 m (Thohoyandou) and 30 m (Syferkuil) from the experiments. The following variables were recorded each day during the experiments: rainfall (mm), maximum and minimum air temperatures (ºC), relative humidity (%), solar radiation (MJ m^{-2} d^{-1}) and evapotranspiration (mm) were recorded. The monthly total or mean variables over the cropping seasons at Thohoyandou are presented in (Table 3.1, Thohoyandou and Table 3.2 Syferkuil).

Table 3.1. Monthly mean temperature, solar radiation, total rainfall, relative humidity and evapotranspiration in Thohoyandou during winter 2015 and 2016.

Month/ Season	Solar radiation (MJ m^{-2} d^{-1})	Average T ^{O}C/ month	Relative humidity (%)	Rainfall (mm)	Evapotranspiration (mm)
Winter 2015					
May	14.84	20.1	62.43	0	92.1
June	12.48	16.3	61.06	1.01	82.2
July	13.05	17.3	58.74	0.76	81
August	15.22	19.13	55.79	1.52	94.5
September	15.55	21.02	64.78	102.86	92.2
Mean/Total	14.23	18.2	60.56	106.15	442
Winter 2016					
April	15.26	23.35	68.01	0.75	92.25
May	12.85	17.8	71.45	55.11	74.15
June	11.95	16.9	68.32	7.61	64.21
July	11.59	16.08	62.69	9.65	68.9
August	16.94	18.3	54.46	3.81	97.9
Mean/Total	13.72	18.5	64.99	76.93	397.41

3.6. Data analysis

Analysis of variance (ANOVA) was performed on measured parameters using the randomized complete block design model of Genstat software version17 (Table 3.3). Treatment mean separation was done where mean difference was significance using the least significant difference (LSD) test at 95% confidence level (α= 0.05).

Table 3.3. Schematic representation of partial analysis of variance

Source of variation	Degree of freedom
Replication	r-1=2
Genotypes (A)	a-1=3
Plant density (B)	b-1=2
Interaction (A x B)	(a-1) (b-1) =6
Error	(r-1) (ab-1) =22
Total	rabc-1 =35

CHAPTER 4: EFFECT OF PLANTING DENSITY AND GENOTYPE ON YIELD AND YIELD COMPONENTS OF FOUR CHICKPEA GENOTYPES HAVING CONTRASTING GROWTH PATTERNS.

4.1. Introduction

Chickpea (*Cicer arietinum*) is adapted to environmental stresses such as drought, high temperatures and poor soils and may thus be an important food security crop for smallholder farmers in the semi-arid tropics (Thangwana and Ogola, 2012). There is currently no commercial chickpea production in South Africa. However, a few small plots for research purposes in Limpopo and Mpumalanga Provinces. Although chickpea is not a common crop in South Africa there is a high demand and this may be due to its excellent nutritional value. Furthermore, its production in South Africa may lead to crop diversification and hence improvement of the productivity of sustainable agricultural systems. However, chickpea yield is determined by combination of suitable genotype and appropriate agronomic practices such as correct planting density in a given environment.

The use of plant density has been identified as one of the most important agronomic practices that increase yields and can facilitate aeration and light penetration into the plant canopy for optimizing rate of photosynthesis (Khan *et al.,* 2010). Too low or high plant density, beyond a certain limit, often adversely affects the crop yield. Optimum plant density for seed yield of chickpea has been studied by many researchers. However, the results from these studies were inconsistent. This could be due to the response of the plant to various agro-climatic conditions since planting density is location and genotype specific. Optimum planting density of a crop variety at one location may not apply at other locations. Therefore, determining appropriate planting density of crop variety at different locations before making conclusion may be one of the most important crop management activities for the enhancement of chickpea production and productivity.

Research has shown that growth of chickpea is affected by management strategies such as planting density and use of genotypes (Biabani, 2011). Production and productivity of the chickpea are also governed by environmental conditions, genotypic trait and

management of the crop. Hence, plant density differs from variety to variety, depending on seed size and plant growth habit. Compact, upright-growing chickpea responded better to increased plant density than the spreading type (Singh, 1981; Calcagno *et al*., 1988). The architecture of the genotype influence the planting density to be used, because different canopy structure may affect light interception, cumulative intercepted radiation and radiation use efficiency, and water use efficiency (Vanderpuye, 2010).

Even though the crop has high consumer demand due to its nutritional value, there is still no commercial production in South Africa. This may be due to lack of suitable varieties for different environmental conditions and recommended location specific planting densities. Furthermore, limited research work has investigated the effect of genotype and planting density on chickpea performance in the Limpopo Province and South Africa at large. There is no location and genotype specific recommendations on the planting density of chickpea in Limpopo Province. Therefore, the objective of the study was to determine the effect of genotype and planting density on yield and yield components of chickpea.

4.2. Material and Methods

The detailed description of material and methods are provided in chapter 3. However, a brief summary of this chapter is provided below. Four field experiments were conducted at two sites in winter 2015 and 2016; the University of Venda's Experimental Farm, in Thohoyandou, and at the University of Limpopo's Experimental Farm-Syferkuil, Limpopo Province, South Africa. Mean average summer day temperature at Syferkuil varies from 28 to 30°C while the area receives mean annual rainfall ranging from 400 to 600 mm (Thabang *et al*., 2013), and Thohoyandou receives an annual rainfall of ± 500 mm that falls predominantly in summer. The average minimum and maximum temperatures are between 18^{o}C and 31^{o}C (Tadross *et al*., 2006).The experiments consisted of a 3 x 4 factorial arrangement with three planting densities (20, 25 and 33 plants^{-2}) and four desi

chickpea genotypes (ACC# 1, 3, 4 and 7) arranged in a randomised complete block design replicated three times.

Plant height and number of branches were determined from three tagged plants per plot from the vegetative growth until physiological maturity. At harvest maturity, 10 plants from 0.6, 0.8 and 0.1 m^2 (33, 25 and 20 plants m^{-2}) of two inner crop rows from each plot were harvested. Pods were removed manually from the plant and counted to determine number of pods per plant and aboveground biomass. The pods were then threshed by hand to determine number of seeds per pod. All the seeds were weighed to determine grain yield (kg ha^{-1}) and from sub-samples of in seeds were used to determine 100 seed weight (100-SW). Harvest index was determined as the ratio of grain yield to aboveground biomass. The data obtained was subjected to ANOVA using the general linear model of Genstat 17th Edition. Significant differences between treatment means were compared using least significant of difference (LSD) at 5% level.

4.3. Results

4.1. Summary of the responses of measured parameters of the main factors and interaction for both sites are presented in (Table 4.1).

	Syferkuil			Thohoyandou					
Years	**2015**			**2016**					
	2015			**2016**					
Parameters	**G**	**PD**	**G*PD**	**G**	**PD**	**G*PD**	**G**	**PD**	**G*PD**	**G**
Plant height	**	ns	ns	**	ns	ns	**	Ns	ns	**
No. of Primary branches	Ns	ns	ns	ns	**	ns	ns	Ns	ns	ns
No. of Secondary branches	Ns	ns	ns	ns	ns	ns	ns	Ns	Ns	ns
No. of pods/plant	Ns	ns	ns	ns	ns	ns	ns	Ns	Ns	ns
No. of seeds/plant	Ns	ns	ns	ns	ns	ns	ns	Ns	Ns	ns
100-SW	Ns	ns	ns	ns	ns	ns	ns	Ns	Ns	ns
Grain yield (kg ha^{-1})	Ns	**	ns	ns	ns	ns	ns	Ns	Ns	ns
Plant biomass (Kg ha^{-1})	Ns	***	ns	ns	**	ns	ns	Ns	Ns	ns
HI	Ns	ns	ns	ns	ns	ns	ns	Ns	S	ns

ns= not significant, G= genotype, PD= planting density, G X PD= interaction of planting density and genotype, * (P<0.001) and ** (P<0.01).**

4.1. Summary of crop phenology

Days to emergence was recorded as the number of days from sowing to when 50% of the plants emerged in each plot. Similarly, number of days to flowering was recorded when 50% of the plants reached flowering stage. Days to maturity was recorded as the number of days from planting to the stage when 90% of the plant reached physiological

maturity, i.e. when the plants and the pods turned pale yellow in colour based on visual observation. The chickpea genotypes tested took between 70 to 90 days to reach physiological maturity (PM). There were no genotype differences to reach 50% flowering. However there were considerate differences in growth duration: ACC# 7 took 70 days to PM, ACC# 3 took 78 days to PM, and ACC # 4 took 81 days to PM whereas ACC # 1 took 89 days to PM. The growth duration recorded shows that the genotypes tested may not be suitable for winter production in the study area Syferkuil due to the incident of frost.

Table 4.2. Summary of planting, crop emergence and harvesting dates for winter 2015 and 2016.

	Syferkuil		**Thohoyandou**	
Activities	**2015**	**2016**	**2015**	**2016**
Planting	02 May 2015	15 April 2016	05 May 2015	19 April 2016
Crop emergence	09 May 2015	23 April 2016	13 May 2015	26 May 2016
Harvesting	10 Sept 2015	26 August 2016	15 Sept 2015	August 2016

4.2. Crop growth

4.2.1. Plant height

Analysis of variance shows that genotype significantly affected plant height at 84 and 118 days after emergence in 2015 at Syferkuil. Planting density did not affect plant height at all sampling dates (Table 4.3). At 84 DAE, genotype ACC#1 (41.1 cm) resulted in significantly (P≤0.05) higher plant height compared to genotypes, ACC# 4 (38.9 cm) ACC# 3 (31.1 cm) and ACC# 7 (27.8 cm). Performance of the genotypes followed similar trend, at 118 DAE where plant height varied from 28.9 cm (ACC#7) to (44 cm) ACC# 1 (Table 4.3).

In 2016, plant height at Syferkuil was significantly affected by genotype at all sampling dates (Table 4.4). The highest plant height was obtained at 114 DAE (66.6 cm) by ACC# 3 compared to ACC# 7 (60.5 cm), ACC# 1 (59.5 cm) and ACC# 4 (57.5 cm). It was observed that genotype ACC# 3 had the highest plant height in all sampling dates.

Planting density did not affect plant height in 2015 at Thohoyandou (Table 4.4). However, plant height was significantly (P≤0.05) affected by genotype at 56 and 63 DAE. At 56, ACC# 1 obtained the highest (41.1 cm) plant height compared to ACC# 4 (38.9 cm), ACC# 3 (31.7 cm) and ACC# 7 (27.8 cm). At 63 days after emergence, ACC# 1 (44 cm) obtained the highest plant height compared ACC# 4 (42.7 cm), ACC# 3 (35.5 cm) and ACC# 7 (28.9 cm) with the lowest plant height (Table 4.4).

The interaction between genotype and planting density did not affect plant height (Table 4.5). However, plant height was significant at 56 and 63 days after emergence in 2016. At 56 days after emergence genotype ACC# 1 had the highest plant height of 39.4cm compared to ACC# 4 (38.6cm) followed by ACC# 3 (31.1cm) and ACC# 7(27.4 cm).

4.2.2. Number of primary branches

The main effects of genotype and planting density and their interactions primary branches were not significant in 2015 at Syferkuil (Table 4.7). The interaction between genotype and planting density did not affect number of primary branches at Syferkuil in 2016 but, planting density had significant effect (Table 4.8). At 64 DAE primary branches were higher at low density (2.8) compared to optimum (2.6) and high density (2.1). Also at 70 DAE, highest number of primary branches were obtained at low density (2.8) compared to optimum (2.7) and high density (2.3). Similar trend was observed at 77 DAE (Table 4.8).

The main effects of genotype and planting density and their interactions had no significant influence on number of primary branches in 2015 at Thohoyandou (Table 4.9). Moreover, main effects of genotype and planting density and their interactions did not affect number primary branches in 2016 (Table 4.10).

4.2.2. Number of secondary branches

The main effects of genotype and planting density and their interactions did not significantly influence number of secondary branches (Table 4.11). At 64 DAE, highest number of secondary branches was recorded at low density (9.9) followed by optimum (9.1) and with the lowest (7.4) at higher planting density. Genotype and planting density

had no significant effect on secondary branches. The main effects of genotype and planting density and their interactions were not significant on secondary branches in 2016 (Table 4.13).

4.3. Yield components and grain yield

4.3.1. Above ground biomass (kg/ha^{-1})

Planting density showed a highly significant effect on biomass in 2015 (P≤0.01) and 2016 (P≤0.001) growing seasons at Syferkuil (Table 4. 14). Genotype had no significant effect on above ground biomass grain yield and yield components in both seasons. Biomass increased with the increase in planting density from 20 to 33 plants m^{-2}. In 2015, above ground biomass was 43% greater for 33 plants/m^2 and 84% compared to 20 plants m^{-2}. In addition, above ground biomass was 28 % greater at 25 plants m^{-2} compared 20 plants m^{-2}.

Genotype and planting density did not affect above ground biomass in 2015 at Thohoyandou (Table 4. 15). In contrast, planting density showed a highly significant (P≤0.01) effect on above ground biomass in 2016. Greatest biomass yield of 3477 kg ha^{-1} was observed in high compared to 1953 kg ha^{-1} at medium and 1500 kg ha^{-1}at low planting density (Table 4.15). Even though biomass was not significant in 2015, on average biomass was 122.4% greater in 2015 compared to in 2016.

From all the experiments, greater above ground biomass was observed in 2015 growing season at both sites.

4.3.2. Number of pods per plant

Genotype and planting density did not affect number of pods/plant at Syferkuil in 2015 and 2016 (Table. 4.14). On average higher numbers of pods were observed in 2015 (28 compared to 2016 (67) (Table 4.14).

The effects of genotype and planting density on number of pods/plants was not significant at Thohoyandou (Table 4.15). Number of pods/plant was greater in Genotype ACC# 1 (22.3) compared to ACC# 7 (20), ACC# 4 (18.1) and the lowest in ACC# 3 (17.9) in 2015.

Even though pods/ plant was not significant the results show a distinct variation where genotype ACC# 1 (48) had the lowest number of pods/plant compared to ACC# 3 (67), ACC# 7(67) and ACC# 4 (62) in 2016. Number of pods was greater in 2016 compared to 2015 (Table 4.15).

4.3.3. Number of seeds per plant

Effect of main treatments and their interaction did not affect number of seeds per pod at Syferkuil (Table 4.14) and Thohoyandou in both seasons (Table 4.15).

4.3.4. 100- Seed weight (100-SW)

The effect of genotype and planting density on 100-seed weight was not significant in both seasons at Syferkuil and Thohoyandou (Table 4.14).

4.3.5. Grain yield

The interaction of genotype and planting density did not affect grain yield in both experiments at Syferkuil (Table 4.14). In contrast, the effect of planting density on grain yield was significant ($P \leq 0.01$) in 2015 but not in 2016. Genotype did not affect grain yield in both seasons. Maximum grain yield of 2642 kg ha^{-1} was recorded at high density compared to 1864 kg ha^{-1} with the lowest grain yield of 1375 kg ha^{-1} at low density. Grain yield was 42% greater at high compared to medium and 92% to low density (Table 4.14).

Even though planting density did not have significant effect on grain in 2016, grain yield was highest at highest (879 kg ha^{-1}) compared to medium (634 kg ha^{-1}) and low (501 kg

ha^{-1}) planting density. Grain yield was 62% greater in 2015 compared to 2016 at high density (Table 4.15).

Genotype did not affect grain yield in both seasons in Thohoyandou (Table 4.16). However grain yield was significantly (P≤0.01) affected by planting density in 2016 but not in 2015; grain yield was recorded at high density (1724 kg ha^{-1}) compared to medium (982 kg ha^{-1}) and low density (680 kg ha^{-1}). Grain yield was 76% greater at high compared to medium and 154% to low density. Grain yield was 26% higher in 2016 compared to 2015.

4.3.6. Harvest index

The effects genotype and planting density on HI at both sites and in the two seasons (Table 4.14).

4.3.7. Crop growth

Plant height

Plant height varied with genotype at 84 and 118 DAE. This may be due to variation in the growth pattern of the genotypes used in the area of study. Genotype ACC# 1 which showed the highest plant height exhibited the erect growth habit, this could be due to less interference among branches since they grows upright. Branches growing erect have the tendency of using high amount of light intercepted by a single branch which result in increased internode length. Qureshi et al., 2004 reported significant variation for growth habit and plant height.

Number of primary branches

Branching is basically a genetic character and plays an important role in enhancing seed yield. Planting density had significant effect on number of primary branches in 2016 at Syferkuil. The number of primary branches increased with the decrease in planting density. The reduction number of primary branches at high density may be due to

increased plant competition for resources such as intercepted light, where overlapping canopies do not access enough sunlight for photo assimilation. Similarly, Bakry et al. (2011) where they reported that the number of primary branches decreased with the increase in density of chickpea. Shamsi (2009) reported that the numbers of branches plant^{-1} were significantly affected by different plant density. High number of primary serves as a primary indicator for the development of secondary branches, hence the intercepted radiation.

Number of secondary branches

The number of secondary branches determines the total number of leaves, and hence the total photosynthetic area. Number of secondary branches were significantly affected by planting density in 2016 at Thohoyandou. The increase in number of primary branches contributed greatly to the increase in secondary branches. Number of secondary branches increased with the decrease in planting density. Shamsi (2009) reported that the numbers of branches plant^{-1} were significantly affected by different plant density. Similar results were found by Singh *et al*., 1988, the significant variation on primary and secondary branches. These results suggest that chickpea genotypes tested have some capacity to compensate for low plant population growth through enhanced growth.

4.3.8. Yield and yield components

Plant biomass (kg ha^{-1})

The analysis of variance revealed that planting density showed a highly significant (P≤0.05) effect on above ground biomass in 2015 and 2016 growing seasons at Syferkuil. Genotype had no significant effect on above ground biomass in both seasons. Biomass increased with the increase in density because of high number of plants per unit area. This is in agreement with Felton *et al*., 2001, who reported that dry matter production was highest at high planting density. Again the increase in plant height which was significant in 2015 could have contributed to the increase in above ground biomass. This may mean that plants at high density have greater use of natural resources and hence the ability to increase its yield components. Shamsi *et al*. (2010) further added that high density

provokes fast growth of canopy in area unit which in turn ejects available stored water in soil.

In 2016 were grain yield was not significant, the plant may have directed all its consumable assimilates to the vegetative growth. Hence there was less number of pods per plant during that season. The increase in aboveground biomass was attributed to the significant in plant height which influenced high plant to plant competition and led to greater utilization of available natural resources.

Above ground biomass was not significant in 2015 at Thohoyandou. Poor crop establishment due to shortage of water and irrigation soon after planting. Planting density had significant effect on above ground biomass at Thohoyandou in 2016. These results suggests that chickpea biomass primarily responses to moisture stress ahead of others factors. The biomass amounts obtained in this study ranged from 1500 kg ha^{-1} at low to 5344 kg ha^{-1} at high planting density and from 1861 kg ha^{-1} by ACC# 1 to 4493 kg ha^{-1} for ACC# 3. These results levels are much higher than those reported in the study by Lusiba et al., (2018) at the same study site. The biomass levels suggest that chickpea has potential to produce biomass levels that can impact livestock feeding or soil fertility amelioration for smallholder farmers with lack of resources, if ploughed in.

Grain yield (kg ha^{-1})

Grain yield is ultimate outcome of various processes such as physiological, biochemical and phenological taking place in plant system. The effect of planting density on grain yield was not significant at Syferkuil and Thohoyandou in 2016 and 2015 growing seasons. In contrast planting density had significant effect ($P \leq 0.001$) on grain yield at Syferkuil in 2015 and Thohoyandou in 2016. Grain yield varied significantly ($P \leq 0.001$) between sites (Thohoyandou and Syferkuil) and seasons (2015 and 2016). Grain yield was 470% greater at Syferkuil (2642 kg ha^{-1}) compared to Thohoyandou (464 kg ha^{-1}) in 2015 at high planting density. In contrast, grain yield was 96% lower at Syferkuil (879 kg ha^{-1})

compared to Thohoyandou (1724 kg ha^{-1}) in 2016. Grain yield was 201% greater (2642 kg ha^{-1}) in 2015 compared to (879 kg ha^{-1}) in 2016 at Syferkuil. However there was no site and treatment interaction. Farshadfar *et al*. (2013), reported that crop growth and development may be influenced by environmental conditions.

Grain yield increased with the increase in planting density at Syferkuil in 2015. The significant increase in grain yield at high planting density indicated a greater partitioning of resources and continuous contribution in vegetative growth throughout the growing season and this was also observed in the high biomass. Similarly, Gan *et al*. (2003) reported that high planting density increases seed yield in areas with a short growing season. This was in line with the results of Thangwana and Ogola, (2012) at the location of the study where grain yield was greater at the high planting density compared to the low planting density. In contrast, study conducted elsewhere reported that plant densities from 33 to 40 plants m^{-2} had no significant effect on yield and yield components (Ali and Singh (1999).

The non-response of grain yield in 2016 at Syferkuil was probably due to the frost damage which occurred during the flowering and early stages of pod initiation and led to high level of floral abortion and failure to set pods. The minimum temperatures went below 2 degree Celsius (Table 4.3.8.1). This probably resulted in plants directing assimilates to regrowth rather than pod filling. Frost (freezing temperatures) is considered to be one of the most important production constraints in chickpea production causing flower sterility and pod abortion (Singh and Jana, 1993; Maqbool et al., 2010).

In the current study, frost occurred just after pod initiation and it caused pods to dry and eventually led to dropping of pods from the plants. Chickpea has an indeterminate growth habit, which implies that the even after frost incident, the crop received more rain which enhanced continuous growth. This resulted in the reduced grain yield in 2016 being 300% lower compared to the grain yield in 2015. The indeterminate growth habit of the crop probably led partitioned assimilates to aboveground biomass instead of reproductive growth. In addition, the non-significance of grain yield in 2016 at Syferkuil was probably due to late harvesting as most early matured pods were rotten and others fell down due to high rainfall received in September (32.26 mm) which occurred when the crop has

reached physiological maturity before harvesting. Similarly, Thangwana and Ogola (2012) reported that high amount of rainfall caused uneven yield loss at harvest maturity.

Genotype and planting density did not affect biomass, grain yield and yield components in 2015 at Thohoyandou. The non-significant effect of planting density and genotype could be due to low rainfall received and poor irrigation system (low pressure) from early stages until physiological maturity. The non-significant response of grain yield to genotype and planting density in 2015 at Thohoyandou could be due to the bird's damage set. This occurred at early stages of podding when pods where still soft and that made it easy for the birds to eat the seeds inside.

Genotype had no effects on grain yield at Thohoyandou in 2016. Grain yield increased with the increase in planting density. Machado *et al*. (2006) reported that higher planting density increased seed yield in chickpea when moisture was not a limiting factor. In agreement with this, Gan *et al*. (2002) found that seed yields of desi and kabuli chickpea increased with the increases in planting density from 20 to 50 plants m^{-2}. Similar results were reported at the current study area, where grain yield increased from a density of 20 to 33 plant m^{-2} (Thangwana and Ogola, 2012).

During 2016 growing season, the crop received adequate moisture during crop establishment which increased as the crop grew compared to the low rainfall received in 2015 compared to previous years at the study area. Grain yield was 26% higher in 2016 compared to 2015. Planting density principally depends on environmental conditions, suitable genotype and soil water availability. It can be tentatively concluded that planting density levels used in the study had not reached the threshold level at study area with maximum efficient use of natural resources which include; maximum light interception, better aeration, hence greater photosynthetic activity.

Harvest index (HI)

Harvest index is a measure of physiological productivity potential of a certain genotype under suitable environmental conditions. The effect of planting density, genotype and their interactions did not affect HI at both locations and seasons. These results may be due to the effect of frost on biomass partitioning. Sharar *et al*. (2001) reported non-

significant effect of seeding densities on HI of chickpea. Similarly, Thangwana and Ogola (2012) and Naim *et al.* (2015) reported that planting density had no significant effect on HI in their winter experiment.

Table 4.3.8.1. Minimum and maximum temperature at Syferkuil in 2016 during the occurrence of frost

Date	Maximum ºC (Tx)	Minimum ºC (Tn)
05 Aug 2016	21.6	-0.81
06 Aug 2016	26.1	-0.35
07 Aug 2016	26.3	1.4
08 Aug 2016	20.2.	1.93

Table 4.3. Effect of genotype on plant height (cm) during growth of chickpea at Syferkuil in 2015.

Treatments	**28 DAE**	**39 DAE**	**44 DAE**	**55 DAE**	**84 DAE**	**118 DAE**
Genotypes						
ACC #1	13.3	19.8	22.7	30.7	41.1^{c}	44^{c}
ACC #3	14.4	21.3	25	28	31.1^{ab}	33.5^{b}

ACC #4	12.4	20.7	20.8	26	38.9[b]	42.7[bc]
ACC #7	10.2	16.6	19.3	21	27.8[a]	28.9[a]
LSD	-	-	-	-	8.08	8.8
CV (%)	0.5	1.4	3.9	3	4.4	3.8
Genotype	Ns	ns	ns	ns	**	**

Means followed by the same letter are not significantly different, *** (P<0.001), ** (P<0.01) and *(P<0.05), CV (coefficient of variation).

Table 4.4. Effect of genotype on plant height (cm) during growth of chickpea at Syferkuil in 2016.

Treatments	**64 DAE**	**77 DAE**	**84 DAE**	**91 DAE**	**107 DAE**	**114 DAE**
Genotypes						
ACC #1	40.9bc	48.7b	50.6b	53.2b	58b	59.5bc
ACC #3	45.5c	53.9c	56.4a	60.3a	63.3c	66.6c
ACC #4	38,1a	45.1a	47.1c	50c	55.1a	57.4a
ACC #7	39.6ab	48.1b	50.4b	53.8b	58.8b	60.5b
LSD	3.59	3.89	4.19	5.0	5.21	5.3
CV (%)	5.1	2.6	2.6	2.3	2.0	1.7
Genotype	**	**	**	**	**	**

Means followed by the same letter are not significantly different, *** (P<0.001),

** (P<0.01) and *(P<0.05), CV (coefficient of variation)

Table 4.5. Effect of genotype on plant height (cm) during growth of chickpea at Thohoyandou in 2015.

Treatments	21 DAE	27DAE	35DAE	42DAE	49DAE	56DAE	63DAE
Genotypes							
ACC# 1	15.06	18.59	22.7	27.7	31.4	41.1c	44cd

ACC# 3	16.48	17.63	25	28.7	28.7	31.7b	35.5b
ACC# 4	14.17	19.70	20.8	24.9	29	38.9bc	42.7c
ACC# 7	11.69	15.04	19.3	21.3	25	27.8a	28.9a
Planting density							
33 plants/m2	14.07	18.59	20.9	24	26	32.4	35.3
25 plants/m2	14.85	19.61	22.8	26.4	31.1	35.5	37.2
20 plant/m2	14.12	16.83	22.2	26.6	28.5	36.8	39.3
LSD	4.02	4.3	6.13	6.5	8.13	8.05	7.62
CV (%)	0.9	8.4	3.9	6.5	0.5	4.4	3.8
Genotype	Ns	ns	ns	ns	ns	**	**

Means followed by the same letter are not significantly different, *** (P<0.001), ** (P<0.01) and *(P<0.05), CV (coefficient of variation).

Table 4.6. Effect of genotype on plant height (cm) during growth of chickpea at Thohoyandou in 2016.

Means followed by the same letter are not significantly different, *** (P<0.001), ** (P<0.01) and *(P<0.05), CV (coefficient of variation)

Treatment	14DAE	28DAE	32DAE	39DAE	46DAE	52DAE	59DAE
Genotype							
ACC# 1	15.07	20.4	23.7	28.1	32.4	39.4cd	43.4bc
ACC# 3	16.08	20.3	22.9	26.3	28.9	31.1b	33.6b
ACC# 4	13.03	19.7	19.7	25.3	29.1	38.6c	42.8b
ACC# 7	11.63	15.5	18.5	20.6	23	27.4a	29a
LSD	-	-	-	-	-	9.12	9.47
CV (%)	1.6	19	3.4	2	0.1	3.8	2.9
G	Ns	ns	ns	ns	ns	**	**

Table 4.7. Effect of genotype and planting density on primary branches during growth of chickpea at Syferkuil, 2015 growing season.

Treatments	64 DAE	78 DAE	85 DAE	118 DAE
Genotype				
ACC# 1	6a	9.6	11.8	13.3

ACC# 3	10.4	12.6	14.3	16.1
ACC# 4	7.6	9.9	12.7	13.5
ACC# 7	9	12.1	14.0	14.9
LSD	-	-	-	-
Planting density				
33 Plants/m^2	9.4	12.5	15.4	16.1
25 plant/m^2	7.8	10.3	12.3	13.8
20 plants/m^2	7.6	10.3	11.9	13.4
LSD	-	-	-	-
CV	19.1	15.8	14.5	11.4
G	ns	ns	ns	Ns
PD	ns	ns	ns	Ns
G*PD	ns	ns	ns	ns

Means followed by the same letter are not significantly different, *** (P<0.001), ** (P<0.01) and *(P<0.05), CV (coefficient of variation).

Table 4.8. Effect of genotype and planting density on primary branches during growth of chickpea at Syferkuil, 2016 growing season

Treatments	64 DAE	70 DAE	77 DAE	84 DAE	91 DAE	98 DAE	107 DAE	114 DAE
Genotype								
ACC# 1	2.6	2.6	2.6	2.7	2.7	2.8	2.9	2.9

ACC# 3	2.4	2.6	2.6	2.7	2.7	2.8	2.9	2.9
ACC# 4	2.4	2.5	2.5	2.5	2.6	2.6	2.9	2.9
ACC# 7	2.6	2.8	2.8	2.7	2.9	3	3	3
LSD	-	-	-	-	-	-	-	-
Planting density								
33 plants/m^2	2.1b	2.3b	2.3b	2.4	2.a	2.5	2.7	2.7
25 plants/m^2	2.6ab	2.7ab	2.7ab	2.7	2.8	2.8	3	3
20 plants/m^2	2.8a	2.8a	2.8a	2.9	2.9	3	3	3.1
LSD	0.46	0.46	0.46	0.52	0.44	0.40	0.33	0.32
CV%	6.8	8.5	8.6	7.9	8.4	10	10.3	10.8
G	ns	ns	ns	ns	ns	ns	ns	ns
PD	**	**	**	ns	ns	ns	ns	ns
G*PD	ns	ns	ns	ns	ns	ns	ns	ns

Means followed by the same letter are not significantly different, *** (P<0.001), ** (P<0.01), ns 9not significant and CV (coefficient of variation).

Treatments	21DAE	27DAE	35DAE	42DAE	49DAE	56DAE	63DAE
Genotype							
ACC# 1	1.29	1.59	2	2.26	2.74	2.96	3.15

ACC# 3	1.07	1.33	1.52	1.74	2.33	2.48	2.59
ACC# 4	1.18	1.48	1.67	1.67	2.67	2.67	2.88
ACC# 7	1.1	1.55	2	2.07	3.33	3.89	4.04
LSD	-	-	-	-	-	-	-
Planting density							
33 plants/m2	1.02	1.36	1.69	1.81	2.36	2.5	2.72
25 plants/m2	1.16	1.41	1.72	1.78	2.86	3.08	3.25
20 plants/m2	1.3	1.69	2	2.22	3.08	3.42	3.50
LSD	-	-	-	-	-	-	-
CV (%)	16.7	11.4	12.2	10.8	16.8	16.8	7.3
G	ns	ns	ns	ns	ns	ns	ns
PD	ns	ns	ns	ns	ns	ns	ns
G*PD	ns	ns	ns	ns	ns	ns	ns

Table 4.9. Effect of genotype and planting density on primary branches during growth of chickpea at Thohoyandou, 2015 growing season.

Means followed by the same letter are not significantly different, *** (P<0.001), ** (P<0.01) and *(P<0.05), CV (coefficient of variation).

Table 4.10. Effect of genotype and planting density on primary branches during growth of chickpea at Thohoyandou 2016 growing season.

Treatments	28DAE	42DAE	49DAE	56DAE
Genotype				
ACC# 1	2.0	2.7	2.9	3.1
ACC# 3	1.5	2.3	2.4	2.5
ACC# 4	1.6	2.6	2.6	2.8
ACC# 7	2.03	3.3	3.8	4.03
LSD	-	-	-	-
Planting density				
33 plants/m^2	1.6	2.3	2.5	2.7
25 plants/m^2	1.7	2.8	3.08	3.2
20 plants/m^2	2.0	3.0	3.4	3.5
LSD	-	-	-	-
CV (%)	12.2	16.8	11.3	7.3
G	ns	ns	ns	ns
PD	ns	ns	ns	ns
G*PD	ns	ns	ns	ns

Means followed by the same letter are not significantly different, CV (coefficient of variation), ns= not significant.

Table 4.11. Effect of genotype and planting density on secondary branches during growth of chickpea at Syferkuil, 2015 growing season.

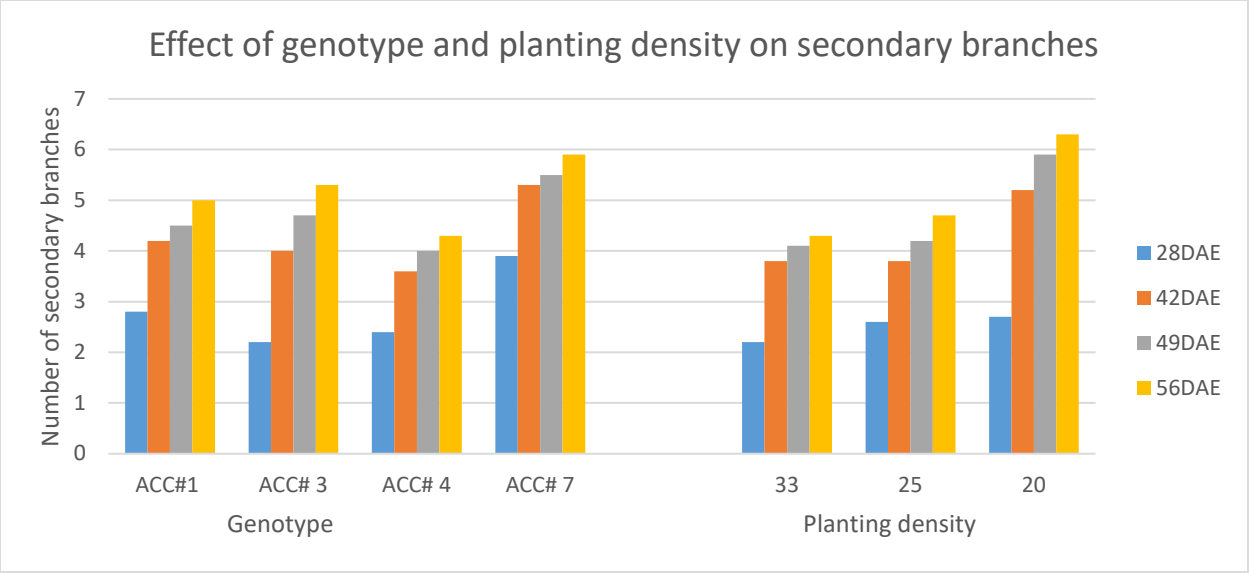
Treatments	64 DAE	78 DAE	84 DAE	118 DAE
Genotype				
ACC# 1	6	9.6	11.8	13.3
ACC# 3	10.4	12.6	14.3	16.1
ACC# 4	7.4	9.9	12.7	13.5
ACC# 7	9	12.1	14	14.9
LSD	-	-	-	-
Planting density				
33 plants/m^2	9.4	12.5	15.4	16.1
25 plants/m^2	7.8	10.3	12.3	13.8
20 plant/m^2	7.6	10.3	11.9	13.4
LSD	-	-	-	-
CV	19.1	3.65	14.5	11.4
Genotype	ns	ns	ns	ns
Planting density	ns	ns	ns	ns
G*PD	ns	ns	ns	ns

Means followed by the same letter are not significantly different, ns =not significant and CV (coefficient of variation).

Table 4.12. Effect of genotype and planting density on secondary branches during growth of chickpea at Syferkuil in 2016.

Treatments Genotype	64 DAE	78 DAE	84 DAE	118 DAE
ACC# 1	6	9.6	11.8	13.3
ACC# 3	10.4	12.6	14.3	16.1
ACC# 4	7.4	9.9	12.7	13.5
ACC# 7	9	12.1	14	14.9
LSD	-	-	-	-
PD				
33 plants/m^2	9.4	12.5	15.4	16.1
25 plants/m^2	7.8	10.3	12.3	13.8
20 plants/m^2	7.6	10.3	11.9	13.4
LSD	-	-	-	-
CV	19.1	3.65	14.5	11.4
G	ns	ns	ns	ns
P	ns	ns	ns	ns
G*PD	ns	ns	ns	ns

CV (coefficient of variation), ns (not significant)



Graph 4.1. Effect of genotype and planting density on number of secondary branches during growth of chickpea at Thohoyandou in 2015.

Table 4.13. Effect of genotype and planting density on secondary branches during growth of chickpea at Thohoyandou in 2016.

Treatment	64 DAE	70 DAE	77 DAE	84 DAE	98 DAE	107 DAE	114 DAE
Planting Density							
33 Plants/m^2	7.4b	9.6b	12.5c	14.3c	19.9c	22c	24.1c
25 plants/m^2	9.1a	11.7ab	15.2b	17.9b	23.6b	26.2	28.2b
20 plants/m^2	9.9a	12.9a	17.1a	20.3a	27a	30.7a	32.6a
LSD	1.89	3.1	3.74	4.39	5.30	5.88	5.97
CV (%)	7.9	10.1	8.2	8.7	7.9	7	7
PD	**	ns	**	**	**	**	**

Means followed by the same letter are not significantly different, ** (P<0.01), CV (coefficient of variation), and ns (not significant)

Table 4.14. Effect of planting density and genotype on above ground biomass, grain yield and harvest index at Syferkuil in winter; 2015 and 2016.

Year	2015						2016					
Treatments	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index	Number of pods per plant	Number of seeds per plant	100 seed weight (g)	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index	Number of pods per plant	Number of seeds per plant	100 seed weight (g)
Genotypes												
ACC# 1	3291	1603.1	0.47	48	50.01	21.06	3119	807	0.23	22.3	10	42.9
ACC# 3	4495	2169	0.49	67	76.4	20.41	2778	527	0.18	17.9	17.1	33.8
ACC# 4	3819	1859	0.44	62	66.4	20.22	2693	644	0.23	18.1	12	40.5
ACC#7	4382	2212	0.50	66	79.1	22	3658	708	0.2	19.9	23	48.1
PD												
33 plants m^{-2}	5344^{c}	2642.4^{c}	0.49	66	74.2	20.2	3701^{c}	879	0.21	19.7	12.3	38.3
25 plants m^{-2}	3740^{b}	1864.3^{b}	0.49	62	70	21.13	3022^{b}	634	0.20	21.4	16	41.8
20 plants m^{-2}	2906^{a}	1374^{a}	0.48	56	60	21.11	2013^{a}	501	0.22	17.5	19	43.9
LSD	1408	743.04	-	-	-	-	-	-	-	-	-	-
Genotype	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PD	**	**	ns	ns	ns	ns	**	ns	ns	ns	ns	ns
G*PD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	4.1	8.3	8.2	10.1	7.4	5.2	33	38	15.5	26.3	27	9.3

Means followed by the same letter are not significantly different, ** (P<0.01) and *(P<0.05), CV (coefficient of variation)

Table 4.15. Effect of genotype and planting density on yield and yield components at Thohoyandou in 2015 and 2016 winter growing seasons.

Year	2015						2016					
Treatments	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index	Number of pods per plant	Number of seeds per plant	100 seed weight (g)	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index	Number of pods per plant	Number of seeds per plant	100 seed weight (g)
Genotypes												
ACC# 1	3687.2	347	0.8	23	12.8	21.12	1861	911	0.49	24.6	30	52.1
ACC# 3	3280.3	432.4	0.10	20	18.2	23.03	2281	1302	0.54	26.5	33.1	65.1
ACC# 4	3707.6	417.5	0.10	18.1	13.5	22	3172	1364	0.39	25.6	33.2	50.3
ACC# 7	4389.9	587	0.13	19.9	25.1	19.8	1926	937	0.50	21.1	28	46.1
PD												
33 plants m^{-2}	4256.4	462.6	0.10	20	13.7	19.5	3477[c]	1724[a]	0.50	31.8	38	59.1
25 plants m^{-2}	3570.1	402.8	0.10	21.4	17.4	22.6	1953[b]	982[b]	0.50	23.1	30.2	54.9
20 plants m^{-2}	3469.3	470.4	0.11	17.5	21.1	22.8	1500[a]	680[c]	0.44	18.4	25	46.2
LSD	2249	404	0.04	9.3	16.9	2.7	1386	351	0.10	12.60	15.1	27.7
Genotype	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
PD	ns	ns	ns	ns	ns	ns	**	**	ns	ns	ns	ns
G*PD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	16.9	24	23	16.5	25	7.3	26	24.8	10.4	15.8	27	22.8

Means followed by the same letter are not significantly different, ** (P<0.01) and *(P<0.05), CV (coefficient of variation

Conclusion

The effect of genotype on plant height was significant in both seasons and locations. Number of primary branches was significantly affected by planting density at Syferkuil in 2016 only. In contrast, secondary branches were significant at Thohoyandou in 2016. At low density, genotype ACC# 3 had high number of secondary branches at Thohoyandou and genotype ACC# 7 had greater number of secondary branches at Syferkuil. The results of these study shows that there was no consistency in the performance of these genotypes across sites. It may be suggested that long term research may be conducted for further investigation of these genotypes at same study sites.

Grain yield increased with the increase in planting density at Syferkuil in 2015 and Thohoyandou in 2016. This results clearly shows that environment play an important role on yield and yield components of chickpea. In 2016, grain yield was high at Syferkuil compared to Thohoyandou vice versa in 2016. The increase in planting density from 20 /to 33 plant m^{-2} increased yield and yield components. It can be concluded that planting density of 33 plants m^{-2} is an optimum in the areas of the study with maximum efficient use of natural resources which include maximum intercepted light, better aeration, hence greater photosynthetic activity.

Thus the use of high planting density may enhance chickpea production and productivity at the current study locations. Therefore, further studies that Thohoyandou may adopt 33 plant m^{-2} as the optimum density and for Syferkuil, long term experiments are required before making any conclusions.

CHAPTER 5: THE EFFECT OF GENOTYPE AND PLANTING DENSITY ON WATER USE EFFICIENCY OF CHICKPEA GENOTYPES IN LIMPOPO, SOUTH AFRICA

5.1. Introduction

Crop production and productivity in arid and semi-arid regions of Limpopo, South Africa, is limited by low and erratic rainfall, high temperatures and poor soils. These conditions are expected to get worse with the predicted climate change. For example, climate assessments for Southern Africa concluded that the sub-region is likely to become warmer and drier; a temperature increase of 2°–5°C is predicted over the coming decades and increasingly variable rainfall is anticipated (IPCC, 2007). Chickpea production is at low levels in major producing countries (Millan *et al*., 2006) and this may be due to various production constraints. This indicates a need to improve chickpea production through enhanced crop management and suitable genotypes with good water extraction and water use efficiency.

The pattern of water extraction contributes to yield determination in crops grown under limited soil water, particularly indeterminate crops such as chickpea, as the maintenance of transpiration and C-fixation during the seed-filling period is crucial for yield (Kato et al., 2008). However, the extraction of water may depend on crop genotypes used and the planting density in a given environment. Bramley *et al*., (2012) reported that canopy size and architecture in the green house will influence WUE and transpiration through its effects on ET and evaporation, whereas in the field it affects ET through soil moisture evaporation.

Genotypes with varying growth habits produce different canopy cover which may influence the evaporation of water from the soil beneath the canopy (Esc), root development, distribution, density and exploitation of water stored at lower soil depth. Thus, the choice of the genotype may influence effective water use because of species differences in both pattern and extent of root and shoot growth (Ogola and Thangwana, 2013). Furthermore, both the pattern of water extraction and the total water extracted are influenced by shoot biomass and rooting depth and will thus tend to vary with genotype (Ogola and Thangwana, 2013). Therefore, genotypes that may retain soil moisture and

enhance water extraction/supply for reproductive and grain filling stages would be appropriate for crop growing on predominantly stored soil moisture.

High planting density is one way of achieving a dense canopy soon after sowing (Ogola *et al*., 2005). Therefore, the use of genotypes and planting density that can enhance early ground cover which may influence direct evaporation from the soil surface (Esc) and transpiration coupled with increased water use may be beneficial. Improved production from a limited water supply can result from an increase in the total amount of water by the crop, and/or an improved use efficiency of the water available (Ogola *et al.,* 2013). The use of management practices that allow more soil water to be transpired, such as population density and selection of suitable genotypes, may improve overall water use efficiency, and hence crop productivity (Ogola *et al*., 2013). Planting density is identified as one of the most important cultural practices in determining grain yield in arid and semi-arid environments. Studies elsewhere reported that the increase in chickpea grain yield at high density was due to increased water use and water use efficiency (Biabani, 2011). Similarly, studies at the study area by Ogola and Thangwana, reported increase in crop water use with increase in planting density. Thus, manipulation of planting density in dry environments may improve grain yield through increased planting density.

Changes in crop management may influence the increase in the volume of water transpired (T) by a crop and hence increasing water use efficiency (Ogola *et al*., 2002; 2013). The response of water use and water use efficiency to various management practices of chickpea genotypes study has been reported (Ogola *et al*., 2013; Ogola and Thangwana, 2013; Lusiba *et al*. 2018). However, information on water use and water use efficiency of chickpea genotypes with contrasting growth habits is scanty. Therefore, the objective of the study was to determine the effect of genotype and planting density on water use and water use efficiency of four chickpea genotypes having contrasting growth habits.

5.2. **Materials and methods**

5.2.1. **Study location**

Detailed description of details of materials and methods are given in chapter three. However a summary is given below. Field experiments were carried at the University of Venda situated in Thohoyandou (latitude and longitude 30°15'50.3'' E and 22°35'14.0''S, respectively, and altitude 595 a.m.s.l), in Limpopo Province, Republic of South Africa on 05 May 2015 and 19 April 2016.

5.2.2. **Field experimental and sampling design**

The experiments consisted of a factorial combination of three planting density levels (20, 25 and 33 plants m^{-2}) and four desi chickpea genotypes (ACC# 1 and ACC# 4 characterized by erect canopy structure and ACC# 3 and ACC#7 which exhibit prostrate growth habit), arranged in a randomized complete block design and replicated three times. Sowing was done in rows that were 30, 40 and 50 cm apart for planting density of 33, 25 and 20 plants m^{-2}, respectively.

5.2.3. **Above ground biomass and grain yield**

Above ground biomass was determined at harvest maturity. Ten plants were cut at ground level from the two innermost rows from a length of 0.6m, 0.8m and 1m for 33, 25 and 20 plantsm^{-2}, respectively. The samples were oven dried at 65℃ until constant weight and dry matter was measured using an electronic scale. Pods were threshed to determine number of seeds per pod as well as seeds per plant. The grain yield was extrapolated to a hectare basis.

5.2.4. **Crop water use**

Crop water use was determined by measuring soil moisture content at 7 day intervals using a neutron probe. Measurements were taken between 20 and 75 DAE in 2015 and from 20 and 90 DAE in 2016. The 16-counts readings were taken at 30, 60 and 90 cm soil depths by lowering the probe into the access tube. On each occasion, the probe was in access tubes inserted at 1.1m deep in each experimental unit soon after crop emergence. Prior to each day's measurements, a standard count was taken and used to calculate count ratios (count readings/standard count). Volumetric water content (Qv) at each depth was calculated using equations 1-3 (Thangwana and Ogola, 2016).

0.30 m: Qv = 0.0818x + 0.0268 (1)

0.60 m: Qv = 0.3227x + 0.2733 (2)

0.90 m: Qv = 0.3736x – 0.3297 (3)

Total crop evapotranspiration or crop water use (ET) was estimated using the standard water balance equation (Howell et al., 1995).

ET= ΔS+R+I-D-R (4)

Where: ET is the crop evapotranspiration (mm), ΔS stands for change in soil moisture storage (mm), calculated as the difference in volumetric water content of the entire profile between the first and the last neutron probe reading; P is precipitation/rainfall (mm), D the drainage and R the runoff. Drainage and runoff were assumed to be negligible (Ogola & Thangwana 2013; Ogola *et al*., 2013; Lusiba *et al*., 2018). WUE was calculated as the ratio of crop biomass or grain yield (GY) to total crop water use (equations 5 and 6, respectively).

Water use efficiency for biomass = WUE_b = $\frac{Biomass}{ET}$ (5)

Water use efficiency for grain = WUE_g = $\frac{GY}{ET}$ (6)

Where WUE_b is water use efficiency of biomass production; and WUE_g- water use efficiency of grain yield production.

5.2.5. **Data analysis**

Data obtained were subjected to ANOVA using the general linear mode of Genstat 17th Edition. Significant differences between treatment means were compared using least significant difference (LSD) at 95% confidence level (α= 0.05).

5.3. **Results**

5.3.1. **Weather data**

The total rainfall (106.15 mm) received during the growth period of the crop (May 2015-September 2015) was 33.6% greater than total rainfall (76.93 mm) received during crop growth in 2016 (May 2016-September 2016) (Table 5.1). Similarly, total evaporation and solar radiation were greater in 2015 compared with 2016. In contrast, relative humidity was greater in 2016 compared with 2016. (Figure 3.1).

5.2.1. **Crop water use**

Genotype did not affect the pattern of water extraction at 30, 60 and 90 cm soil depths in 2015 (Fig 1 a-c). The pattern of soil moisture extraction varied with genotype at 30cm depth in 2015 (Fig 1a). ACC# 7 extracted more water from the soil between 20 and 60 DAE (Fig. 1a). Soil moisture content was constant between 20 and 45 DAE (Fig. 2c), followed by a steep decline between 60 and 75 DAE (Fig 2b-c).

Planting density did not affect the pattern of water extraction at all soil depths in 2015 (Fig 2 a-c). However, at 30 cm depth the rate of soil moisture depletion was greater at 25 plants m^{-2} compared to 20 and 33 plants m^{-2} between 20 and 60 DAE (Fig. 2a). Moreover, there was a steep decline in soil moisture between 30 and 60 DAE and a sharp increase between 60 and 75 DAE (Fig 2a). At 60 cm depth, there was a steady decline between 20 and 45 DAE, sharp increase between 45 and 60 DAE and steep decline between 60 and 75 DAE (Fig. 2b). On average, soil moisture was fairly constant between 20 and 45 DAE, with the sharp increase between 45 and 60 DAE and steep decline between 60 and 75 DAE (Fig. 2c).

Genotype and planting density did not affect the pattern of water extraction at all depths in 2016 (Fig. a-c). Genotypes did not show any clear pattern of water extraction at 30 cm depth in 2016. Although ,there was no clear pattern of water extraction between 20 and 45 DAE at 60 and 90 cm depth , soil moisture content declined between 45 and 60 DAE and a sharp increase at 75 DAE (Fig. b-c). ACC# 7 extracted more soil water from the soil at 60 DAE at 60 cm depth (Fig 4b). There was a steady increase in soil moisture content at 20 and 45 DAE (Fig. 4c). In contrast, ACC# 3 extracted more water from the soil at 60 DAE at 90cm (Fig. 4c).

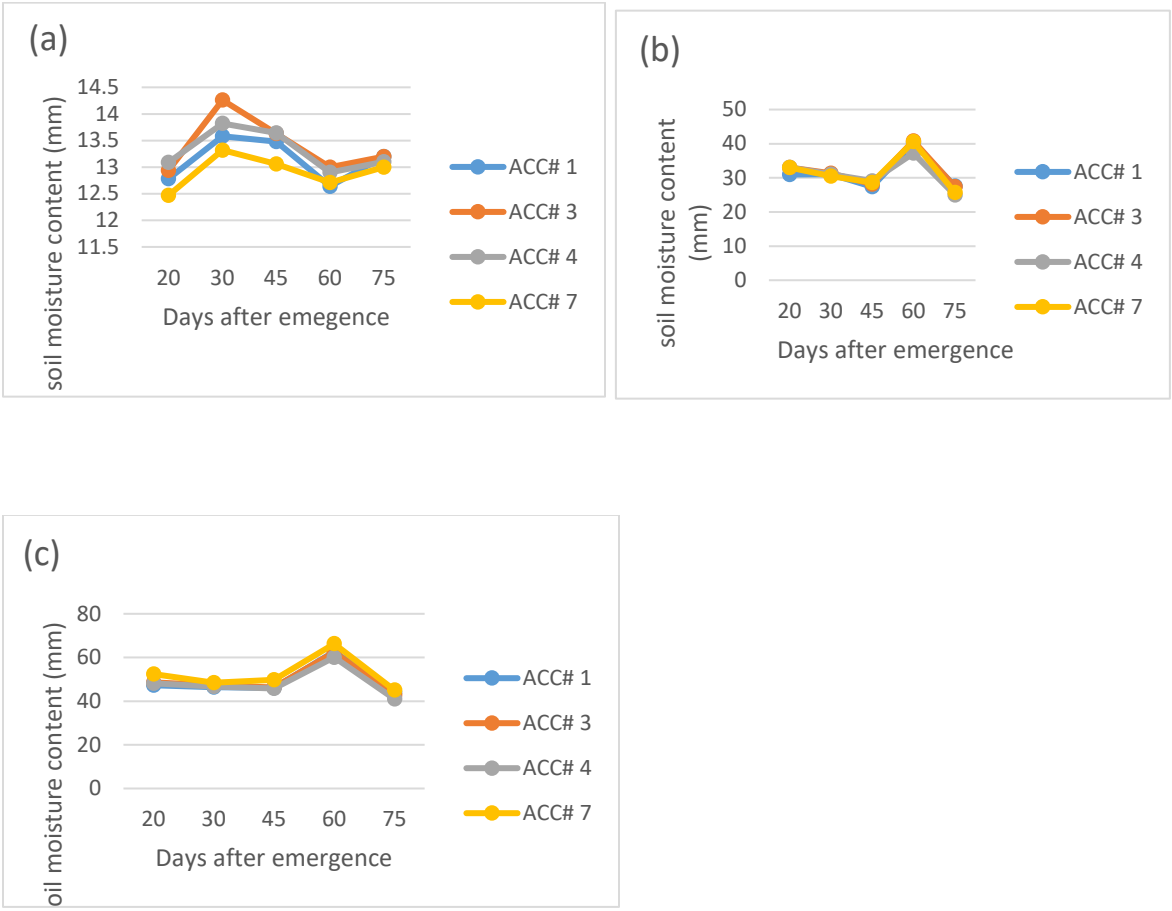
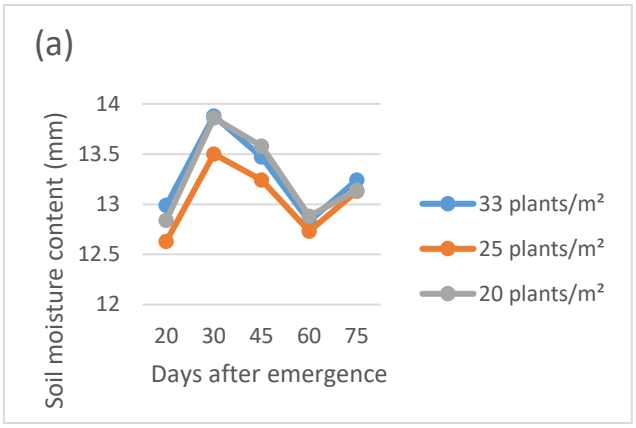
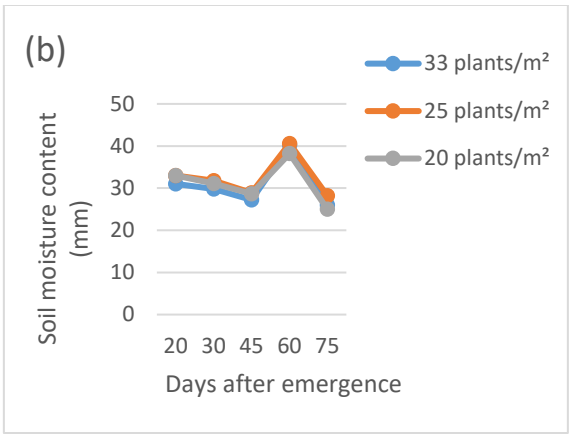


Figure 5.1. Effect of genotype on soil water depletion at 30 (a), 60 (b) and 90 (c) cm depth in 2015.





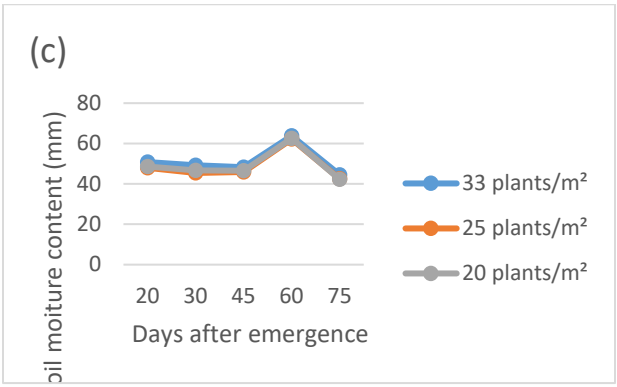


Figure 5.2 Effect of planting density on soil water depletion at 30 (a), 60 (b) and 90 (c) cm depth in 2015.

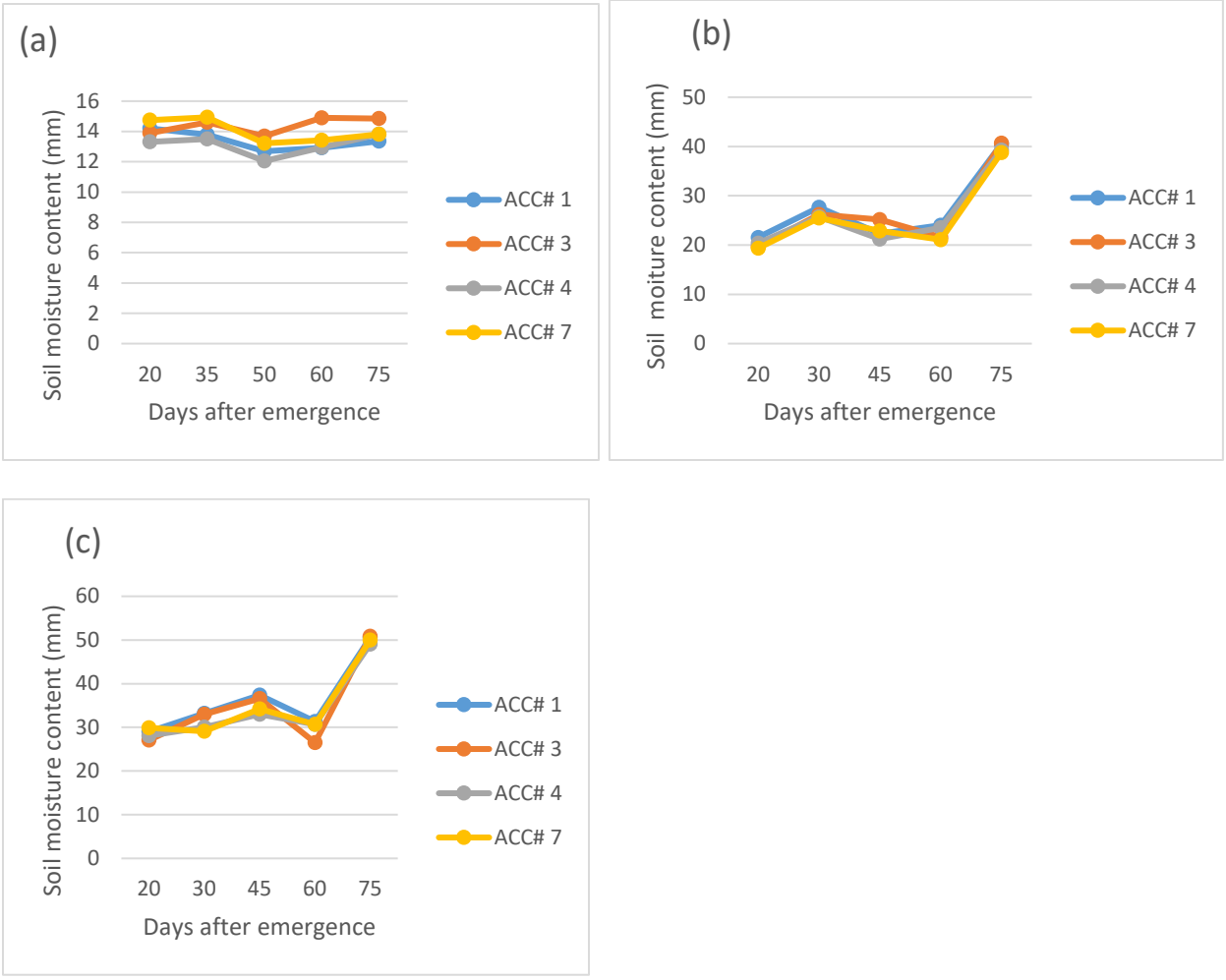


Figure 5.3 Effect of genotype on soil water depletion at 30 (a), 60 (b) and 90 (c) cm depth in 2016.

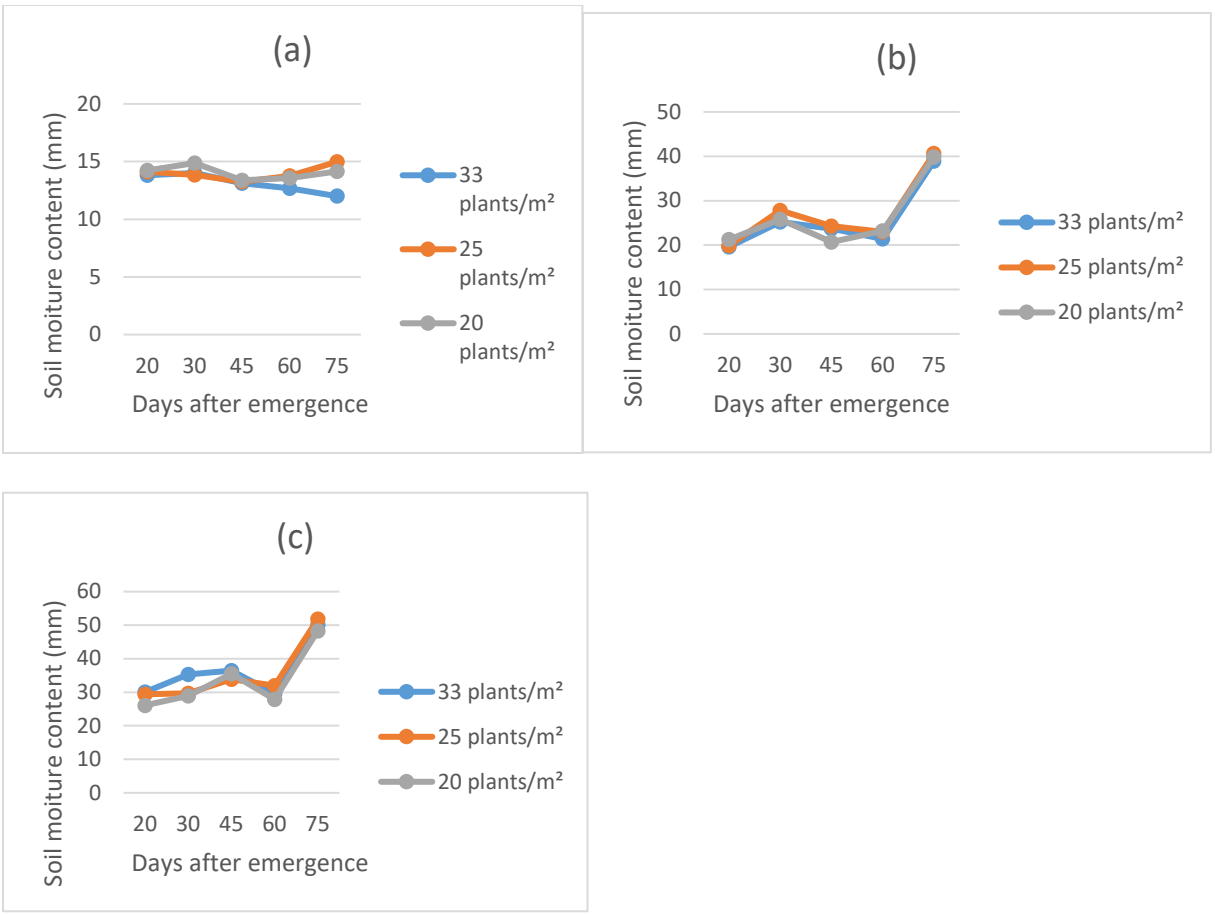


Figure 5.4 Effect of planting density on soil water depletion at 30 (a), 60 (b) and 90 (c) cm depth in 2016.

5.2.2. **Water use efficiency**

The effects of planting density and genotype did not affect WUE_g and WUE_b in 2015 (Table 5.1). Although genotype did not affect WUE_b and WUE_g, ACC# 7 had high (16. 6 kg ha^{-1} mm^{-1}) WUE_b and (2.22 kg ha^{-1} mm^{-1}) WUE_g. Also, WUE_b increased at high (16.2 kg ha^{-1} mm^{-1}) planting density compared to low (13.2 kg ha^{-1} mm^{-1})) and medium (13.8 kg ha^{-1} mm^{-1}) (Table 5.2).

The effect of planting density on water use efficiency of grain yield (WUE_g) and biomass (WUE_b) was significant ($P<0.05$) in 2016 but not in 2015 (Table 5.2). WUE_b was significantly greater at high planting density (45.6 kg ha^{-1} mm^{-1}) compared to medium (25. 6 kg ha^{-1} mm^{-1}) and low (19.7 kg ha^{-1} mm^{-1}) in 2016. Also, WUE_g varied with planting density ranging from 8.9 kg ha^{-1} mm^{-1} at low to 22.6 kg ha^{-1} mm^{-1} at the high planting density (Table 5.2).

Genotype had no significant effect on WUE_g and WUE_b in 2016. However, ACC# 4 (41.6 kg ha^{-1} mm^{-1}) had high WUE_b compared to ACC# 3 (29.9 kg ha^{-1} mm^{-1}), ACC# 7 (28.3 kg ha^{-1} mm^{-1}) and ACC# 1 (24.4 kg ha^{-1} mm^{-1}) (Table 5.2). ACC# 4 (17.9 kg ha^{-1} mm^{-1}) had high WUEg followed by ACC# 3 (17.1 kg ha^{-1} mm^{-1}) and ACC# 1 & 7 (12.3 kg ha^{-1} mm^{-1}) were at par with each other. On average WUEg and WUEb were greater in 2016 compared to 2015.

Table 5.1. Effects of chickpea genotype and planting density on water use and water use efficiency in 2015.

Treatments	Water use (mm)	WUE_b	WUE_g
Genotypes			
ACC# 1	304.1	14.5	1.38
ACC# 3	307.4	15.4	1.64
ACC# 4	299.8	13.9	1.57
ACC# 7	318.9	16.6	2.22
LSD	-	-	-
Planting density			
33 plants m^{-2}	308.9	16.2	1.76
25 plants m^{-2}	308.1	13.8	1.56
20 plants m^{-2}	305.1	13.2	1.78
LSD	-	-	-
CV (%)	0.7	1.79	25
Genotype	ns	ns	ns
Planting density	ns	ns	ns
G*PD	ns	ns	ns

Means followed by the same letter are not significantly different, ** ($P<0.01$), CV (coefficient of variation), and ns (not significant)

Table 5.2. Effects of chickpea genotype and planting density on water use and water use efficiency in 2016.

Treatments	Water use (mm)	WUE_b	WUE_g
Genotypes			
ACC# 1	281	24.4	12
ACC# 3	277.9	29.1	17.1
ACC# 4	269.2	41.6	17.9
ACC# 7	283	28.3	12.3
LSD	-	-	-
Planting density			
33 plants m^{-2}	266	45.6b	22.6c
25 plants m^{-2}	277.4	25.6a	12.9b
20 plants m^{-2}	292.8	19.7a	8.9a
LSD	-	6.7	3.25
CV (%)	21.6	26.1	24
Genotype	ns	ns	ns
Planting density	ns	*	*
G*PD	ns	Ns	ns

Means followed by the same letter are not significantly different, *(P<0.01), CV (coefficient of variation), and ns (not significant).

5.3. **Discussion**

5.3.1. **Crop water use**

Chickpea genotype did not affect soil moisture depletion in 2015 and 2016 growing seasons. The non- significant effect of genotype maybe due to similar water extraction by genotypes and this is observed at all soil depths. The non-response of genotypes could have been influenced by the low rainfall received during the vegetative growth which was lower than the rainfall amount received in the previous studies and this might have been less than the crop requirement (Ogola and Thangwana, 2013; Ogola et al., 2013), and inconsistency in water distribution of the poor irrigation system (sprinklers not releasing same amount of water due to poor pressure from the main source).

Similarly, Lusiba at el. (2018) reported non-significant effect of biochar and P fertilizer on WUE of chickpea genotypes in winter and summer season. In addition, Ogola et al. (2013) reported non-significant effect of genotype and phosphorus rates on chickpea water use. In contrast, Ogola and Thangwana (2013), found that planting density and genotype had significant effect on water use and water use efficiency of chickpea at the same study area. This can suggest that the response of chickpea to water use depends on genotypes, growth duration, management practices and environmental conditions at a given season.

Although genotype had no significant effect on soil moisture content in 2015, it was observed that genotype ACC# 7 extraction higher soil moisture compared to ACC# 1, 4 and 3 (Fig. 1a). At early stages of growth, greatest root proliferation is in the soil surface and the amount of roots produced depends on the inherent early growth vigour of the genotype.

Furthermore, soil moisture increase was observed at 30 cm by genotype ACC# 7. This imply that, genotypes (Prostrate), with large canopy the crop was able to channel available moisture to support transpiration under high evaporative demand than erect genotypes with small canopy. Prostrate genotypes develop rapid canopy closure which allows it to quickly shade the ground. The early ground cover in prostrate genotypes often leads to lower evaporation of water from the soil beneath the canopy (Esc), development of better root distribution and density, hence better exploitation of water stored at lower

soil depth. Furthermore, in early stages of growth intra-crop competition in chickpea is common and it further promotes more roots growth and improves water use (Siddique *et al*., 1990; Richards, 2008). Also, more primary and secondary branching results in a higher number of reproductive nodes in the bushy habit (prostrate) lines (Vanderpuye, 2010). This higher productivity of the prostrate over erect cultivars agrees with Rubio *et al*. (2004) who reported higher seed yield of chickpea lines with prostate growth habit than those with erect habit. Richards, (1996) reports that plant vigour affects radiation use efficiency and also helps in reducing soil evaporation which then helps maximizing the availability of soil water for transpiration, hence increase in the acquisition of nutrients and average grain yield (Condon *et al*., 2004).

In grain legumes, large genotypic variations in rooting depth and ability to extract water at depth has been shown to affect the seed yield through better water acquisition and increased transpiration efficiency (Kashiwagi *et al*., 2006). Furthermore, the water uptake is directly proportional to root surface area whereas water transport is proportional to root diameter and degree of separation of the xylem vessels (Waised and Eshel, 2002).). In addition, shoots and roots play an important role in regulating water use by the crop (Subbaroa et al., 1995). In contrast, there was a decline in soil moisture content at 60 and 90 cm depth at 60 DAE in 2016, which coincided with flowering. The decline could be due to flowering where higher metabolic rates occur. The chickpea root system responds to water deficit by increasing root growth deeper in the soil profile (Liu *et al*., 2010). This probably led to delay in flowering because cool temperatures generally delay phenological stages and lengthens crop duration. Temperatures below 20ºC were also reported to have adverse effects on pollen germination and pollen tube growth (Srinivasan, 1999). Under stress conditions, chickpea produces few number of nodes which in turn determines flowering.

At 75 DAE, there was great increase in soil moisture extraction. The timing of flowering is dependent on seasonal temperature profile, photoperiod and vernalization responses of the plant. Similarly, Muhammad *et al*. (2012) reported that days to flower initiation in chickpea were significantly affected due to moisture levels and the plants under moisture stress had early flowering (60 DAE) whereas well-watered treatment had delayed

flowering (71 DAE). Generally, moisture stress shortened the crop life cycle which results in early flowering as well as early maturity. It is well known that cooler temperatures delay the developmental stages in chickpea as a consequence of requiring greater number of calendar days to aggregate the required growing degree days (Summerfield *et al*., 1990).

Although planting density did not affect water use, soil water extraction varied with planting density at different depths. There was no consistency in the extraction of soil water at all planting densities. At 30 cm and 90 cm depth high soil water was extracted at high density compared to low and medium densities. Whereas at 60 cm depth more soil water content was extracted at medium planting density. The non-response of planting density to soil water extraction may be due to contrasting growth habits of genotypes tested. Ogola and Thangwana (2013) who reported that the contrasting results could be due to differences in soil water availability, vapour pressure deficit and crop growth habits. Crop growth habits influence the density to be used in a given environments, because the density requirements of erect genotypes may be different from those of erect and prostrate genotypes. Due to variation in architecture of the branches, prostrate genotypes may require high planting density compared to erect genotypes. In contrast, Ogola and Thangwana (2013) found significant differences with planting density and genotype on chickpea water use and water use efficiency.

In 2016, crop water use was higher at medium compared to low and high planting densities (Fig. 3a-c). This may probably mean at medium there is less competition and thus create less limitation to natural resources such as radiation, reduced transpiration and hence increased net photosynthesis. High planting density aggravates competition between plants and reduces yield and yield components. Moreover, there was a great a decline in soil moisture at 75 DAE, which might have led to drought stress. Furthermore, chickpea is sensitive to water stress especially during flowering and reproductive stages (Turner *et al*., 2001). At flowering and pod setting stages appear to be the most sensitive stages to drought (Nayyar *et al*., 2006). Flowering stage in chickpea production is a critical and requires enough soil moisture. Rahbarian *et al*. (2011) confirmed that in chickpea, water is used more efficiently at early flowering than seedling stage but this utilization is reduced at pod development, hence there was a great decline at 75 DAE.

5.3.2. **Water use efficiency**

Planting density had significant effect on WUE_b and WUE_g in 2016 but not in 2015. Water use efficiency increased with the increase in planting density. WUE_b was significantly greater at high planting density (45.6 kg ha^{-1} mm^{-1}) compared to medium (25. 6 kg ha^{-1} mm^{-1}) and low (19.7 kg ha^{-1} mm^{-1}) in 2016. The increase in high water use efficiency with planting density could be due to increased number of plants m^{-2} which created early ground cover, reduced E_{sc} and improved transpiration. Early vigor may be important for improving seed yield and WUE of chickpea through reduction of soil evaporation and associated increase in transpiration (Tanner and Sinclair, 1983; Richards *et al*., 2002) particularly, in water-limited short season production systems. The higher plant density could be attributed to the beneficial effect of increased evapo-transpiration on yield. Ogola and Thangwana (2013), reported that greater water use at high planting density was due to greater transpiration rather than the wasteful E_{sc} hence better partitioning of crop ET. Pandey *et al.* (1988) observed that higher plant density (200,000 plants/ha) of rainfed pearl millet gave higher consumptive use, rate of moisture use and water use efficiency as compared to the lower plant density of 1,00,000 plants/ha, owing to larger crop canopy. Singh *et al.* (2003) reported that water use efficiency of wheat was higher at higher population density (15 cm, 205 kg seed/ha) than low population density (22 cm, 140 kg seed /ha). Water use efficiency is important to crop production in dry environment areas. Therefore, management practice such as planting density and identifying canopy traits of chickpea genotypes that promote water use may be beneficial to chickpea production on semi-arid regions of Limpopo.

5.4. **Conclusion**

The effect of genotype and planting density on water use of four chickpea genotypes was not significant in 2015 and 2016. Genotypes did not show any clear pattern of water extraction. However, prostrate genotypes ACC# 3 and 7 extracted higher moisture content compared to erect genotypes ACC# 1 and 4. It is clear that genotype selection in

dry environments may be important in improving chickpea productivity. However, more research is required using wide range of genotypes before drawing definite conclusions.

The effect of genotype on water use efficiency of biomass and grain was not significant in 2015 and 2016. In contrast, WUE_b and WUE_g were significantly affected by planting density in 2016 (Table 5.2). WUE_b and WUE_g increased with increase in planting density. The greater water use efficiency at high planting density could possibly be due to greater portioning of ET into transpiration and also through high number of plant m^{-2} that created enough ground cover and reduced E_{sc}. It is clear that WUE_b and WUE_g may be improved through the use of high planting density. However, further studies using wide range of planting densities is required before drawing conclusion and recommendations.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

The effect of genotype on plant height was significant in both seasons and locations. Genotype ACC# 1 resulted in significantly higher plant height compared to ACC# 4, 3 and 7. In contrast, planting density had no significant effect on plant height. Furthermore, planting density had significant effect on number of primary branches at Syferkuil in 2016 but not at Thohoyandou. Planting density had significant effect on secondary branches at Thohoyandou in 2016 but not at Syferkuil. At low density, genotype ACC# 3 had high number of secondary branches at Thohoyandou and genotype ACC# 7 had greater number of secondary branches at Syferkuil. The results of the study shows that there was no consistency in the growth performance of these genotypes across sites. It is thus suggested that long term research may be conducted for further investigation of these two genotypes at more study sites before definite conclusions.

Grain yield increased with the increase in planting density at Syferkuil in 2015 and Thohoyandou in 2016. These results clearly show that various climatic conditions play an important role on yield and yield components of chickpea. In 2016, grain yield was higher at Syferkuil compared to Thohoyandou and vice versa in 2016. The increase in planting density from 20 to 33 plant m^{-2} increased yield and yield components. It can be concluded that planting density of 33 plants m^{-2} is optimum in the areas of the study. Therefore, further studies at Thohoyandou may adopt 33 plant m^{-2} as the low density and for Syferkuil, long term experiments are required before making any conclusions.

The main effects of genotype and planting density on water use of the four chickpea genotypes were not significant in 2015 and 2016. Genotypes did not show any clear pattern of water extraction. However, prostrate genotypes ACC# 3 and 7 extracted higher moisture content compared to erect genotypes ACC# 1 and 4. This suggest that prostrate genotypes of chickpea are likely to perform better than erect genotypes in dry environments. However, more research is required using a wider range of genotypes and sites before drawing definite conclusions.

The effect of genotype on water use efficiency of biomass and grain was not significant in 2015 and 2016. In contrast, WUE_b and WUE_g were significantly affected by planting

density in 2016 (Table 5.2). WUE_b and WUE_g increased with increase in planting density. The greater water use efficiency at high planting density could possibly be due to greater portioning of ET into transpiration and also through higher number of plants m^{-2} that created enough ground cover and reduced E_{sc}. The findings suggests that WUE_b and WUE_g may be improved through the use of high planting density. However, further studies using a wider range of planting densities could refine the conclusions on this aspect.

The overall yield performance of the current study was relatively close to those of previous studies

References

1. Akibode, S. and Maredia, M. 2011. Global and Regional Trends in Production, Trade and Consumption of Food Legume Crops. Department of Agricultural, Food and Resource Economics. Michigan State University. Report Submitted to SPIA, March 27.

2. Alam, M.Z. and Haider, S.A. 2006. Growth attributes of barley (*Hordeum vulgare* L.) Cultivars in relation to different doses of nitrogen fertilizer. *Journal of Life Earth Science.* 1: 77-82.

3. Al-Suhaibani, N., El-Hendawy, S., and Schmidhalter, U. 2013. Influence of varied plant density on growth, yield and economic return of drip irrigated Faba bean (*Vicia faba* L.). *Turkish Journal of Field Crops*, 18, 185–197.

4. Aslamshad M, Pervez H, Zafar Z, Zia-ul-Haq M and Nawz H. 2009. Evaluation of Biochemical Composition and Physiochemical Parameters of from Seeds of Desi Chickpea Varieties Cultivation in Arid Zones of Pakistan. *Pakistan Journal of Botany* 41(2), 655 - 662.

5. Ayaz, S., McKenzie, B.A., McNail, D.L and Hill. G.D. 2004. Light interception and utilization of four grain legumes sown at different plant populations and depths. *Journal of Agronomy Science Cambridge. 142: 297-308.*

6. Azizi, K. and Kahrizi, D. 2008. Effect of nitrogen levels, plant density and climate on quantity and quality in cumin (*Cuminum cyminum* L.) under the conditions of Iran. Asia *Journal of Plant Science. 7(8): 710-716.*

7. Bacon, M.A. 2004. Water use efficiency in plant biology Blackwell Publishing Oxford, UK.

8. Bakhsh, A., S. R. Malik, U. Iqbal, and W. Arshad. 2007. Heterosis and heritability studies for superior segregants selection in chickpea. *Pakistan Journal of Botany.* 39(7): 2443-2449.

9. Barkry, B.A., Elewa T.A., El-Karamany M.F., Zeidan, M.S., Tawfik, M.M. 2011. Effect of row spacing on yield and its components of some faba bean varieties under newly reclaimed sandy soil conditions. *World Journal of Agricultural Science. 7(1): 68-72.*

10. Beech, D.F. and Leach, G.L. 1989. Effect of plant density and row spacing on the yield of chickpea (cv. Tyson) grown on the Darling Down, South-eastern Queens land. *Australia Journal of Experimental Agriculture*.

11. Begum, N., Hussain, M. and Chowdury, S.I. 1992. Effect of sowing date and planting density of pod borer incidence and grain yield of chickpea in Bangladesh. International Chickpea Newsletter. 27: 19-21.

12. Beck, D. P. (1992). Yield and nitrogen fixation of chickpea cultivars in response to inoculation with selected rhizobial strains. *Agronomy Journal*, 84 (3), pp 510-516.

13. Bhatnagar, H., Yadavendra, J.P and Palci, K.V. 2005. Nutritional constituents in chickpea varieties. *International chickpea and pigeonpea Newsletter. 12: 7-8.*

14. Biabani, A. 2011. Journal of Agricultural Science and Technology, ISSN 1939-1250, USA. 5: 1 (32)

15. Bouteillé, M., Rolland, G., Balsera, C., Loudet, O., and Muller, B. 2012. Disentangling the intertwined genetic bases of root and shoot growth in arabidopsis. *PLoS ONE* 7:e32319.

16. Brahmane R. O., Bharud R. W. and Deshmukh D. V. 2017. Study of growth and yield variation of chickpea genotypes under moisture stress condition (physiological basis of growth and yield variation of chickpea genotypes under moisture stress condition). *International Journal of Genetics* ISSN: 0975-2862 & E-ISSN: 0975-9158, 9, (4), 2017, pp.-266-270. R. Aroca (ed.),

17. Bramley, H., Palta, A.J and Berger, D. 2012. Plant Responses to Drought Stress., DOI: 10.1007/978-3-642-32653-0_16

18. Chappin, S.F and Moilanen L. 1991. Nutritional controls over nitrogen and phosphorus resorption from Alaskan Birch leaves. *Journal of ecological society of America*. 72 (2).709-715.

19. Cokkizgin, A. 2012. Botanical characteristics of chickpea genotypes (Cicer arietinum L.) under different plant densities in organic farming. *Science Research. Essays* 7 (4): 498-503.

20. Condon, A. G., Richards, R. A., Rebetzke, G. J., and Farquhar, G. D. 2004. Breeding for high water-use efficiency. *Journal of Experimental. Botany.* 55, 2447–2460.

21. Dejene, D. 2010. Study on the Effect of Traditional Processing on Proximate Composition and Bioavailability of Minerals in Chickpea (*Cicer arietinum*) grown in Ethiopia. M.Sc. thesis, Addis Ababa University, Addis Ababa.

22. Dhanda, S.S., Behl. R.K. and Elbassam H. 1995. Breeding wheat genotypes for water deficit environments. *Landbanforschung volkenrode.* 45: 159-169.

23. El Naim, M., Abadalla, A.A, Ahmed, F.M and Taha, B.M. 2015. Biological yield and Harvest Index faba bean (Vicia Faba L) as affected by difficult Agro-ecological environment. World journal of Agricultural Research. 3(2), 78-82.

24. FAOSTAT: The food and Agriculture Organization of the United Nations .2014. Production of chickpea by countries. Available at http://faostat.fao.org/site/567/default.aspx#anco. Accessed May 2016.

25. FAO: Food and Agricultural Organization of the United Nations. 2016. FAOSTAT, Available at http://faostat3.fao.org/home/index.html. Accessed May 2016.

26. Farshadhar, E., Mahtabi, E and Jowkar, M.M. 2013. Evaluation of genotype x environment in chickpea genotypes using path analysis. *International Journal of Advanced Biological and Biomedical research*. ISSN: 2322-4827, 1(16), 2013: 583-593.

27. Felton, W.L, Marcellos, H and Murison, R.D. 1996. The effect of row spacing and seedling rate on chickpea yield in Northern New South Wales. Proceedings 8th. In Australia. Agronomy conference. Toowoomba. Pp. 251-253.

28. Gan, Y.T., Miller, P.R., McConkey B.G., Zertner, R.R, Liu, P.H. and McDonald, C.L. 2002. Optimum plant population density for chickpea and dry pea in semiarid environments. *Canadian Journal of Plant Science*. 83:1-9.

29. Gomez, K.W. and Gomez, A.A. 1984. Statistical procedures for Agricultural research. John Wiley & Sons.

30. Goyal, S, Verma, H.D. and Nawange, D.D. 2010. Studies on growth and yield of Kabuli chcickpea (*Cicer arietinum* L.) genotypes under different plant densities and fertility levels. *Legume Research*. 33 (3): 221-223.

31. Gurbuz, A., M. Kaya, A.D. Turkan, G. Kaya, M.D. Kaya, C.Y. Ciftci. 2009. The effects of seed size and drought stress on germination characteristics of chickpea (*Cicer arietinum* L.) Akdeniz University ZIraat Fakultesi Dergisi. 22(1): 69-74. ICARDA (1990). Annual report food legume Improvement program India.

32. Henser, M., Piot-Lepetit.I., Ferrari, E., Mellado, A.G., Banse, M, Grethe, H., Parisi, C and Helain, S. 2013. On the asynchronous approval of GM crops; potential markets impacts at a trade disruptions of EU soy imports. *Food policy,* 41.166-176.

33. IPCC. 2007. Climate change: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

34. Jha, U.C., Chatarvede, S.K., Bohra, A., Khan, M.S. and Barh, D. 2014. Abiotic stresses, constrains and improvement strategies in chickpea. *Plant Breeding*. 133(2) 163-178.

35. Johansen, c., Balder, B., Brouwer, J.B,Erskine,W., Jermyn, W.A., Li-Juan, L., Malik, B.A. and Ahad Miah, A. 1994. In: Muehlbauer, F.J. and Kaiser, W.J. (eds.) Expanding the production and use of cool season food legume*. Current Plant Science and Biotechnology in Agriculture*, Vol.19 Springer, Dordrecht.

36. Kaiser, W.J. 1992. Epidemiology of Ascochyta rabiei. In: Disease resistance breeding in kabuli chickpeas. Singh, K.B. and Saxena, M.C. (eds). ICARDA, Aleppo, Syria. pp. 117-143.

37. Kato, Y., Kamoshita, A., Yamagishi, J. 2008. Pre-flowering abortion reduces spikelet number of upland rice (*Oryza sativa L*) under water stress. *Crop Science* 48, 2389-2395.

38. Khan, E.A., Aslam, M., Ahmad, H.K., Himayatullah, Khan, M.A. and Hussain, A. 2010. Effect of row spacing and seedling rates on growth and yield and yield components of chickpea. *Sarhad Journal of Agriculture*. 26 (2).

39. Kashiwagi, J., Krishnamurthy, L., Crouch, J.H. and Serraj, R. 2006. Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L.) under terminal drought stress. *Field Crops Research* 95, 171–181.

40. Kholova, J., Hash, C.T., Kakkera, A., Kocova, M. and Vadez, V. 2010.Constitutive water- conserving mechanisms are correlated with the terminal drought tolerance of pearl millet [*Pennisetum glaucum* (L.) R. Br.] *Journal of Experimental Botany*. 2010; 61:369–377.

41. Kumar, D. 1995. Problems, prospects and management strategies of pulse Production under rain fed situations. *Sustainable Development of Dry land Agriculture in India,* 23: 335-373.

42. Kumar, P., P.S. Deshmukh, S.R. Kushwaha, and S. Kumara. 2001. Effect of terminal drought on biomass production its partitioning and yield of chickpea genotypes. *Annual Agricultural Research,* 22:408-411.

43. Ladizinsky, G. 1975. A new *Cicer* from Turkey. Notes from the Royal Botanic Gardens, Edinburgh 34: 201-202.

44. Leport, L., Turner, N.C., Davies, S.L., Siddique, K.H.M. 2006. Variation in pod production and abortion among chickpea cultivars under terminal drought. *European Journal of Agronomy*. 24,236-246.

45. Lusiba, S., Odhiumbo,J and Ogola, J. 2018. Growth yield and water use efficiency of chickpea (*Cicer arietinum* L): response to biochar and phosphorus fertilizer application. *Archives of agronomy and soil science*, 64(6) 819-833.

46. Liu, L., Gan, Y., Bueckert, R, Rees, K.V and Warkentin, T. 2010. Fine root distribution in oil seed and pulse crops. *American society of Agronomy*. 5(1), 222-226.

47. Lu'quez, J.E., Aguirreza, L.A.N., Aguero, M.E. and Pereyra, V.R. 2002. Stability and adaptability of cultivars in non-balanced yield trials: Comparison of methods for selecting 'high oleic' sunflower hybrids for grain yield and quality. *Crop Science*. 188: 225.

48. Macar T. K., Turan O. and Ekmekcd Y.2009. Effects of water deficit induced by PEG and NAcl on Chickpea (Cicer arietinum L.) Cultivars and Lines at Early Seedling stages, G.U. *Journal of Science* 229(1):5-14.

49. Machado, S., C. Humphreys, B. Tuck and Corp, M. 2006. Seeding date, plant density and cultivar effects on chickpea yield and seed size in eastern Oregon. Online. Crop Mgt. doi: 10.1094/CM-2006-0621-01-RS.

50. Madzivhandila, T., Ogola, J and Odhiumbo, J. 2012. Growth and yield response of four chickpea cultivars to phosphorus fertilizer rates. *Journal of Food and Agriculture Environment.*10:451-455.

51. Malik, S. R., A. Bakhsh, M. A. Asif, U. Iqbal and S. M. Iqbal. 2010. Assessment of Genetic variability and interrelationship among some agronomic traits in chickpea. *International Journal of Agriculture and Biology*. 12(1):81-85.

52. Maqbool, A., Shaita, S and Lake, L (2010). Radiant frost tolerance in pulse crops-a riview. *Euphytica* 172:1-12.

53. Matthews, P. W., Carpenter, D. J., Smith, A., and Fettell, N. (2001) Faba bean seeding rates for central and southern New South Wales. In Proceedings of the 10th Australian Agronomy Conference. Hobart: Australian Society of Agronomy.

54. Merah, O. (2001). Potential importance of water status traits for durum wheat improvement under Mediterranean conditions. *Journal of Agricultural Sciences.* 137, 139-145.

55. Miller, P.R., McConkey, B.G., Clayton, G.W., Brandt, S.A., Staricka, J.A., Johnston, A.M., Lafond, G.P., Schatz, B.G., Baltensperger, D.D. and K.E. Neill. 2002. Pulse crop adaptation in the northern Great Plains. *Agronomy Journal.* 94:261-272*.*

56. Mohammad, K. 2013. Effect of drought stress on yield and water relative content in chickpea. *International Journal of Agronomy and Plant Production.* 4 (6), 1168-1172, 2013.

57. Moreno, M and Cubero J.I. 1978. Variation in *Cicer arietinum L. Euphytica* 27, 465-485.

58. Moshia, M.E. 2005. Standard correlations between extractable Ca, Mg, K and P from fresh and laboratory prepared soil samples. Masters dissertation. University of Limpopo, South Africa. Pp 18-69.

59. Mpangane, P.N.Z., Ayisi, K.K., Mishiyi, M.G., and Whitbread, A. 2004. Grain yield of maize, grown in sole and binary cultures with cowpea and lablab in the Limpopo province of South Africa. Tropical Legumes for Sustainable Farming Systems in Southern Africa and Australia. In: Whitbread, A, M., and B.C. Pengelly (eds.), ACIAR Proceedings. 115: 106-114.

60. Nageswara Rao, R.C. and G.C. Wright. 1994. Stability of the relationship between specific leaf area and carbon isotope discrimination across environments in peanut. *Crop Science*. 34:98-103 World Journal of Agricultural Research, 2015

61. Nayyar, H, Singh, S, Kaur, S, Kumar, S and Upadhyaya, HD. 2006. Differential sensitivity of macrocarpa and microcarpa types of chickpea (*Cicer arietinum* L) to water stress: associated of contrasting stress response with oxidative injury. *Journal of Integrative Plant Biology*. 48: 1318-1329.

62.. Ogola, J.B.O. and Thangwana, N.M. 2013. Water use efficiency of summer sown chickpea in tropical environment: Response genotype and planting density. *Journal of Food, Agriculture & Environment* 11 (3 & 4).

63. Ojiem, J.O., Vanlauwe, B., de Ridder, N., and Giller, K.E., 2007. Niche-based assessment of contributions of legumes to the nitrogen economy of Western Kenya smallholder farms. *Plant Soil*, 292, 119–135.

64. Pandey.S and Gardener, C.O. 1992. Recurrent selection for population variety, and hybrids improvement in tropical maize. *Advances in agronomy*. 48, 1-89.

65. Parthasarathy, P., Birthal, P.S., Bhagvatula, S. and Bantilan M.C.S., 2010. Chickpea and Pigeonpea Economies in Asia: Facts, Trends and Outlook. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, pp. 76.

66. Pereira, J.S. and Chaves M.M. 1993. Plant water deficits in Mediterranean ecosystems. In Water Deficits: Plant Responses from Cell to Community. Eds. J.A.C. Smith and H. Griffiths. Bios Scientific Publishers, Oxford, pp 235--251.

67. Qureshi, A. S., Shaukat A, Bakhsh A, Arshad M, and Ghafoor A. 2004. An assessment of variability for economically important traits in chickpea. *Pakistan Journal of Botany.* 36(4): 779-785.

68. Rahbarian, R., Khavari-Nejad, R, Ganjeali, A, Bagheri, A and Najafi, F. 2011. Drought stress effects on photosynthesis, chlorophyll fluorescence and water relations in tolerant and susceptible chickpea (*Cicer arietinum* L.) genotypes. *Acta Biol. Crac. Ser. Bot. 53, 47—56.*

69. Rahman, M.M. 1990. Infestation and yield loss in chickpea due to pod borer in Bangladesh. *Bangladesh Journal of Agriculture Research.* 15(2): 16-23.

70. Richards, R. A. 1996. Defining selection criteria to improve yield under drought. *Plant Growth Regulators.* 20, 157–166.

71. Rubio, J., Flores, F, Morano, M.T., Cubero, J.I and Gil, J. Effects of the erect/bushy habit, single/double pod and late/early flowering genes on yield and seed size and their stability in chickpea. *Field crops research*. 90 (2-3) 255-262.

72. Rupela, O.P., and Saxena, M.C. 1987. Nodulation and nitrogen fixation in chickpea. (Eds. Saxena M.C. and Singh K.B.) Walling ford, United Kingdom, CAB International, pp.191-206.

73. Saxena, M.C. 1979. Plant population of chickpea recent advances in chickpea agronomy. Proc. Introduction. Workshop on chickpea improvement. 28 Feb-2 Mar. Hyderabad, India pp: 89-96.

74. Saxena, M.C. and Singh, K.B. (Eds.). 1987. In: The chickpea, 409 pp. CAB International, Oxon, UK.

75. Shad, K. K., Aahab, A. Rehman A, Muhammad F, Wahab S, Khan A.Z, Zubair M, Shah, M.K., Khalil I.H and Amin, R. 2010. Density and Planting Date Influence Phenological Development Assimilate Partitioning and Dry Matter Production of Faba Bean. *Pakistan Journal of Botany,* 42(6): 3831-3838.

76. Shamsi, K. 2009. The effect of planting density on grain filling, yield and yield components of three chickpea (*Cicer arietinum* L.) varieties in Kermanshah, Iran. *Journal of Animal and Plant Science* 2(3): 99-103.

77. Shamsi, K., Kobraee, S and Rasekhi, B. 2010. The effects of different planting densities on seed yield and quantitative traits of rainfed chickpea (Cicer arietinum L.) varieties. *African Journal of Agriculture Research* 6(3), Pp 655-659.

78. Sharar, M.S., Ayub, M, Ather Nadeem, M and Noori, S.A. (2001). Effect of Different Row Spacing's and Seeding Densities on the Growth and Yield of Gram (*Cicer arietinum* L.). Department of Agronomy, University of Agriculture, Faisalabad. *Pakistan Journal of Agricultural Sciences,* 38 (3-4): 51-53.

79. Shengel, V.K. and Ujagir, R. 1990. Effect of synthetic pyrethroids neem extracts and other insecticides for the pod damage by *Helicoverpa amigera* on chickpea and pod damage-yield relationship at Patancheru in Northern India. *Crop Protection*. 9:29-32.

80. Shiferaw, B, Jones R, Silim S, Hailemariam, T and E. Gwata, 2007. Analysis of Production Costs, Market Opportunities and Competitiveness of Desi and Kabuli Chickpeas in Ethiopia. IPMS Working Paper 3. ILRI, Addis Ababa, Ethiopia. 48 pp.

81. Siddique K.H.M, Belford R.K., Tennant D., Root:shoot ratios of old and modern, tall and semidwarf wheats in a Mediterranean environment, *Plant and Soil* 121 (1990) 89-98.

82. Sié, M., Futakuchi, K., Gridley, H., Manneh, M. B., Ndjiondjop, M. N., Efisue, A., Samejima, H. (2008). Drought research at WARDA: Current situation and prospects. In J. Serraj, J. Bennett, & B. Hardy Eds.), Drought frontiers in rice: Crop improvement for increased rainfed production (pp. 61–73). Singapore, Los Baños, Philippines: World Scientific, International Rice Research Institute.

83. Singels, A., Annandale, J.G., Stirzaker, R.J., Van der Laan, M and Laker, M.C. 2010. Irrigation scheduling research: South Africa Experiences. African Journals online. 37 (5).

84. Sinclair, T.R., Tanner, C.B and Bennett, J.M. 1983. Water-Use Efficiency in Crop Production. *BioScience* 34,(1) 36-40

85. Sinclair, T.R. 1986. Water and nitrogen limitations in soybean grain production I. Model development. *Field Crops Research*, 15:125-141.

86. Sinclair, T.R. and Ludlow, M.M. 1985. Who taught plants thermodynamics? The unfulfilled potential of plant water potential*. Australian Journal of Plant Physiology 12:213217.*

87. Singh, U and Jambunathan, R. 1981. Sudies on Desi and Kabuli chickpea (*Cicer arietinum* L) cultivars: Levels of protease inhibitors, levels of polyphenolic compounds and in vitro protea. *Journal of food science*. 46(5) 1364-1367.

88. Singh, A. Prasad, R. and Sharma, P.K. 1988. Effects of plant type and population density on growth and yield of chickpea. *Journal of Agricultural Science* 110(1):1-4.

89. Singh, F. and Diwakar, B. 1995. Chickpea Botany and Production Practices. ICRISAT Training and Fellowship Programs. Skills Development Series no. 16.

90. Singh, K. B. and Saxena, M. C. 1996. Winter chickpea in Mediterranean-type environments a technical bulletin. International Centre for Agricultural Research in Dry Areas, Aleppo, Syria.

91. Singh, K.B and Jana, S 1993. Diversity of response of some biotic and abiotic stresses and multivariate associations in Kabuli chickpea (*Cicer arietinum L*.) *Euphytica*, 68:1-10.

92. Soil Classification Working Group. (1991) Soil Classification: a taxonomic system for South Africa. Department of Agriculture Development, Pretoria, South Africa. 257p.

93. Srinivasan, A., Saxena, N.P and Johansen, C. 1999. Cold tolerance during early development growth of chickpea (Cicer arietinum L) genome variety in gamete development and function. *Field crops research*. 60 (3), 209-222.

94. Subbarao, G. V. C., A. E Johansen, A. E. Slinkard, R. C. N. Rao, N. P. Saxena and Y. S. Chuhan. 1995. Strategies for improving drought resistance in grain legumes. *Critical Reviews in Plant Science*, 14:469-523.

95. Summerfield, E.H., Erskine, W., Ellis, R.H., Robots, E.H and Hussain, A. 1990. Charecterization of responses to temperature and photoperiod for time to flowering in a world lentil collection. *The ecological and applied genetics.* 80 (2) 193-199.

96. Tadross, M., Jack, C. and Hewingston, B. 2006. On RCM- based projections of change in southern African summer. *Geophysical Research Letters*, 32, L23713, doi 1029/2005 GL024460.

97. Thabang, S.S., Moshia, M.E., Shaker, P. and Fouche, P.S. 2013. The impact of in-field spatial variability in a uniformly managed small-scale corn (*Zea mays* L) field. *African Journal of Agricultural Research* 7(31): 4416-4426.

98. Thangwana, N.M. and Ogola, J.B.O. 2012. Yield and Yield components of chickpea (*Cicer arietinum* L.): Response to genotype and planting density in summer and winter sowings. *Journal of Food, Agriculture & Environment Vol. 10 (2): 710-715. 2012.*

99. Thangwana, N.M and Ogola, J.B.O. 2016.Calibration of a neutron probe in a clay soil in Thohoyandou. Combined Congress 2016. Book of Abstracts. 250.

100. Turner, N.C., Wright, G.C. and Siddique, K.H.M. 2001. Adaption of grain legumes (pulses) to water-limited environments. *Advanced Agronomy*. 7: 194-23.

101. Valimohammadi, F., Tajbakhsh, M. and Saeed, A. 2009. Effects of planting date and planting density on grain yield, yield components and some quality and morphological traits of chickpea (*Cicer arietinum* L.), *Journal of science and Technology of Agriculture and Natural Resources. 46. 31-40.*

102. Vanderpuye, A.W. 2010. Canopy Architecture and Plant Density Effect in Short-season Chickpea (C*icer arietinum* L.). A Thesis submitted to the College of Graduate Studies and Research for the Degree of Doctor of Philosophy, University of Saskatchewan, Saskatoon.

103. Verghis, T. I.1996. Yield and yield development of chickpea (*Cicer arietinum* L.). Unpublished PhD thesis, Lincoln University, New Zealand.

104. Walley, F.L., Kyei-Boahen, S., Hnatowich, G. and Stevenson, C. (2005). Nitrogen and phosphorus fertility management for desi and kabuli chickpea*. Canadian Journal of Plant Science*, 85 (1), pp. 73-79.

105. Yagoob. M.Y., Holington, P.A and Gorham, J. 2012. Shoot, root and flowering time studies in chickpea (Cicer arietinum L) under two moisture regimes. *Emirates Journal of Food and Agriculture*, 24(1), pp. 73-78.

106. Yigitoglu, D. 2006. Research on the effect of different sowing densities on the yield and yield components of some chickpea (*Cicer arietinum* L.) cultivars that sown in winter and spring in Kahramanmaras region. Ph.D. Thesis, Department of Field Crops, Institute of Natural and Applied Science.

APPENDICES

Appendix 1. Correlation analysis for grain yield and yield components at Syferkuil in 2016

Grain yield	1	1 -					
Seeds/pod	2	0.3204	2 -				
Secondary branches	3	-0.1054	-0.0076	3 -			
Primary branches	4	-0.0346	0.1157	0.3673	4 -		
Plant height	5	0.1981	0.1687	0.0543	0.1609	5 -	
Pods/plant	6	0.8374	0.0003	0.1328	0.0191	0.1661	6 -

Appendices 2. Correlation analysis for grain yield and components at Thohoyandou in 2016.

Grain Yield	1	-1				
%100_sw	2	0.3759	-2			
Pods/plant	3	<0.001	0.5005	-3		
Seeds/plant	4	<0.001	0.3952	<0.001	-4	
Seeds/pod	5	0.1421	0.7598	0.1170	0.3303	-5
Biomass	6	<0.001	0.8726	<0.001	<0.001	0.1338