Planting date as an adaptive strategy to improve yield of Chickpea *(Cicer arietinum)* under climate change conditions in Southern Africa.

By

MICHAEL TICHARWA MUBVUMA

11636288

A Thesis Submitted to the Department of Plant Production

School of Agriculture

For the Degree of

DOCTOR OF PHILOSOPHY

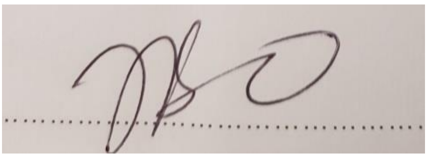
AT

THE UNIVERSITY OF VENDA

June 2018

Certification page

I certify that Mr Michael Ticharwa Mubvuma carried out this work in the Department of Plant Production of University of Venda.



(Promoter)

J. B. O. Ogola, Ph. D.

Professor in the Department of Plant Production, University of Venda

(Co-promoter)

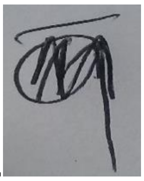
T. Mhizha, Ph. D

University of Venda
Creating Future Leaders

June 2018

Declaration by candidate

I……Michael Ticharwa Mubvuma…….hereby declare that the Thesis for the…Doctor of Phylosophy (Plant Production)…..Degree at the University of Venda hereby submitted by me has not been previously submitted for a degree at this or any other University, and that it is my own work in Design and in execution and that all reference material contained therein has been duly acknowledged.

Signature…………………  **…………………………………………………………..**

Date………… 17 June 2018………………………………………………………………...

Acknowledgements

I would like to express my sincere gratitude to my promoter Prof J. B. O Ogola for his unreserved support and guidance. His patience, leadership and comfort during this whole study period was pivotal for my studies. Prof Ogola's comments, suggestions and follow ups were stimulating even during difficult times.

I would like to thank my core promoter, Dr T. Mhizha for his supervision, comments and suggestions. His support and encouragement was excellent and unwavering throughout the study period.

To my collegues, comrades and friends: I say thank you for such a priceless team. A. Thangwana, Patty, Terry, Malele, Chapungu, Chikodzi, Mabhegedhe and Mandiudza, I say thank you. Your help and support was unmeasurable. I learnt a lot from you team.

To my wife and children: Pheris, Ryan, Ruvarashe and Kudiwanashe, I love you so much and you are the best.

This research was funded by the University of Venda Research and Publications Committee.

Abstract

Planting chickpea genotypes at different dates within the same season may expose the crop to different environmental factors (temperature and moisture) during their vegetative and reproduction stages. Thus, knowledge of optimum planting date that minimises extreme temperature and water stress conditions during crital stages of chickpea plant development may increase biomass and grain yield. The objective of the study was to determine the effect of planting date and genotype on aboveground biomass and grain yield of chickpea under climate change scenario in North Eastern Region of South Africa. The hypothesis tested was that planting date and genotype have an effect on biomass and grain yield of chickpea under climate change scenario. Thus, a study design incorporating a combination of field and modelling experiments was set to run in 2014 and 2015 winter planting seasons at the University of Venda, South Africa. Field experiments determined the effect of planting date and genotype on chickpea flower retention and pod abortion, aboveground biomass and grain yield, water use and radiation use efficiency, whilst modelling experiments calibrated and validated the FAO AquaCrop model to simulate chickpea aboveground biomass and grain yield using climate datasets (1950 - 2100), simulated from 15 global circulation models (GCMs) under the representative carbon dioxide concentration pathways (RCP) 4.5 and 8.5.

Field experiments results showed significant effect of planting date and genotype on biomass and grain yield of chickpea. Planting early, particularly under well-watered conditions appeared to be the most suitable sowing period for chickpea in this region. In contrast, late planting had lowest biomass and grain yield. The high grain yield in early planting (1.99 t ha^{-1}) was supported by greater yield components (seed weight (13.8 gm^{-2}) and pod weight 23 gm^{-2}), number of pods per plant (75 pods $plant^{-1}$) and harvest index (43 %)). Moreover, plant phenological factors such as plant height (46 cm) and number of branches per plant (16 branches) were also greater in early planting, with late planting recording lowest values in all the measured parameters. In addition, the greater biomass and grain yield in early planting compared with the normal and late sowings was caused by greater intercepted radiation (91%), improved flower retention (45.2%) and minimised water use (174 mm) and pod abortion (13.6%). Late maturing genotypes (Range 4 & 5) showed greater water use efficiency of grain yield (7.3 & 7.1 kg ha^{-1} mm^{-1}) and had the highest radiation use efficiency of grain yield, which was on average 7.2% (0.07 g MJ^{-1}) greater than ICCV9901, and 15.6% (0.13 g MJ^{-1}) greater than Range 1 & 3, but this depended on soil moisture availability.

The simulation results, indicated a significant increase in temperature (by 4.2 to 5.5 ^{o}C) over a period from 1950 to 2100. This increase lead to a concomitant increase in chickpea evapotranspiration and accumulated growing degree days. Moreover, optimal planting date for chickpea shifted from mid-month of April during 1950 to end of May in 2100 and reduced growing season length from 140 days in 1950 to 85 days in 2100. Aboveground biomass increased from 2.0 & 2.05 t ha^{-1} in 1950 to 4.3 & 4.57 t ha^{-1} in 2100, respectively in RCP 4.5 and 8.5, whilst grain yield increased from 1.07 & 1.08 t ha^{-1} in 1950 to 1.68 & 2.21 t ha^{-1} in 2100, respectively under RCP 4.5 and 8.5. Planting dates that were recommended by AquaCrop model recorded the highest increase in aboveground biomass and grain yield compared with early, normal and late planting dates. Late maturing genotypes (Range 4 & 5) showed greater grain yield and biomass, whilst early and medium maturing genotypes had low biomass and grain yield.

The study recommend early planting date together with late maturing chickpea genotypes (Range 4 and 5) in the region so as to improve water use efficiency, radiation use efficiency, heat use efficiency and aboveground biomass and grain yield of the crop under the present time and under climate change scenario. The early maturing genotype (Range 1) and medium maturing genotypes (Range 3 and ICCV9901) may only be recommended under normal planting date, although there will not be any significant yield advantages compared with late maturing genotypes. The study also recommend the use of planting dates generated by AquaCrop model so as to improve biomass and grain yield when chickpea is sown under climate change scenario in Southern Africa. The yield improvement using AquaCrop recommended planting dates was partly caused by greater water use efficiency, heat use efficiency and corbon dioxide productivity. Given the potential importance of planting dates in improving current and future productivity of chickpea shown in the study, there is need to work on development of a sowing (planting date) criteria for chickpea in the region. The criteria should clearly state chickpea sowing management options as decision support tools for smallholder farmer in the region.

Table of Contents

List of Tables

List of Figures

List of Abrevations

AGDD	Accummulated growing degree days
AGRITEX	Agricultural Research and Extenition Servises
BCM2	Bjerknes Centre for Climate Research C-Carbon
CC-	Canopy Cover
CCx	Maximum Canopy Cover
CERES	Crop Environmental Resource Synthesis
CGC	Canopy Growth Coefficient
CGMR	Canadian Centre for Climate Modelling and Analysis
CNCM3	Centre National de Recherches Meteorologiques
CP	Carbon dioxide Productivity
CSMD (2005)	FGOALS Institute of Atmospheric Physics
CSMK3	Commonwealth Scientific and Industrial Research
DAE	Days after emergence
DSSAT	Decision Support System of Agrotechnology Transfer
ELCROS	Elementary Crop Growth Simulator
FAO	Food and agriculture organization
FAOSTAT	Food and Agriculture Organization statistics
GCM	Global circulation model
GDD	Growing degree days
GFCM21	Geophysical Fluid Dynamics Laboratory
GIAOM	Goddard Institute for Space Studies
HadCM3	UK Meteorological Office
HADGEM	UK Meteorological Office
HI	Harvest index
HUE	Heat use efficiency

INCM3	Institute for Numerical Mathematics
IPCC	International panel of climate change
IPCM4	Institute Pierre Simon Laplace
Ks	Soil fertility stress coefficient
LAN	Limestone Ammonium Nitrate
MIHR	National Institute for Environmental Studies
mm	milimeters
MPEH5	Max-Planck Institute for Meteorology
N	Nitrogen
NCCCS	National Centre for Atmospheric Research
NCPCM	National Centre for Atmospheric Research
P	Phosphorus
PAR	Photosynthetically active radiation
RCP 4.5	Low concentration representative pathway scenario
RCP 8.5	High concentration representative pathway scenario
RUE_b	Radiation use efficiency of biomass
RUE_g	Radiation use efficiency of grain yield
S_a, IR	Total intercepted radiation
SW	Seed weight
SWC	Soil water content
T_{base}	Base temperature
T_{max}	Mean maximum temperature for the day
T_{min}	Mean minimum temperature for the day
Tr	Canopy Transpiration
VPD	Vapour pressure deficit
WP	Water Productivity
WU	Water use

WUE_b	Water use efficiency of biomass
WUE_g	Water use efficiency of grain yield
Y_i	Grain yield

CHAPTER 1

Introduction

1.1 Background Information

Chickpea *(Cicer arietinum.* L*)*, also known as garbanzo, pois chiche, kichar, chanu, bengal gram, nakhut or nohut (Saxena and Singh, 1987; Van der Maesen, 1987), is an important grain legume that is ranked third amongst legumes after dry bean *(Phaseolus vulgaris)* and field pea *(Pisum sativum)* (FAO, 2016). The diploid legume (2n= 2x =16) belongs to the genus *Cicer*, tribe *Cicereae*, family Fabaceae, and subfamily papilonaceae (Saxena and Singh, 1987; Singh and Diwakar, 1995; Giovanni et al., 2016). It is widely cultivated in tropical and subtropical regions of the world (FAO, 2016). Interest in chickpea production is growing in many countries because of its multiple uses as a source of food, livestock feed, fuel, and fertilizer (Gaur et al*.,* 2010). For example, there is growing demand for chickpea seed and its products in South Africa.

Despite its global importance for food, livestock feed, fuel and fertilizer, there is hardly any chickpea production in South Africa (Kassie et al*.,* 2009) and hence limited research on chickpea has been conducted in the region. Chickpea production is often constrained by factors that include pests and diseases, water stress, soil fertility problems, insufficient radiation interception, extreme temperatures, poor management practices and climate change. Amid such challenges, studies on the response of chickpea to several management practices such as planting density (Ogola & Thangwana*,* 2013), fertilizer rates (Siddique and Sedgeley, 1986, Ogola et al., 2013), and different irrigation treatments (Anwar et al*.,* 1999) have been documented. However, hardly any studies have reported the effect of planting date and genotype on chickpea resource use efficiency, flowering and yield components. Morever, the likely effect of climate change on chickpea planting date has hardly been reported in literature. Currently, there are no recommended planting dates for chickpea in Southern Africa, and neither is there an adaptation strategy to improve chickpea yield under expected climate change scenario (IPCC, 2014).

Planting date and genotype have been reported to affect biomass and grain yield of chickpea in different parts of the world (Siddique and Sedgley, 1986; Anwar, et al*.,* 2003; Pal Singh et al*.,* 2007; Kabir et al*.,* 2009). Grain yield variation as high as 31% related to planting date variations has been observed in chickpea (Singh et al., 1987; Lliads, 2001) and in other crops (Sun et al*.,* 2003; Tsimba et al., 2013). Moreover, in most of the areas across the world, planting date has been reported to improve chickpea grain yield (Lliads, 2001; Kabir et al., 2009). For example, yield increase as high as 70% and 188% were reported in Syria (Singh et al., 1987) and in Greece (Lliads, 2001), respectively, suggesting the importance of planting date as an agronomic strategy to improve grain yield. In Bangladesh, Kabir et al. (2009) suggested that the effect of planting date on chickpea grain yield may depend on chickpea genotypes.

It is clear from the foregoing that planting date affects chickpea yield in diverse environments. However, the physiological basis for grain yield improvement due to manipulation of planting date has rarely been reported in literature. For example, the response of water use and water use efficiency, radiation use, and radiation use efficiency amongst chickpea genotypes to planting date has scantly been researched in the past years. Likewise, the response of thermal time of growth, heat use efficiency, and flower retention and pod abortion in chickpea genotypes grown under different planting dates has not been investigated exhaustively enough to enable implementation of grain yield improvement strategies. Because there is a dearth of information in literature on the physiological effect of planting date on the chickpea plant which may result in grain yield improvement, it has not been possible to develop adaptation strategies to improve chickpea grain yield under climate change conditions.

An early planting date in Southern Africa during winter may expose the crop to extremely low temperatures (less than 8 ^{o} C) (Nayyar, 2005, Viatcheslav et al., 2007) during the early reproductive stage, which may affect flower retention. In contrast, late planting of chickpea during the winter season may result in flowering stage coinciding with high temperatures during reproduction period and may consequently affect fruit set and hence chickpea grain yield (Wang et al., 2006). Furthermore, water use and water use efficiency of grain yield and of biomass has been reported to vary significantly with planting date in maize (Nyakudya and Stroosnijder, 2014; Hai-dong et al., 2016), sunflower (Ucak et al., 2016) and Sorghum (Hadebe et al., 2017) but limited studies have assessed the effect of planting date on chickpea crop water use and water use efficiency. In addition, flower retention and pod abortion has been observed to vary with various management strategies that affect plant growth (Pang et al., 2017), temperature (Clark and Siddique, 2004) and moisture regime (Siddique et al., 2001) in chickpea crop. However, hardly any study has reported the effect of planting date and genotype on chickpea flower retention and pod abortion. Indirectly, planting date may affect water and radiation use efficiency, flower retention and pod abortion by ensuring that certain critical stages of crop growth and development take place at a time of the year when temperature and moisture are naturally at optimal levels so as to escape or avoid loss of flowers, pods and hence improve yield.

Optimum planting date for other crops such as maize (Tsimba et al., 2013; Nyakudya and Stroosnijder, 2014; Hai-dong et al., 2016), potatoes (Kawakami et al., 2005) and soybean (Hankinson, 2015) has been reported to vary with environment and genotype and season suggesting that planting date for chickpea may also be affected by season and expected climate change scenario in Southern Africa (Singh et al*.,* 2014; Tadross et al*.,* 2009). The onset of the rainy season which determines the starting of the growing period and date of planting for the crop (Mupangwa, 2011) may change with climate change (Zinyengere, et al*.,* 2011). A delay in the onset of the rains will delay the date of chickpea planting in summer season and may result in the crop extending its physiological maturity date into the dry winter season, where the prevailing lower temperatures at night may affect fruit set and grain yield (Clarke and Siddique, 2004). Changes in winter temperatures in the form of extremely cold or high temperatures are likely to shift the winter planting date (Kharin and Zwiers, 2000, Viatcheslav et al*.,* 2007; IPPC, 2014). High temperatures due to climate change, in absence of irrigation will cause moisture stress as potential evapotranspiration exceeds plant available water (Allen et al., 1998). Because chickpea phenology is often highly temperature responsive, it is likely that chickpea heat, water, and radiation use efficiency and carbon dioxide productivity will vary with season and also with climate change. Moreover, the high temperatures may reduce growing season length (Fiwa, 2015), change biomass development pattern, branching (Verghis et al., 1993) or fecundity of plant and reduce grain yield (Ma et al., 2017). However, Chart-zoulakis and Psarras (2005) reported that the synergistic benefits of increased Carbon dioxide concentration levels with WUE may off-set temperature effects in C_3 plants.

Several studies have proposed combining the Global Circulation Models (GCMs) and crop simulation models to determine the possible effects of climate change on crops grown under different management strategies (Erda et al., 2005; Koocheki et al., 2006; Challinor and Wheeler, 2008; Hajarpoor et al., 2014; Mahomed et al., 2016). Simulation models, driven by daily climatic data, such as AquaCrop model can be used to predict the impact of long-term climate variability on the probability of success of a range of planting dates (Mhizha et al., 2014). Where studies have explored the possible range of climate change impacts on chickpea crops, contrasting results regarding yield variability have been reported (Koocheki et al., 2006; Kalra et al., 2008; Singh et al., 2014). Some predictions have shown a yield increase (Hajarpoor et al., 2014; Mahomed et al., 2016) possibly due to anticipated increase in carbon dioxide concentration levels (DaMatta et al., 2010), whilst others have shown a yield decrease possibly due to high temperatures off-setting the carbon dioxide advantages (Koocheki et al, 2006. Implication of the variation in predictions may indicate that the impact of climate change might be crop or location specific and unfortunately there is a dearth of information on growth and yield of chickpea crop under anticipated future climate scenarios in Southern Africa. Therefore, this study evaluated the effect of planting date on growth and yield of chickpea grown under future climate change scenarios in South Africa. It is envisaged that outcomes from this study may enhance adaptive capacity of chickpea farmers to possible changes in planting date due to climate change.

1.2 Hypotheses

i. Planting date and genotype have an effect on chickpea flower retention and pod abortion.
ii. Planting date and genotype have an effect on aboveground biomass and grain yield of chickpea.
iii. Planting date and genotype have an effect on chickpea water use, water use efficiency.
iv. Planting date and genotype have an effect on chickpea radiation use, radiation use efficiency.
v. Planting date and genotype have an effect on chickpea thermal time of development.
vi. AquCrop model may be parameterised to predict chickpea crop biomass and grain yield in the North Eastern part of South Africa.
vii. Climate change will affect winter planting date for chickpea crop in the North Eastern part of South Africa.
viii. Planting date and genotype have an effect on aboveground biomass and grain yield of chickpea crop grown under future climate scenarios.

1.3 Objectives

The main objective of the study was to evaluate the effect of planting date and genotype on biomass and grain yield of chickpea crop under future climate scenarios in North Eastern part of South Africa. The specific objectives were:

i. To assess the effect of planting date on chickpea flower retention and pod abortion and identify suitable planting date and genotypes for the North Eastern part of South Africa.

ii. To assess the effect planting date on aboveground biomass and grain yield of chickpea and identify suitable planting date and genotypes with greater aboveground biomass and grain yield in the North Eastern part of South Africa.

iii. To assess the effect of planting date on chickpea water use, water use efficiency and identify suitable planting date and genotypes with greater water use efficiency in the North Eastern part of South Africa.

iv. To assess the effect planting date on chickpea radiation use, radiation use efficiency and identify suitable planting date and genotypes with greater radiation use efficiency in the North Eastern part of South Africa.

v. To assess the effect planting date on chickpea thermal time of development and identify suitable planting date and genotypes with greater thermal time of development in the North Eastern part of South Africa.

vi. To parameterise and validated AquCrop model to predict chickpea crop biomass and grain yield in the North Eastern part of South Africa.

vii. To determine the effect of climate change on winter planting date for chickpea crop in the North Eastern part of South Africa.

viii. To assess the effect of planting date and genotype on aboveground biomass and grain yield of chickpea crop grown under future climate scenarios, and identify suitable planting date and genotypes with greater biomass and grain yield under future climate scenarios.

1.4 Thesis layout

CHAPTER 1 Study background, problem statement, justficatication and study objectives	The need to assess the effect of planting date on biomass and grain yield of chickpea under climate change scenario in North Eastern Region of South Africa.
Chapter Two Literature Review	This chapter discusses the effects of planting date and genotype on RUE, WUE, CP, HUE and grain yield of chickpea under current and future dates.
Chapter Three Determining the effect of planting date on chickpea flower and pod abortion.	This chapter assess the effect of planting date and genotype on chickpea flower retention and pod abortion and identify the most suitable planting date for the study area.
Chapter Four Determining the effect of planting date on biomass and grain yield of chickpea	This chapter assess the effect of planting date and genotype on chickpea biomass, yield and yield components. The chapter also describes experimental data which forms the bases for AquaCrop model calibration and validation
Chapter Five Determining the response of water use and water use efficiency of chickpea to planting date and genotype	This chapter assess the effect of planting date and genotype on chickpea water use and water use efficiency. The chapter also describes experiments on soil water extraction which forms the bases for AquaCrop model calibration and validation
Chapter Six Determining the response of radiation use and radiation use efficiency of chickpea to planting date and genotype	This chapter assess the effect of planting date and genotype on chickpea intercepted radiation use and radiation use efficiency. The chapter also describes field experiments on radiation interception and canopy cover which forms the bases for AquaCrop model calibration and
Chapter Seven Determining the effect of planting date on thermal time of chickpea.	This chapter assess the response of accumulated growing degree days, and heat use efficiency to planting date and genotype. The chapter also describes field experiments on chickpea heat units

Chapter Eight

To parameterise and validate AquaCrop model for chickpea biomass and grain yield in North East South Africa.

The chapter describes model parameterisation and discusses validation results from early, normal and late planting

Chapter Nine

To test for climate change signatures in North Eastern Region of South Africa

This chapter assessed effect of climate change on winter planting date for chickpea crop in the North Eastern part of South Africa. Temperature, rainfall, carbon dioxide generated from 15 global circulation models and planting dates generated by AquaCrop model are subjected to man-kendal and variability tests to determine if they are affected by

Chapter Ten

To determine the effect of future planting date on biomass and grain yield of chickpea crop

FAO AquaCrop model 5.0 that was parameterised and validated in chapter 8 was used for simulating future heat units, evapotranspiration, biomass and grain yield. These parameters were then used to calculate heat use efficiency (HUE), water use efficiency (WUE), and biomass and grain yield of chickpea crop for the years 1950 to 2100. Effect of climate change on simulated data was tested by man-kendall and variability tests.

Chapter Eleven

Combined discussion

A combined discussion of all results from chapters 3-10. The discussion is on use of planting date and genotype as an adaptive strategy under climate change scenario.

Chapter Twelve

Conclusion and recommendations

Conclusion and recommendations for the study are presented in this chapter.

References

Steduto, P. and Albrizio, R., 2005. Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea: II. Water use efficiency and comparison with radiation use efficiency. *Agricultural and Forest Meteorology*, *130* (3-4), pp.269-281.

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 1999. Water use efficiency of chickpea (Cicer arietinum L.) cultivars in Canterbury: effect of irrigation and sowing date. *Agronomy New Zealand*, *29*, pp.1-8.

Clarke, H.J. and Siddique, K.H.M., 2004. Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research*, *90*(2-3), pp.323-334.

De Giovanni, C., Pavan, S., Taranto, F., Di Rienzo, V., Miazzi, M.M., Marcotrigiano, A.R., Mangini, G., Montemurro, C., Ricciardi, L. and Lotti, C., 2017. Genetic variation of a global germplasm collection of chickpea (Cicer arietinum L.) including Italian accessions at risk of genetic erosion. *Physiology and molecular biology of plants*, *23*(1), pp.197-205.

FAO. 2016. Production Yearbook. Food and Agricultural Organization of the United Nations, Rome, 58.

Gaur, P.M., Tripathi, S., Gowda, C.L., Ranga Rao, G.V., Sharma, H.C., Pande, S. and Sharma, M., 2010. Chickpea seed production manual.

IPCC., 2014. Climate change: impacts, adaptation, and vulnerability. Part B: regional aspects. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.J., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA pp 688.

Kabir, A.F., Bari, M.N., Karim, M.A., Khaliq, Q.A. and Ahmed, J.U., 2009. Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed condition. *Bangladesh Journal of Agricultural Research*, *34*(2), pp.335-342.

Kashiwagi, J., Krishnamurthy, L., Upadhyaya, H.D., Krishna, H., Chandra, S., Vadez, V. and Serraj, R., 2005. Genetic variability of drought-avoidance root traits in the mini-core germplasm collection of chickpea (Cicer arietinum L.). *Euphytica*, *146*(3), pp.213-222.

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*(2-3), pp.171-181.

Kassie, M., Shiferaw, B., Asfaw, S., Abate, T., Muricho, G., Ferede, S., Eshete, M. and Assefa, K., 2009. Current situation and future outlooks of the chickpea sub-sector in Ethiopia. *ICRISAT and EIAR (http://www. Icrisat. org/tropicallegumesll/pdfs/Current_Situation. pdf)*.

Kharin, V.V. and Zwiers, F.W., 2000. Changes in the extremes in an ensemble of transient climate simulations with a coupled atmosphere–ocean GCM. *Journal of Climate*, *13*(21), pp.3760-3788.

Ma, L., Wang, X., Liu, Y., Su, M.Z. and Huang, G.H., 2017. Temperature effects on development and fecundity of Brachmia macroscopa (Lepidoptera: Gelechiidae). *PloS one*, *12*(3), p.e0173065.

Mohammed, A., Tana, T., Singh, P., Korecha, D. and Molla, A., 2017. Management options for rainfed chickpea (Cicer arietinum L.) in northeast Ethiopia under climate change condition. *Climate Risk Management*, *16*, pp.222-233.

Mhizha, T., Geerts, S., Vanuytrecht, E., Raes, D. and Makarau, A., 2014. Use of the FAO AquaCrop model in developing sowing guidelines for rainfed maize in Zimbabwe. *Water SA*, *40*(2), pp.233-244.

Mupangwa, W., Walker, S. and Twomlow, S., 2011. Start, end and dry spells of the growing season in semi-arid southern Zimbabwe. *Journal of Arid Environments*, *75*(11), pp.1097-1104.

Nayyar, H., 2005. Putrescine increases floral retention, pod set and seed yield in cold stressed chickpea. *Journal of agronomy and crop science*, *191*(5), pp.340-345.

Ogola, J.B.O. and Thangwana, N.M., 2013. Water use efficiency of summer sown chickpea in a tropical environment: Response to genotype and planting density. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.2689-2695.

Ogola, J.B., Madzivhandila, T. and Odhiambo, J.J., 2013. Water use of chickpea (Cicer arietinum L.): Response to genotype and phosphorus fertilizer rates in winter and summer sowings. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.1341-1347.

Singh, T.P., Deshmukh, P.S. and Kushwaha, S.R., 2007. Response of different sowing dates on seed protein content and productivity of chickpea (Cicer arietinum) genotypes. *Indian journal of agricultural science*, *77*(9), pp.57-58.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Singh, P., Nedumaran, S., Boote, K.J., Gaur, P.M., Srinivas, K. and Bantilan, M.C.S., 2014. Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European journal of agronomy*, *52*, pp.123-137.

Singh, D.P., Peters, D.B., Singh, P. and Singh, M., 1987. Diurnal patterns of canopy photosynthesis, evapotranspiration and water use efficiency in chickpea (Cicer arietinum L.) under field conditions. *Photosynthesis research*, *11*(1), pp.61-69.

Singh, F. and Diwakar, B., 1995. Chickpea botany and production practices. Skill Development Series number 16.

Sun, H., Shao, L., Chen, S., Wang, Y. and Zhang, X., 2013. Effects of sowing time and rate on crop growth and radiation use efficiency of winter wheat in the North China Plain. *International Journal of Plant Production*, *7*(1).

Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, D. and Muchinda, M., 2009. Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize. *Climate Research*, *40*(2/3), pp.147-161.

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Van der Maesen, L.J.G., 1987. Origin, history and taxonomy of chickpea. In *The chickpea* (pp. 11-34).

Vanuytrecht, E., Raes, D. and Willems, P., 2011. Considering sink strength to model crop production under elevated atmospheric CO2. *Agricultural and Forest Meteorology*, *151*(12), pp.1753-1762.

Kanwar, K., 2014. *Response of Chickpea (Cicer arietinum L.) to Benzyladenine (BA) and Thiourea in Relation to Antioxidant System and Physiological Traits for Heat Tolerance (SKNAU)*(Doctoral dissertation, SKNAU).

Kharin, V.V., Zwiers, F.W., Zhang, X. and Hegerl, G.C., 2007. Changes in temperature and precipitation extremes in the IPCC ensemble of global coupled model simulations. *Journal of Climate*, *20*(8), pp.1419-1444.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Zinyengere, N., Mhizha, T., Mashonjowa, E., Chipindu, B., Geerts, S. and Raes, D., 2011. Using seasonal climate forecasts to improve maize production decision support in Zimbabwe. *Agricultural and Forest Meteorology*, *151*(12), pp.1792-1799.

CHAPTER 2

Literature review

2.0 Introduction

The overall objective of the study was to evaluate the effect of planting date on growth and yield of chickpea grown under future climate change scenarios in Southern Africa. This chapter introduced chickpea plant in terms of its origins, botany, production and uses before reviewing previous work and research gaps on the effect of planting date and genotype on chickpea crop. Reaserch gaps on the effect of planting date and genotype on water use, water use efficiency, intercepted radiation, radiation use efficiency, flower retention, pod abortion, aboveground biomass and grain yield was discussed. The physiological effects of temperature, moisture, and radiation on chickpea crop was dissucussed since the factors are likely to vary with planting date. The chapter also discussed the likely effect of climate change on chickpea planting date and consequently the likely effect of a possible shift in planting date on biomass and grain yield of chickpea. Literature on AquaCrop model, the Global Circulation Models and chickpea genotypes used in the study were also reviewed.

2.1 Origins of chickpea crop

Chickpea *(Cicer arietinum. L)* is ranked third after dry bean *(Phaseolus vulgaris)* and field pea *(Pisum sativum)* (FAO*,* 2016). The crop belongs to the genus *Cicer*, tribe *Cicereae*, family Fabaceae, and subfamily papilonaceae (Saxena and Singh, 1987; Singh and Diwakar, 1995). Chickpea is believed to have originated from South-eastern Turkey (Ladizinsky, 1975, Van dar Maesen, 1987). Evidence from botanical and archaeological research (Van der Maesen, 1972) supports the belief that chickpea was first domesticated in the Middle East. Redden and Berger (2007) identified the desi chickpea as the oldest type and suggested that it originated in South-eastern Turkey. However, Tanno and Willcox (2006) reported that the earliest records of using chickpea (desi) as food were found in Tell el-kerkh in Syria; suggesting that Syria and not Turkey could be the place of origin of desi chickpea. In contrast, Ladizinsky (1975) and Toker (2009), suggest that kabuli chickpea could have directly emerged from *C. reticulatum* (a wild progenitor) of the domestic chickpea in ancient eastern Turkey. So the origin of the two types of chickpea is not clear, but available information suggests that desi chickpea may have originated in Syria whilst kabuli chickpea may have originated in Turkey. In addition, Van der Maesen (1972) reported that the Mediterranean region is the primary centre for diversity for kabuli chickpeas, whilst the Indian continent is the primary centre for desi chickpeas. The differences between the two chickpea types in their centres of origin and diversity may only explain small differences in climatic requirements between the two chickpea types, since the climate conditions of the two centres of origin are similar (IPCC, 2014).

2.2 Chickpea production

Chickpea is grown in about 63 countries (FAO, 2016). The crop now constitutes 20% of the world pulses production, with India being the largest producer, followed by Australia and Parkstain (FAO, 2016). In the year 2016, chickpea was grown on 10.6 million ha worldwide, with a total production of 11. 3 million tonnes (FAO, 2016). On continental scale, 89% of chickpea production area is in Asia, 4.3% in Africa, 2.6% in Oceania, 2.9% in Americas and 0.4% in Europe (Gaur et al*.,* 2010). In Africa, Ethiopia is the leading producer. The crop is hardly grown in Southern Africa, except in Tanzania where close to 150 tonnes of seed yield was produced during the year 2015 (FAO, 2016). No significant production was noted in South Africa (FAO, 2016).

2.2.1 The importance of chickpea in South Africa

Chickpea crop is being introduced in South Africa with the objective to increase the resilience of South African farmers to the impacts of drought and climate change. The crop is drought tolerant and is capable of producing significant yield in poor soils of South Africa. Compared to maize, chickpea requires less amount of nutrients and water for its growth and development. Despite the crop's agronomic advantages, no commercial production is taking place in South Africa (FAO, 2016). Thus, this study chose chickpea with the objective to add on to earlier efforts by Mathews et al., (2011 and 2012) of introducing chickpea crop in South Africa. Like most legumes, chickpea functions in improving soil fertility by fixing atmospheric nitrogen into the soil (Mohammed et al*.,* 2013). Besides its agronomic superiority, chickpea is a nutritious crop capable of redressing protein deficiency problems in South Africa. The seed contains 17-24% proteins, 38-59% carbohydrate, 3% fibre, 4.8-5.5% oil, 3% ash, 0.2% calcium, and 0.3% phosphorus (Tawaha et al*.,* 2005). There is greater demand for chickpea seed and its products in South Africa. The country is currently importing 2000 tones of chickpea seed annually to service its demand. The crop is consumed as a dry pulse crop or as green vegetables (singh et al., 2005). The white and yellow seeds can be roasted or boiled and eaten plainly or salted as snacks. Chickpeas are added to many dishes as dessert, salads and soup (Gaur et al*.,* 2010). After harvesting, chickpea can be sold in markets as dry peas, canned, or processed into flour. The crop is used to make industrial starch that is used in the textile and in adhesive industries (Sanjeewa, 2008). Chickpea may also be used for feeding animals, where the gram husks, stems and leaves are a very nutritious stock feed that can be chopped and mixed with other cereal straws (Mohammed et al*.,* 2013). It is clear from the foregoing that chickpea has several advantages and should be grown in South Africa. Therefore, research on the crop in terms of planting date becomes more critical in mapping where and when the crop may be planted.

2.3 Types of chickpea

There are two different types of chickpea; the desi type and the kabuli type (Malhotra et al, 1982). The physical appearance of the seeds is shown in Fig 1 below:

Desi seeds Kabuli seeds

Fig 2-1 Differences between desi and kabuli seeds (Gaur et al., 2010)

Desi chickpea have a thick seed coat that is brown, yellow, green or black in colour depending on the cultivars (Malhotra et al., 1982, Fang et al., 2010), and are generally small and angular (Fig 2.1), with a rough surface (Leport et al., 2006, Gaur et al., 2010). Their flowers (desi) have a pink colour (Hawtin and Singh, 1980) and the plants show various degrees of anthocyanin pigmentation on the stem (Farzaneh, et al., 2009). Desi seeds are the most grown type of chickpea, with around 80% of chickpea area (FAO, 2016). Kabuli chickpea seeds are large (Fig 2.1), with a thin seed coat, smooth seed surface and are white or beige in colour, with a ram's head shape (Leport et al., 2006). The flowers are white and lack anthocyanin pigmentation (members of flavonoids) on the stem (Lila, 2004; Gaur et al., 2010). On physio-chemical composition, kabuli seeds have higher levels of sucrose and lower levels of fibre than desi types (Kaur and Singh, 2005). The two types of chickpea are different in their climatic requirements. This difference in climatic requirements may slightly be attributed to their areas of origin. Desi type which originated from Syria (Tanno and Willcox, 2006) show more signs of tolerance to dry conditions than kabuli type (Leport et al., 2006). Also, desi type is more tolerant to water stress than kabuli type (Leport et al., 2006). In a study by Wang et al., (2006), it was shown that desi varieties produced 26% more seed yield than kabuli varieties when both seeds were exposed to high temperature stress during the reproductive development stage. This difference in temperature tolerance may also be explained by the differences in climate conditions of the centres of origin and diversity of the two chickpea types. Therefore, in Southern Africa, although both types are expected to perform better during winter than in summer season (Thangwana and Ogola, 2012), it is also expected that desi chickpea will perform better than kabuli in the both winter and summer season.

There is a wide variation in terms of the agro-climate of the areas where chickpea is grown around the world (Farzaneh, et al., 2009); these areas differ in photoperiod, temperature and rainfall. Chickpea is drought tolerant and requires an annual rainfall of between 400 to 600 mm. Extremely high temperatures (above 30 ^{O}C) or frost activity may be harmful to the plant during any growth stage but is more critical at flowering and pod formation because of loss of potential yield (Bhattacharya and Pandey, 1999, Leport et al*.,* 2006, Devasirvatham, et al*.,* 2012). It is not possible to use field management strategies such as planting date to control rainfall, but perhaps, temperature at different critical stages of development of chickpea may be managed as a function of the choice of planting date. In this case, the crop should be planted at a time that ensures that flowering and podding stages coincide with optimum temperature that is ideal for flower retention and pod setting. With climate change being expected to affect rainfall and temperature regimes, optimal planting date for either summer or winter season is expected to change (IPCC), 2014).

2.3.1 Chickpea genotypes used in the study

The genotypes used in the study were selected based on their availability and days to physiological maturity. Out of the five genotypes used in the study, one cultivar (Range 1) was an early maturing cultivar. The other two cultivars (Range 4 & 5) were late maturing, whilst two cultivars Range 3 and ICCV9901, were medium maturity cultivars.

Range 1 is a desi, short season cultivar that takes 100-115 days to reach physiological maturity. It has an erect canopy structure and can reach a height of between 10 and 16 cm. Its flowers are pink and it has different pigmentation of anthocynin on the stem. The seeds are small, angular and with a rough surface.

Range 4 and 5 are long season cultivars and take between 130 and 145 days to reach physiological maturity. Range 5 has an erect structure, whilst Range 4 has a branching structure. Range 5 grows to a height of between 16 and 30 cm, whilst Range 4 a height of between 7 cm and 12 cm. Both cultivars are desi types and the flowers have pink colour. The plants in both cultivars show different pigmentation of anthocynin on the stem. The seeds are small, angular and with a rough surface.

The cultivar ICCV9901 is a Kabuli type and requires 110 – 120 days to reach physiological maturity. It grows to a height of 14 cm to 20 cm. The seeds are large, beige in colour and have a thin coat and a soft surface. The cultivar have got white coloured flowers.

2.4 Chickpea plant growth and development

Chickpea crop takes 7-15 days to emerge after planting. The seedlings are hypogeal (Saxena and Singh, 1987). It has an indeterminate growth habit (Van dar Maesen, 1987), where its vegetative stage continues even when flowering has started. The crop follows a normal growth sequence of leaf, flower bud, and flower and pod development on each branch. A number of pseudo-flowers or false flower buds develop on the plant stem (Singh and Diwakar, 1995). The time from emergence to flowering ranges from 40 to 80 days. Chickpea is an upright (erect) annual legume, ranging from 30 to 70 cm in height, with primary, secondary and tertiary branching system that resemble a small bush (Saxena and Singh, 1987). The plant has a strong taproot system with 3 or 4 rows of lateral roots (Farzaneh, et al., 2009). Chickpea leaves are petiolate, compound, and unimparipinnate (pseudoimparipinnate) (Hawtin and Singh, 1980) but vary with types, with some chickpea varieties having compound leaves whilst others have simple, pubescent leaves with top rachis ending in a leaflet (Singh and Diwakar, 1995). The leaflets are ovate to elliptic in shape, and are olive, dark green or bluish in colour (Hawtin and Singh, 1980). The flowers are indeterminate, and bisexual (Singh and Diwakar, 1995). Desi varieties have purple/violet flowers while kabuli varieties have white flowers (Farzaneh, et al., 2009, Gaur et al*.*, 2010). The crop is self-pollinating, but negligible cross pollination may occur (Singh, 1987).

2.5 Planting date

Planting date of chickpea is the sowing time of seeds or transplanting time of chickpea seedlings when conditions are optimum for their germination, development and yield (Odekunle, 2003). For the purpose of this study, optimum planting date was defined as the date where chickpea grain yield is maximixed sustainably, with minimal production risks, whilst ensuring the crop fits within the overall cropping system (Tsimba et al., 2013). Planting date varies with place, season, type of crop and climate (Rease et al., 2004; Mhizha et al., 2014), and is a function of available moisture, temperature and growing season length. In Southern Africa, planting date during summer season is usually associated with onset of rainfall because most of the crops are rainfed. Keatinge et al. (1995) defined planting date as the first rainfall event capable of supporting germination. This definition has implementation challenges as it is difficult for farmers to know if the rainfall event is enough to sustain germination. Several methods of determining planting date have been reported in literature. Reas et al. (2004) put forward the DEPTH method of determining summer planting date.

Although the method was tested on maize crop, it is likely to be useful in different crops such as chickpea. In Southern hemisphere and in summer season, the DEPTH method defines a planting date as the first day after 1 October on which the occurrence of 40 mm of rain falls within a 4-day period. In Zimbabwe, the Department of Agriculture and Technical Services (AGRITEX) determines the planting date for all crops to be grown in summer as the occurrence of 25 mm of rainfall within 7 days (Reas et al., 2004).

However during the winter season in North Eastern Region of South Africa, there is no significant rainfall activity except some drizzles. Therefore planting date for winter crops including chickpea is determined by residual moisture management, and avoidance of temperature extremes that affect flowering and pod setting. There are no recommended planting dates for chickpea crop in South Africa, neither is there any clear criteria for determining when to plant chickpea in winter or in summer season. However, early studies on chickpea in the region (Mathews et al., 2011 and 2012) used to plant chickpea during the month of May. Furthermore, several studies in North Eastern region of South Africa, where chickpea is grown have used mid-May as the normal planting date. Late April to early days of the month of May have been used as early planting dates for chickpea, whilst end of May have been viewed as late planting date in the Region. Therefore, South Africa has a small planting window. Thus, this study selected 1st of May as the early planting date, 14th of May as the normal planting date and 28 May as late planting date. Although the last week of April could have been used in selecting the early planting date, it was felt that most of the farmers would still be finalising harvesting of summer crops. The farmers' desirable scenario is to plant chickpea when residual moisture from the ending summer season is still plenty, whilst making sure that flowering and pod setting process occur when temperatures are cool; i.e. between 20^{o} C and 26^{o} C (Summerfield et al., 1984; Devasirvathan et al., 2012).

The differences in early, normal and late planting date comes with yield variability as expected mostly because of different environmental conditions the crop is exposed to at planting, flowering and podding stages. An early planting date in Southern Africa during winter may expose the crop to extremely low temperatures (less than 10 ^{o} C) which affects flower retention and podding during the early reproductive stage (Nayyar, 2005, Viatcheslav et al*.,* 2007). In contrast, late planting of chickpea during the winter season may result in flowering stage coinciding with high temperatures during early month of August; this may affect fruit set and hence chickpea yield (Wang et al*.,* 2006).

2.6The physiological effect of climatic factors on Chickpea growth and development

Chickpea crop is affected by several climate factors such as temperature, moisture stress, vapour pressure deficit and radiation during its growth and development process. These climate factors may affect the crop individually but at most their interaction effect on crop growth and development has been reported in literature. The effect of climatic factors on chickpea has been reported on crop physiological parameters such as plant height, number of branches per plant, heat units, and on resource use efficiency. Planting chickpea at different dates may expose the crop to different climatic conditions (temperature, radiation and moisture) during their vegetative and reproduction stages. This, consequently may affect biomass and yield. Therefore, the following three paragraphs are a narration reports of earlier studies on temperature, moisture and radiation on chickpea crop.

2.6.1 Temperature

Temperature is one of the most important abiotic factors that affect chickpea yield across the world (Summerfield et al*.* 1990; Clarke and Siddique, 2004; Devasirvatham et al*.,* 2012). Wahid et al. (2007) reported that high temperature affects seed germination, photosynthesis, respiration, fertilization and seed quality of chickpea. Summerfield et al. (1984) observed that depending on planting date, chickpea genotypes experience different temperature regimes which may affects vegetative and reproduction performance of the crop. Siddique et al. (1999) observed greater sensitivity of chickpea genotypes to high temperatures, and also a marked reduction in seed size and seed weight when the crop was exposed to high temperatures of 30-35^{o}C at seed filling. Similar views were reported by Devasirvatham et al. (2012), Leport et al. (2006) and Karla et al. (2008), who noted that high temperatures (> 32^{o}C) may cause anther indehiscence, reduced pollen production, and shrunken stigma, style and ovary. Berger et al. (2004) reported that temperatures greater than 16^{o}C at flowering had an effect of delaying pod set by up to 70 days due to repeated cycles of flowering and abortion. In support of this report, abortion and abscission rate of flowers and pods were reported to depend on temperature stress, among other factors (Siddique and Sedgley, 1986; Singh et al., 1989; Clarke and Siddique, 2004; Wang et al., 2006; Khattak et al., 2006; Thakur et al., 2010; Devasirvatham et al., 2012; Shukla et al., 2013). Similar effects of temperature were reported by Ram et al. (2006) in other legumes (*Pisam sativum* L) and in other crop (*Zeya maize*) by Tsimba et al. (2013).

Conversely, Chaturvedi and Dua (2003) reported that low temperature during early plant growth was associated with slow and poor growth. Kumar et al. (2010) noted that low temperature stress caused egg and secondary nucleus in ovules to disintegrate before fertilization. Similar observations had ealierly been made by Srinivan et al. (1998), who had reported that low temperatures may cause flower abscission, low pod set, impaired pod filling and poor yields. In addition, Nayyar (2004) reported that chickpea crop is affected by cold stress when temperature fall below 8^{o}C during reproduction stage.

Optimum growth and development in chickpea is greatly affected by temperature. Soltani et al (2006) reported an upper optimum temperature of 32°C for 21 hours for chickpea reproduction stage, while, Devasirvatham et al. (2012), reported threshold of between 27-32°C for chickpea reproduction.

Moreover, Allen et al*.* *(*1998) reported that the amount of heat energy an organism accumulates over a period of time is often expressed as a “growing degree-day” (GDD). Whish et al*.* (1997) reported that heat units expressed in growing degree-days (GDD) can be used to describe crop development. Biabani et al*. (*2011) reported that the concept of GDD can be used to determine the growing stages of crops, predict best timing of fertilizer or herbicides application and to assess the suitability of a region for production of a particular crop. Whish et al*.* (1997) stated that GDD is calculated for each day and is added cumulatively to come up with heat units for the whole crop cycle. Allen et al*. (*1998) reported that GDD are calculated each day using maximum daily temperature (T_{max}), the minimum daily temperature (T_{min}), and a base temperature (T_{base}). The fomular to calculate GDD is as follows:

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base} \qquad (2.1)$$

T_{base} is the temperature below which no growth takes place and is taken as 5 °C for chickpea crop by some authors (Whish et al*.,* 1997, Biabani et al*.,* 2011). However, other authors use a chickpea base temperature of 4 °C (Verghis et al*.,* 1999), Thangwana and Ogola (2012) used 8°C in the study area whilst Parthasarathi et al*., (*2013) uses a base temperature of 0 °C. The requirement for GDD for chickpea ranges from 1678-1802 and is based on a base temperature of 0 ° (Parthasarathi et al*.,* 2013). However, other studies have reported higher GDD values for chickpea (Berger et al*.,* 2004). Mukesh, et al*.,* (2010), in Bangladesh, Bundelkhand region, evaluated the effect of planting date on growing degree days of chickpea crop and revealed that chickpea crop with an early planting date had higher growing degree days (1980.2 day °C) than late planted crop (1975.5 day °C), but no differences were significant across all planting date on heat use efficiency (1.06 grain kg ha^{-1} °Cday). The effect of planting date on GDD have been reported also in other crops such as sorghum, rice and wheat (Ottman et al*.,* 1997) and the results have shown that early planted crops accumulate higher growing degree days than late planted crops. Therefore, a good choice of planting date, for chickpea crop has the potential to promote higher growing degree days, heat use efficiency and improve yield. This study will also determine the effect of planting date on accumulation of growing degree days of chickpea crop types.

2.6.2 Soil moisture

Availability of moisture is vital for chickpea growth and development. Sharm and Piri (2006) reported the significant effect of irrigation on chickpea plant height, biomass and grain yield. Siddique et al (2001) reported that plant genotypes differ in water extraction capacity and this had a bearing on water use and water use efficiency. Similarly, Maharaja et al. (2008) observed that the level of soil moisture in the soil had an effect on water use and water use efficiency of the crop. Anwar et al (2003) reported that irrigation substantially increased water use but had low water use efficiency.

Likewise, water stress may affect chickpea growth and development. Moisture stress may cause impairment of stigma, pollen or pistil function (Fung et al., 2010; Leport et al., 2006) in chickpea, thus causing flower and pod abortion. Leport et al (1999) reported yield reduction as high as 58 to 95% in water stressed crop compared to irrigated crop. Nouda and Saini (1992) observed 17% yield reduction due to mosture stress at reproduction stages of chickpea crop. In addition, Singh (1991) reported the influence of moisture stress on phenology and suggested that reproductive stage in chickpea was inversely correlated to normalised evapotranspiration.

2.6.3. Radiation

Improved radiation interception and utilization is very important in chickpea production. Haverkot (2007) reported that increased growing season length as a result of early planting had a significant effect on intercepted radiation. Oluwasemire and Odungbenro (2014) reported that the amount of intercepted radiation is affected by plant density and genotypes. Rahman et al., (2000) reported variation in leaf area, conopy cover and radiation capture as a result of water stress. Similary, Anwar et al. (2003) reported greater radiation use and radiation use efficiency in irrigated plants compared to non irrigated plants. Azam et al. (2004) showed that early planting increased radiation interception by 80% compared with late planting. Similar findings were confirmed by Confalone et al. (2009), who reported that early planting intercepted greater radiation compared with late planting which showed lower extinction coefficient. Singh et al. (2008) reported highest radiation use efficiency in early planting.

Brown et al. (2006) and Sinclair and Muchow (1999) reported that radiation use efficiency was affected by temperature and suggested that high temperatures may affect plant photosynthesis and hence affect radiation capture. Andrade (1994) reported interactions between temperature and genotypes on radiation use efficiency. Jones and Kiniry (1986) reported that interaction of high temperatures and water stress had a negative affect on leaf area and reduce the extinction coefficient, which influences leaf radiation interception. Their views were concomitantly supported by Farre et al (2000).

2.7 Effect of planting date on above ground biomass and grain yield of chickpea

The average seed yield for chickpea per hectare varies with production regions but it ranges from 0.6 to 2.3 t ha^{-1}. The world average seed yield is 0.86 t ha^{-1} (FAO, 2016). This yield is low compared with average seed yield that has been reported from research trials across the world (Thangwana and Ogola, 2012; Siddique and Sedgeley, 1986; Kabir, 2009). The biggest challenge facing chickpea researchers is to improve chickpea grain yield at farm level to the levels that have been reported in research trials.

The low seed yield in chickpea may be a result of several factors such as temperature stress (Krishnamurthy et al., 2011; Devasirvatham et al., 2012), pest and diseases, moisture stress (Leport et al*.,* 2006) and genotype (Siddique and Sedgeley, 1986). The use of optimum planting date is one management option that may lead to (Tsimba et al., 2013; Fiwa, 2015) improved grain yield through environment x genotype interaction. Several studies have reported the significance of planting date and genotype selection on biomass and grain yield of chickpea (Bahal et al., 1984, Dixit et al*.,* 1993, Hussain et al*.*, 1997, Kabir 2009). For example, in Bangladesh, Kabir et al*.* (2009) observed that sowing time had a significant effect on chickpea growth parameters, yield and yield components. Similar reports have been given across the world and in different crops (Tsimba et al., 2013; Fiwa, 2015). Planting date affects acquisition and utilisation of resources such as water and radiation in crops (Andrade et al., 1993; Soltani et al., 2006), and influences crop source – sink balance and the progression of how available assimilates from plant leaves (source) are translocated to flowers or growing pods (sink) (Tsimba, et al., 2013).

Variation in planting dates may expose crops to different environmental conditions (temperature, photoperiod and moisture) at various stages of growth and consequently affect biomass accumulation and partitioning. For example, an early planting date in Southern Africa during winter may expose the crop to extremely low temperatures (less than 8 ^{o} C) during the early reproductive stage (Nayyar, 2005, Viatcheslav et al*.,* 2007) which may affect flower retention and pod abortion. In contrast, late planting of chickpea during the winter season may result in flowering stage coinciding with high temperatures during early reproduction period which may affect fruit set and hence chickpea yield (Wang et al*.,* 2006). Moreover, exposure to high temperatures in late planting will reduce chickpea growing season length as potential evapotranspiration exceeds plant available water and because chickpea phenology is often highly temperature responsive (Devasirvatham et al. 2012, 2013). Reduced growing season length is likely to reduce yield. Furthermore, rising temperatures coupled with increasing day length may reduce growing cycle period by shortening vegetative and reproduction stages (Veghis et al., 1999).

Studies also show that planting date determines the period when critical stages will take place in plants, for example when to flower or when the crop switches over to podding stage (Veghis et al., 1999). Knowledge of optimum planting date that minimises extreme temperature and water stress conditions during reproduction period may increase yield. Production of high and stable seed yield strongly depends on maximising yield components with a stable harvest index (HI) (Veghis et al., 1999). However, HI for chickpea has been reported to vary considerably with genotype and cultivars (Veghis et al., 1999) due to genetic instability, emanating from genotype by environment interaction (Chijoke et al, 2010; Krishnamurthy et al., 2011). Because of this instability, yield components such as number of pods per plant, pod weight and 100 seed weight have remained low. Whether manipulation of planting date may stabilize HI, improve yield components and increase biomass and grain yield is not known. Although a number of studies have reported on the effect of planting date on biomass accumulation and partitioning in chickpea in different regions (Chetia and Kumar, 2005; Singh et al., 2005; Tenguria and Tikle, 2005; Confalone et al., 2009), hardly any study has reported optimum planting date for chickpea that may improve and stabilize grain yield in the region. Where planting date has been reported to affect chickpea yield (Tenguria and Tikle, 2005; Confalone et al., 2009), it has been difficult to separate whether the effects were caused by temperature stress, water stress, genotype or normal seasonal variations.

2.8 Effect of planting date on water use efficiency of chickpea

Water use efficiency (WUE) is defined as the biomass or grain yield per unit of crop water use (Sinclair et al., 1984), and is influenced by physiological traits such as biomass accumulation and daily crop water use. Therefore any management practices that affect these traits will have implications on chickpea WUE. Ogola and Thangwana (2013) suggested that manipulation of management practices that increase the efficiency of water utilization may increase the productivity of chickpea crop.

Chickpea grain yield is affected by moisture stress conditions at various stages of growth and development (Siddique and Sedgley, 1987; Leport et al., 2006). The effects of moisture stress on crops may vary with genotype (Siddique et al., 2001) and possibly with planting date (Anwar et al., 2003). Planting chickpea early or late in the season may result in crops experiencing variation in moisture regime depending on the daily pattern of weather elements such as temperature, vapour pressure deficit and evapotranspiration (Siddique and Sedgley, 1986). A delay in planting chickpea, coupled with high temperatures may delay canopy growth and promote high evaporation at the expense of transpiration during the late stages of plant growth (Siddique et al., 2001). In contrast, early planting may allow the crop to take advantage of residual moisture in the soil and promote a faster and early canopy growth. Thus, depending on the prevailing temperatures, early planting may lead to larger canopy cover that reduces evaporation and promotes transpiration. In previous studies (Ogola et al., 2002 & 2005), it was shown that grain yield and hence water use efficiency is improved by reducing evaporation and concurrently increase transpiration in plants. Also, high transpiration may promote improved extraction of water by plants because of increased transpiration pull, thus reducing wasteful loss of water by evaporation (Ogola et al., 2005). Whether the anticipated increase in soil water extraction in early plantings may lead to efficient use of water to produce grain yield is not known and may depend on the planted genotypes (Ogola et al., 2002, 2007 and 2013; Ogola and Thangwana, 2013) and their interaction with the environment (Tsimba et al., 2013). Planting date may also affect root length, density and rooting pattern and this may affect soil water extraction (Benjamin and Nielsen, 2006). Information on the effect of planting date and genotype on chickpea water extraction is far elusive.

Chickpea genotypes have different canopy structures and varying rooting depth (Zhang et al., 2000). The variation in canopy structure may affect crop water use, partly because of variation in canopy microclimate which may affect the partition of water use into evaporation and transpiration (Ogola et al., 2002). Similarly varying rooting depth may affect water extraction by plants and consequently alter water use amongst genotypes (Benjamin and Nielsen, 2006). Moreover, the indeterminate nature of some chickpea genotypes may also affect crop water use and water use efficiency. For instance, the indeterminate flowering habit in chickpea may result in genotypes promoting vegetative growth at the expense of flowering in well-watered conditions and vice versa in moisture stress conditions. This continuation of vegetative growth once the crop has reached the flowering/podding stage may result into variation in plant canopy cover amongst genotypes and hence affect crop water use. In addition, this concurrent flowering and vegetative habit in indeterminate crops may affect the sink-source balance of plants and result in grain yield variation, which consequently will also affect water use efficiency amongst genotypes. However, using planting date as a strategy to improve water use efficiency of indeterminate chickpea genotypes by ensuring a good environment and genotype interaction is not known. Such studies have rarely been reported in literature.

Furthermore, manipulation of planting date provides crops with an opportunity to adapt to environmental moisture challenges by either allowing the crops to escape, avoid or tolerate moisture stress without a compromise on final grain yield. For instance, early planting of early maturing chickpea genotypes may escape or avoid period of moisture stress through better timed crop phenology. Siddique et al (2001) reported that early maturing genotypes had a better yield when planted early, flowered early, and produced seed yield before terminal drought. Indeed, by choosing an optimum planting date in which the crops may utilize available water efficiently to improve yield, chickpea water use efficiency may also increase. Moreover, a correct planting date for crops may ensure better water extraction and high water use efficiency. However, water extraction, water use and water use efficiency in any crop may vary with planting season. Cooler seasons with neutral day length (for chickpea) may reduce water use, improve grain yield and promote water us efficiency. Likewise, hot seasons may encourage high water use and lower crop water use efficiency. Thus it is important to determine whether the variation in water use and water use efficiency of chickpea is caused by variation in planting date and genotype or is caused by normal seasonal variation. Although the effect of planting date on water use and water use efficiency in chickpea is well documented (Anwar et al., 2003; Zhang et al., 2010), there are very few reports in literature that have clearly shown soil profile water extraction patterns in response to chickpea planting date. Moreover, these studies did not make any attempts to isolate the effects of temperature and moisture caused by different planting dates on water use and water use efficiency

2.9 Effect of planting date on radiation use efficiency of chickpea crop

Photosynthetically Active Radiation (PAR) is the waveband that is useful to plants (Monteith, 1977) and is defined as the intercepted radiation in the 400 to 700 nanometre waveband (Ting and Giacomelli, 1987). Quantitative understanding of the ability of chickpea genotypes *(Cicer arietinum* L.*)* to convert intercepted (PAR) into dry matter under different planting dates is important in enhancing adaptive strategies to improve chickpea yield. Studies have compared performance of different chickpea genotypes grown under different management strategies using PAR, Radiation Use Efficiency (RUE), harvest index (HI) and yield (Y_i), (Tesfaye et al., 2006; Ogola, 2015). Much earlier, Gullagher and Biscoe (1978) reported a direct relationship between Y_i and PAR, HI and RUE as illustrated by equation 2.1.

$$Y_i = IR * RUE * HI \qquad (2.2)$$

Whilst HI tends to be constant and genotype dependent (Gifford et al, 1984; Hay and Walker, 1989), IR and RUE can be manipulated for yield improvement using several management strategies such as the choice of planting date within a season (Tsimba, 2011).

Planting early or late in the season may affect radiation capture depending on climate factors such as temperature (Andrade et al., 1993; Soltani et al., 2006), rainfall and vapour pressure deficit (VPD) (Kiniry et al., 1998). For example, in the Southern Hemisphere, early crop growth in late plantings normally coincides with winter solstice; a condition when the sun is furthest away from the earth, sunshine hours are shortest and temperatures also very low (Nautical Almanac office, 1999). Thus available radiation will be reduced and this may affect total intercepted radiation. In contrast, early planting of chickpea during winter season may allow the crop to take advantage of available radiation when winter solstice is at least 55 days from planting date. This could be the reason why early plantings normally experience higher temperatures (by 2^{o}C - 3^{o}C) during vegetative stage compared with late planting. Moreover, earlier reports have shown that radiation capture is directly affected by temperature (Muchow et al., 1990). Suggestions are that low temperatures may reduce total intercepted radiation in plants (Andrade et al., 1993; Soltani et al., 2006). Thus, because of temperature variations between planting dates, early planting may capture more radiation compared with late planting during early vegetative growth stage. However, whether the anticipated increase in radiation capture in early planting may be used efficiently to produce biomass and grain yield is not known and may depend on the planted genotypes (Miralles et al., 1997) and other factors.

Variation in radiation capture amongst genotypes may be due to differences in growth habit brought about by their indeterminate nature, and differences in days to maturity and in canopy structures (Mariscal et al., 2000). For example, variation in growth habit, where a plant may exhibit different source and sinks strength at the same time may affect crop canopy cover and hence affect amount of intercepted radiation (Miralles and Slafer, 1997). Also, different source and sink balance amongst genotypes may affect biomass and grain yield and hence affect radiation use efficiency (Sinclair and Muchow, 1999). In addition, variation in canopy structure in terms of number of branches, plant height and leaf orientation and phyllochron may affect the amount of intercepted radiation (Miralles and Slafer, 1997). Furthermore, early maturing cultivars exhibit faster canopy growth that captures more radiation during early stages of growth compared with late maturing cultivars (Confalone et al., 2009). In contrast, by having a longer growth duration, late maturing cultivars have more time to capture radiation and thus compensate for low radiation capture during early stages of growth (Brown, 2006; Singh et al., 2008). However, the indeterminate nature of chickpea makes it difficult to understand how radiation is captured at reproduction stage as this will be affected by translocation of assimilates which is also affected by planting date. Moreover radiation interception may depend on the interaction between genotype and environmental factors (Jha et al., 2012). Knowledge of genotype x environment interaction as influenced by planting date is far elusive and has rarely been reported in literature.

Indeed, a correct planting date for chickpea crop may ensure stable radiation capture, across genotypes and environments. However, the amount of intercepted radiation and the efficiency of utilization of the radiation may also depend on planting season, which normally varies from time to time. For instance, hot season conditions may reduce radiation interception and radiation use efficiency even if photosynthetically active radiation is maximised (Sinclair and Muchow, 1999). In contrast, a season characterised by moderate temperatures combined with high photosynthetically active radiation may improve radiation interception, photo thermal quotient, increase radiation use efficiency and improve grain yield (Muchow et al., 1990; Dreccer et al., 2018). Therefore, it is not easy to make inferences about the effects of planting date and genotype on radiation use and radiation use efficiency because of the effects of seasonal variations. Moreover, depending on level of residual moisture or rain drizzle that intermittently fall during the winter season, some seasons may have greater moisture during vegetative growth stage and this may affect radiation capture (Anwar et al., 2003).

2.10 Effect of planting date on thermal time of chickpea

Planting chickpea under different dates within the same season may expose the crop to varying temperature and water regime during critical stages of growth and development (Siddique and Sedgley, 1986). For example, late sowing in winter season (Southern Hemisphere) may be associated with effects of low soil temperatures which causes uneven and slow seedling emergence (Chaturvedi and Dua 2003), reduced plant growth and poor canopy development (Soltani et al., 2006). In contrast, early planting may expose the crop to relatively warm temperatures during early seedling emergence stage that improves seedling vigour, growth and development. Moreover, the rate of canopy development and leaf expansion during early development are influenced by ambient temperature (10^{o}C -25^{o}C) (Khanna-Chopra and Sinha, 1987). High temperatures at reproductive stage, experienced by late planted crops during winter season may reduce chickpea growing season length and consequently yield as potential evapotranspiration exceeds plant available water in the absence of irrigation water supply. However, there is dearth of information in literature on the interaction of planting date and genotypes on heat use efficient and consequently the final yield.

Tsimba et al. (2013) argued that genotypes that tolerate early temperature stress or are adapted to cool conditions may have some comparative advantage in late sowings. In addition, Siddique and Sedgley, (1986), reported variation in chickpea grain yield between early and late maturing varieties and attributed that variation to temperature and moisture conditions experienced by the crops. More recently, Chijiike et al. (2017), found that late planting was associated with insufficient thermal time for biomass accumulation because of reduced growing season length, particularly to late maturing genotypes. Thus, the interaction of planting date and genotypes may affect accumulated growing degree days and heat use efficiency in chickpea due to differences in temperature regime. Moreover, although the effect of temperature on chickpea plant height, and number of primary and secondary branches is well documented in literature (Siddique and Sedgley, 1986; Iannucci et al*.,* 2008; Keatinge et al*.,* 1998; Papastylianou et al*.,* 2011), the magnitude of the effect of temperature on chickpea crop yield sown on diverse dates within the same season has hardly been reported.

The effect of planting date and genotype on AGDD, HUE, plant height and number of primary and secondary branches has been reported in cotton (Gudadhe et al*.,* 2013), forage legumes (Papastylianou et al*.,* 2011), and wheat (Ottman et al*.,* 1997), but, there is little evidence in literature on the effects of planting date and genotype on AGDD, HUE, plant height and number of primary and secondary branches per plant in chickpea.

2.11 Climate change and planting date

Projections of future climate place the Southern Africa region at the forefront of climate change vulnerability with negative potential impacts on revenue from dryland farming (IPPC, 2007). Agricultural activities, particularly chickpea production will be affected by changes in temperature and precipitation conditions in large parts of sub Saharan Africa (Muller et al*.,* 2011, Waha et al*.,* 2012). Under climate change, many areas in Southern Africa will experience a decrease in the length of the growing season, while in some highland areas, rainfall changes may lead to prolonged growing season (Tadross, et al*.,* 2009). Therefore farmers’ choice of planting date may be an important adaptation strategy to changing climate conditions (Waha et al*.,* 2012). Omotosho et al*.* (2000) and Odekunle (2003) suggested that a reliable understanding of rainfall onset and cessation times will greatly assist in timely preparation of farmlands, mobilization of seed and will thus reduce the risk involved in planting too early or too late. Waha et al*.* (2012), working with historical data from 1971-2000 and GCM model projections from 2070-2099, reported that sowing dates in sub Saharan Africa were changing with changes in the start of the main rainy season. A delay in the onset of the rainy season, particularly in the semi-arid Southern Africa region will delay the date of planting (Tadross, et al. 2009) and may result in crops extending their growing date into the winter season. This situation may be beneficial to chickpea production since high summer temperatures may affect flowering and pod setting (Devasirvatham et al*.,* 2012). An early cessation of the rainy season has an effect of cutting short the growing season of crops and may result in crops failing to reach physiological maturity.

The strategies of using planting date as an adaptive response to climate change have been observed among farmers in Tanzania (O' Brien et al., 2000), Semi-arid West Africa (Mation and Kristjanson, 1988), and South Africa (Benhin, 2006). In the Northern Provinces of South Africa, 3% of surveyed farmers shift their planting date to match delayed or early rainfall (Gbetibouo, 2009), whilst in the Nile Basin of Ethiopia, 5% shift their planting date (Deressa et al., 2009). Hassan and Nhemachena (2008) reported that 16% of farmers in Southern Africa use planting date as an adaptive strategy to climate change. Therefore, this study aims to build on earlier studies on the use of planting date in response to climate change, focusing on the response of chickpea crop physiological traits such as water use, radiation use efficiency, water use efficiency, flower retention and pod abortion on planting date.

2.12 Crop models

Developing easy-to-use decision-support tools that may assess the effect of planting date on biomass and grain yield may help in the development of planting date guide lines for chickpea in the region (Mhizha et al., 2014). Such decision support tools (in the form of simulation models) may help to account for likely biomass and yield projections of crops under different climate scenarios. This information is important to improve field crop management strategies, whilst giving an understanding of the likely behaviour of crops when faced by conditions of temperature increase of the order 2 to 3^{o}C, or when global carbon dioxide concentration has increased to 600 pmm by 2100 (IPCC, 2014). A number of crop simulation models have been developed over years; these include CERES model (Jones and Kiniry, 1986), CropSyst model (Stockle et al., 2003), Cropwat model (FAO, 1992), DSSAT cropping system model (Jones et al., 2003), APSIM model (Keating et al., 2003), ELCROS model, (de Wit, et al., 1970) etc. However, these models were rarely used by farmers, extension personnel, and planners. Furthermore, these models require an extended number of variables and input parameters which are not easily available for the diverse range of crops and sites around the world.

AquaCrop model has been identified as a better model for crop yield simulation because of its sufficiency, transparency, simplicity, accuracy and robustness (Steduto et al., 2006, 2009; Raes et al 2011). AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate yield of most of the major field and vegetable crops (Steduto et al., 2009). The model may be used to simulate probabilistic crop yield for different planting date.

2.13 AquaCrop model

AquaCrop is a water driven crop yield simulation model (Raes et al., 2009; Steduto et al., 2009). The model has been used in multiple herbaceous crops for simulating biomass and yield under varying field conditions in different locations across the world. The model can be used to develop optimum planting period for different crops to increase and stabilize crop yields. The model simulate aboveground biomass for each day during crop cycle as a function of temperature stress coefficient, water productivity and the summation of the ratio of crop transpiration to the reference evapotranspiration (equation 2.3).

$$B = K_{sb}.W^{P^*}\sum\frac{T_r}{ETo} \qquad 2.3$$

Where K_{sb} is the temperature stress coefficient. WP* is water productivity and is normalised for place and climate. T_r is crop transpiration and is normalised for climate by reference evapotranspiration for each day of transpiration.

Grain yield (Y): AquaCrop simulate grain yield as a product of above ground biomass and the harvest index as shown by equation 8.2.

$$Y = f_{HI}.HI_o.B \qquad 2.4$$

Where f_{HI} is a multiplier factor which considers various stresses that may affect harvest index (HI) from its reference value. HI is the ratio of grain yield to total dry matter of the crop and is affected by water and temperature stress before the beginning of yield formation, at flowering and during yield formation. Thus HI is constantly adjusted during yield formation (Raes et al., 2011) and is affected by water stress during various stages of crop development.

Transipiration (Tr): AquaCrop calculate transpiration as a product of crop coefficient (K_{cb}) and the evaporative power of the atmosphere (ETo). This calculation is done by considering water stress factor (Ks) as shown in equation 8. 3. In circumstances where water shortage provokes closure of stomatal openings, a stress coefficient (Ks_{sto}) is considered.

$$Tr = K_s.(K_{cbx}.\ CC^*).ETo \qquad 2.5$$

Where CC* is crop canopy cover adjusted for interrow micro-advection.

The operation of AquaCrop, its interface between organs and climate factors and how it determines several parameters for crop growth is shown in Fig 8.1 below.

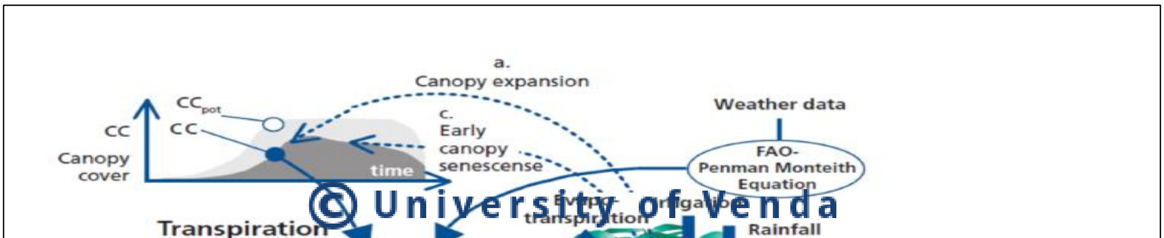


Figure 2.2 AquaCrop flow chart. The dotted arrows indicate the processes (a - e) affected by water stress. CC is simulated canopy cover, CCpot the potential canopy cover, Kssto the water stress for stomatal closure, Kc,tr the crop transpiration coefficient, ETo the reference evapotranspiration, WP* the normalized water productivity for ETo and air CO2 concentration and HI the harvest index (Raes et al., 2009; Steduto et al., 2012).

Currently, AquaCrop model has been calibrated and validated for maize (Hsiao et al., 2009, Garcia-Vila and Fereres, 2012), soybeans (Steduto et al*.,* 2009), sorghum, sunflower (Stricevic et al*.,* 2011), teff (Araya et al., 2010), tomatoes (Rinaldi et al*.,* 2011, Katerji, et al., 2013), wheat (Xiangxiang et al*.,* 2013, Jin et al*.,* 2014), sugar beet (Stricevic et al*.,* 2011), potatoes (Casa et al*.,* 2013), rice (Shrestha et al*.,* 2013), cotton (Farahani et al*.,* 2009) and barley (Araya et al., 2010). However, no published information is readily available on the calibration and validation of AquaCrop for chickpea. Therefore the objective of this study was to calibrate and validate the performance of AquaCrop model in simulating attainable yields in chickpea in response to varying planting dates at a representative site of the dry environments of North Eastern South Africa.

2.14 Using Global circulation models for generating climate data in evaluating crop yield.

Climate change experiments to simulate past, current and future crop biomass and yield should include simulations for climate assessments as tabled in the fifth assessment report (AR 5) of the International Panel of Climate Change (IPCC). CMIP 5 agreement functions by setting out standards and guidelines for model simulations in order to evaluate how realistic models are in predicting the past, current and the future climate. These predictions should be conducted on two time scales notably near term (up to 2035) and long term (up to 2100 and beyond). CMIP 5 experimental design is composed of the following suites; i) decadal hind casts and prediction simulations, ii) long term simulations and, iii) atmospheric-only simulations for especially computationally-demanding models.

For models to be used in simulating climate data, they should have completed all core simulations within the suit of CMIP 5's long term experiments and some prioritised tier 1 and 2 experiments aimed at determining simulations of "forced with specified concentrations" that are consistent with near representative pathway scenario (RCP 2.6), medium mitigation representative pathway scenario (RCP 4.5 and 6.0) and high representative pathway emissions scenario (RCP 8.5). Some of the models that have followed CMIP 5 agreement include; the Beijing Normal University Earth System Model (BNU-ESM), The Euro-Mediterranean Centre on Climate Change (CMCC), Centre for National Researches in Meteorology (CNRM), The Geophysical Fluid Dynamics Laboratory (GFDL), IPSL-CM5, BNU-ESM.

Representative Concentration Pathways RCPs) are a set of four pathways containing concentration and land use trajectories (Vuuren et al., 2011). The purpose of RCPs is to provide information on possible trajectories for the main forcing agents of climate change that are relevant to the current literature on climate change (Riahi et al., 2011; Fisher et al., 2007; IPCC, 2008). It is expected that climate modellers will use the time series of future concentrations and emissions of greenhouse gases and air pollutants and land use change from the four RCPs when conducting climate model experiments (Moss et al., 2010). The four RCPs together span a radiative forcing values ranging from 2.6 wm^{-2} to 8.4 wm^{-2} (Riahi et al., 2011). RCPs were named according to radiative forcing target level for the year 2100, and include a very low forcing level (RCP 2.6), two medium stabilizations scenarios (RCP 4.5 and RCP 6.0) and one high baseline emission scenarios (RCP 8.5) (Vuuren et al., 2011). RCP 4.5 and RCP 8.5 were used for this study. RCP 4.5 is characterised by stabilization without overshooting pathway to 4.5 wm^{-2} at stabilization after 2100 (Thomson et al., 2010). RCP 4.5 is a scenario of long term global emissions of greenhouse gases short-lived species, and land use, land cover which stabilize at 4.5 wm^{-2} in the year 2100. Riahi et al, (2011), characterised RCP 8.5 as a pathway that combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in absence of climate policies. RCP 8.5 is characterised by stabilization without overshooting pathway to 8.5 wm^{-2} at stabilization after 2100 (Moss et al., 2010).

References

Albrizio, R and Steduto, P. 2005. Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea: II. Water use efficiency and comparison with radiation use efficiency. *Agricultural and Forest Meteorology*, *130*(3-4), pp.269-281.

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 1999. Water use efficiency of chickpea (Cicer arietinum L.) cultivars in Canterbury: effect of irrigation and sowing date. *Agronomy New Zealand*, *29*, pp.1-8.

Auld, D.L., Bettis, B.L., Crock, J.E. and Kephart, K.D., 1988. Planting date and temperature effects on germination, emergence, and seed yield of chickpea. *Agronomy Journal*, *80*(6), pp.909-914.

Bahl, P.N., Singh, K.P. and Singh, D., 1984. Evaluation of tall chickpea genotypes for normal and late sowings. *Indian Journal of Agricultural Sciences*.

Benhin, J.K., 2006. *Climate change and South African agriculture: Impacts and adaptation options*, 21. CEEPA discussion paper.

Berger, J.D., Turner, N.C., Siddique, K.H.M., Knights, E.J., Brinsmead, R.B., Mock, I., Edmondson, C. and Khan, T.N., 2004. Genotype by environment studies across Australia reveal the importance of phenology for chickpea (Cicer arietinum L.) improvement. *Australian Journal of Agricultural Research*, *55*(10), pp.1071-1084.

Bhattacharya, A. and Pandey, P.S., 1999. Physiological studies in chickpea varieties: Effect of temperature and time of sowing. *Indian Journal of Pulses Research*, *12*(1), pp.57-64.

Biabani, A. and Katozi, M., 2011. Correlation and relationships between seed yield and other characteristics in chickpea (Cicer arietinum L.) cultivars under deterioration. *African Journal of Agricultural Research*, *6*(6), pp.1359-1362.

Casa, A., Ovando, G., Bressanini, L. and Martínez, J., 2013. Aquacrop model calibration in potato and its use to estimate yield variability under field conditions. *Atmospheric and Climate Sciences*, *3*(03), p.397.

Clarke, H.J. and Siddique, K.H.M., 2004. Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research*, *90*(2-3), pp.323-334.

Cumming, G. and Jenkins, L., 2011. Chickpea: Effective Crop Establishment Sowing Window, Row Spacing, Seeding Depth & Rate. *Australian Pulse Bulletin PA*, *7*.

de Wit, C.D., Brouwer, R. and De Vries, F.P., 1970. The simulation of photosynthetic systems. In *Proceedings of the IBP/PP technical meeting, Trebon, 14-21 September 1969.* pp. 47-70.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T. and Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global environmental change*, *19*(2), pp.248-255.

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Tokachichu, R.N., Trethowan, R.M. and Tan, D.K., 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology*, *39*(12), pp.1009-1018.

Dixit, J.P., Pillai, P.V.A. and Namdeo, K.N., 1993. Response of chickpea (Cicer arietinum) to planting date and irrigation schedule. *Indian Journal of Agronomy*, *38*, pp.121-121.

Fang, X., Turner, N.C., Yan, G., Li, F. and Siddique, K.H., 2009. Flower numbers, pod production, pollen viability, and pistil function are reduced and flower and pod abortion increased in chickpea (Cicer arietinum L.) under terminal drought. *Journal of experimental botany*, *61*(2), pp.335-345.

FAO., 2016. Production Yearbook. Food and Agricultural Organization of the United Nations, Rome, 58.

Farzaneh, M., Wichmann, S., Vierheilig, H. and Kaul, H.P., 2009. The effects of arbuscular mycorrhiza and nitrogen nutrition on growth of chickpea and barley. *Pflanzenbauwissenschaften*, *13*(1), pp.15-22.

Fisher, B., Nakicenovic, N., Alfsen, K., Corfee Morlot, J., De la Chesnaye, F., Hourcade, J.-C., Jiang, K., Kainuma, M., La Rovere, E., Matysek, A., Rana, A., Riahi, K., Richels, R., Rose, S., van Vuuren, D.P., Warren, R., 2007. Chapter 3: Issues related to mitigation in the long-term context. In: Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Gallagher, J.N. and Biscoe, P.V., 1978. Radiation absorption, growth and yield of cereals. *The Journal of Agricultural Science*, *91*(1), pp.47-60.

Gan, Y.T., Miller, P.R., Liu, P.H., Stevenson, F.C. and McDonald, C.L., 2002. Seedling emergence, pod development, and seed yields of chickpea and dry pea in a semiarid environment. *Canadian Journal of Plant Science*, *82*(3), pp.531-537.

Gaur, P.M., Tripathi, S., Gowda, C.L., Ranga Rao, G.V., Sharma, H.C., Pande, S. and Sharma, M., 2010. Chickpea seed production manual.

Gbetibouo, G.A., 2009. *Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa,* 849. Intl Food Policy Reasech Institute.

Gholipoor, M. and Shahsavani, S., 2008. Simulation study of past climate change effect on chickpea phenology at different sowing dates in Gorgan, Iran.

Hassan, R. and Nhemachena, C., 2008. Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. *African Journal of Agricultural and Resource Economics*, *2*(1), pp.83-104.

Hussain, A., Nawaz, M. and Chaudhry, F.M., 1998. Radiation interception and utilization by chickpea (Cicer arietinum L.) at different sowing dates and plant populations. *Journal of Agricultural and Marine Sciences [JAMS]*, *3*(2), pp.21-25.

Hawtin, G.C. and Singh, K.B., 1980, February. Kabuli-desi introgression: problems and prospects. In *Proc Int Workshop on Chickpea Improvement, ICRISAT, Hyderabad, India* (pp. 51-56).

Intergovernmental Panel on Climate Change., 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.

IPCC., 2008. Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies. IPCC Expert Meeting Report on New Scenarios, Noordwijkerhout, Intergovernmental Panel on Climate Change,

IPCC., 2014. Climate change: impacts, adaptation, and vulnerability. Part B: regional aspects. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.J., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA pp 688.

Jin, X.L., Feng, H.K., Zhu, X.K., Li, Z.H., Song, S.N., Song, X.Y., Yang, G.J., Xu, X.G. and Guo, W.S., 2014. Assessment of the AquaCrop model for use in simulation of irrigated winter wheat canopy cover, biomass, and grain yield in the North China Plain. *PloS one*, *9*(1), p.e86938.

Jones, C.A., Kiniry, J.R. and Dyke, P.T., 1986. *CERES-Maize: A simulation model of maize growth and development*. Texas A& M University Press.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T., 2003. The DSSAT cropping system model. *European journal of agronomy*, *18*(3-4), pp.235-265.

Kabir, A.F., Bari, M.N., Karim, M.A., Khaliq, Q.A. and Ahmed, J.U., 2009. Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed condition. *Bangladesh Journal of Agricultural Research*, *34*(2), pp.335-342.

Karrou, M. and Oweis, T., 2012. Water and land productivities of wheat and food legumes with deficit supplemental irrigation in a Mediterranean environment. *Agricultural Water Management*, *107*, pp.94-103.

Kaur, M. and Singh, N., 2005. Studies on functional, thermal and pasting properties of flours from different chickpea (Cicer arietinum L.) cultivars. *Food Chemistry*, *91*(3), pp.403-411.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N., Meinke, H., Hochman, Z. and McLean, G., 2003. An overview of APSIM, a model designed for farming systems simulation. *European journal of agronomy*, *18*(3-4), pp.267-288.

Keatinge, J.D.H., Qi, A., Wheeler, T.R., Ellis, R.H. and Summerfield, R.J., 1998. Effects of temperature and photoperiod on phenology as a guide to the selection of annual legume cover and green manure crops for hillside farming systems. *Field Crops Research*, *57*(2), pp.139-152..

Kerr, N.J., Siddique, K.H.M. and Delane, R.J., 1992. Early sowing with wheat cultivars of suitable maturity increases grain yield of spring wheat in a short season environment. *Australian Journal of Experimental Agriculture*, *32*(6), pp.717-723.

Koocheki, A., Nassiri, M., Soltani, A., Sharifi, H. and Ghorbani, R., 2006. Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran. *Climate Research*, *30*(3), pp.247-253.

Kumar, S., Nayyar, H., Bhanwara, R.K. and Upadhyaya, H.D., 2010. Chilling stress effects on reproductive biology of chickpea. *Journal of SAT Agricultural Research*, *8*, pp.1-14.

Ladizinsky, G., 1975. A new Cicer from Turkey. *Notes Roy. Bot. Gard. Edinburgh*, *34*(2), pp.201-202.

Leport, L., Turner, N.C., Davies, S.L. and Siddique, K.H.M., 2006. Variation in pod production and abortion among chickpea cultivars under terminal drought. *European Journal of Agronomy*, *24*(3), pp.236-246.

Leport, L., Turner, N.C., French, R.J., Barr, M.D., Duda, R., Davies, S.L., Tennant, D., Siddique, K.H.M. (1999). Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. *European Journal of Agronomy*. 11, pp 279–291.

Madzivhandila, T., Ogola, J.B.O. and Odhiambo, J.J.O., 2012. Growth and yield response of four chickpea cultivars to phosphorus fertilizer rates. *J. Food, Agric. Environ*, *10*, pp.451-455.

Malhotra, R.S., Pundir, R.P.S. and Slinkard, A.E., 1987. Genetic resources of chickpea. *The chickpea*, pp.67-81.

Mathews, C., Ogola, J.B.O., Vilane, M. and Gaur, P.M. 2011. Optimum planting period for chickpea in one dry region of South Africa. Paper presented at the 10th African Crop Science Society Conference held in Maputo, Mozambique, 10-13 October 2011.

Mation, P.J. and Kristjanson, P.M., 1988. Farmers' Strategies to Manage Crop Risk in the West African Semi-Arid Tropics.

Mhizha, T., Geerts, S., Vanuytrecht, E., Raes, D. and Makarau, A., 2014. Use of the FAO AquaCrop model in developing sowing guidelines for rainfed maize in Zimbabwe. *Water SA*, *40*(2), pp.233-244.

Mohammadi, E., Asghari, H., Gholami, A., Abbasdokht, H., Rahim, M. (2013). Effects of mycorrhiza inoculation and phosphorus fertilizer on yield and some growth indices of chickpea (*Cicer arietinum* L.) Hashem cultivar. *Technical Journal of Engineering and Applied Sciences*. 3, pp190-197.

Monteith, J.L. and Moss, C.J., 1977. Climate and the efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *281*(980), pp.277-294.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., Van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T. and Meehl, G.A., 2010. The next generation of scenarios for climate change research and assessment. *Nature*, *463*(7282), pp.747.

Mubvuma. M. T., Ogola. J. B. O., Mhizha. T. 2015. The effect of planting date on growth and yield of chickpea (*Cicer* arietinum) under future climate scenario.

Muchinda, M. 2009. “Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize”. *Climate Research*. 40, pp 147-161.

Mukesh, C., Dhananjai, S., Nishi, R., Vijay, K., and Singh, R. B. 2010. Effect of growing degree days on chickpea production in Bundekland Region of Uttar Predesh. *Journal of Food Legumes*. 23, 41-43.

Müller, C., Cramer, W., Hare, W.L. and Lotze-Campen, H., 2011. Climate change risks for African agriculture. *Proceedings of the National Academy of Sciences*, *108*(11), pp.4313-4315.

Nayyar, H., 2005. Putrescine increases floral retention, pod set and seed yield in cold stressed chickpea. *Journal of agronomy and crop science*, *191*(5), pp.340-345.

Ngetich, K. F., Reas, D., Shisanya, C. A., Mugwe, J., Mucheru-Muna, M., Mugendi, D. N and Diels, D., 2012. Calibration and Validation of AquaCrop model for Maize in Sab-humid and semi-arid regions of central highlands of Kenya. Third RUFORUM Biennial meeting 24-28 September 2012, Entebbe, Uganda.

Nielsen, D.C., 2001. Production functions for chickpea, field pea, and lentil in the central Great Plains. *Agronomy Journal*, *93*(3), pp.563-569.

Niharika, S., 2013. Flower numbers, Pod production, pollen viability are reduced with flower and pod abortion increased in Chickpea *(Cicer arietinum L)* under heat stress. Research Journal of Recent Sciences, 2, pp116-119.

O'Brien, K., Sygna, L., Næss, L.O., Kingamkono, R. and Hochobeb, B., 2000. Is information enough? User responses to seasonal climate forecasts in southern Africa. *CICERO Report*.

Odekunle, T.O., 2004. Rainfall and the length of the growing season in Nigeria. *International journal of climatology*, *24*(4), pp.467-479.

Ogola, J.B.O. and Thangwana, N.M., 2013. Water use efficiency of summer sown chickpea in a tropical environment: Response to genotype and planting density. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.2689-2695.

Ogola, J.B.O., Thangwana, N. and Mathews, C., 2009. Water use of chickpea: response to genotype and planting density. In *9th African Crop Science, Conference Proceedings, Cape Town, South Africa, 28 September-2 October 2009* (pp. 217-219). African Crop Science Society.

Ogola, J.B., Madzivhandila, T. and Odhiambo, J.J., 2013. Water use of chickpea (Cicer arietinum L.): Response to genotype and phosphorus fertilizer rates in winter and summer sowings. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.1341-1347.

Ogola, J.B., 2015. Growth and yield response of chickpea to Rhizobium inoculation: productivity in relation to interception of radiation. *Legume Research: An International Journal*, *38*(6).

Ottman, M.J., Husman, S.H., Gibson, R.D. and Rogers, M.T., 1997. Planting Date and Sorghum Flowering at Mariopa. *Forage and Grain Agriculture Report, Publication AZ1059*.

Oweis, T., Hachum, A. and Pala, M., 2004. Water use efficiency of winter-sown chickpea under supplemental irrigation in a Mediterranean environment. *Agricultural water management*, *66*(2), pp.163-179.

Parthasarathi, T., Velu, G. and Jeyakumar, P., 2013. Impact of crop heat units on growth and developmental physiology of future crop production: A review. *Journal of Crop Science and Technology*, *2*(1), pp.2319-3395.

Piggin, C., Haddad, A., Khalil, Y., Loss, S. and Pala, M., 2015. Effects of tillage and time of sowing on bread wheat, chickpea, barley and lentil grown in rotation in rainfed systems in Syria. *Field Crops Research*, *173*, pp.57-67.

Polley, H.W., 2002. Implications of atmospheric and climatic change for crop yield and water use efficiency. *Crop science*, *42*(1), pp.131-140.

Raes, D., Sithole, A., Makarau, A. and Milford, J., 2004. Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. *Agricultural and forest meteorology 125 (3-4)*, pp. 177-185.

Redden, B and Berger, J., 2007. History and origin of chickpea. In: Yadav SS, Redden B, Chen W, Sharma B (eds.). Chickpea Breeding and Management. CAB International, Wallingford. pp.1-13.

Regan, K.L., Siddique, K.H.M., Brandon, N.J., Seymour, M. and Loss, S.P., 2006. Response of chickpea (Cicer arietinum L.) varieties to time of sowing in Mediterranean-type environments of south-western Australia. *Australian Journal of Experimental Agriculture, 46(3),* pp. 395-404.

Richards, R.A., Hunt, J.R., Kirkegaard, J.A. and Passioura, J.B., 2014. Yield improvement and adaptation of wheat to water-limited environments in Australia—a case study. *Crop and Pasture Science*, *65*(7), pp.676-689.

Sanjeewa, T., 2008. *Physico-chemical properties of chickpea flour, starch and protein fractions and their utilization in low-fat pork bologna* (Doctoral dissertation).

Saxena, M.C. and Singh, K.B., 1987. *The chickpea*. Commonwealth Agricultural Bureaux International.

Sinclair, T.R. and Muchow, R.C., 1999. Radiation use efficiency. In *Advances in agronomy* (Vol. 65, pp. 215-265). Academic Press.

Singh, A., Aggarwal, N., Aulakh, G.S. and Hundal, R., 2012. Ways to maximize the water use efficiency in field crops–A review. *Greener Journal of Agricultural Sciences*, *2*(4), pp.108-129.

Singh, D.P., Peters, D.B., Singh, P. and Singh, M., 1987. Diurnal patterns of canopy photosynthesis, evapotranspiration and water use efficiency in chickpea (Cicer arietinum L.) under field conditions. *Photosynthesis research*, *11*(1), pp.61-69.

Singh, F. and Diwakar, B., 1995. Chickpea botany and production practices.

Singh, K.B. and Saxena, M.C., 1996. Winter chickpea in Mediterranean-type environments.

Singh, N., Kaur, M. and Sandhu, K.S., 2005. Physicochemical and functional properties of freeze-dried and oven dried corn gluten meals. *Drying technology*, *23*(4), pp.975-988.

Singh, P., Nedumaran, S., Boote, K.J., Gaur, P.M., Srinivas, K. and Bantilan, M.C.S., 2014. Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European journal of agronomy*, *52*, pp.123-137.

Smith, M., 1992. *CROPWAT: A computer program for irrigation planning and management* (No. 46). Food & Agriculture Org.

Steduto, P., Fereres, E., Hsiao, T.C. and Raes, D., 2006, January. 'Yield Response to Water': The FAO revision framework and the crop-water productivity model AquaCrop. In *Proceedings*.

Steduto, P., Hsiao, T. C., Raes, D., Fereres, E., 2009. AquaCrop: The FAO crop model to simulate yield response to water: 1. Concepts and underlying principles. *Agronomy Journal*. 101, 426-435.

Stöckle, C.O., Donatelli, M. and Nelson, R., 2003. CropSyst, a cropping systems simulation model. *European journal of agronomy*, *18*(3-4), pp.289-307.

Summerfield, R.J., Hadley, P., Roberts, E.H., Minchin, F.R. and Rawsthorne, S., 1984. Sensitivity of Chickpeas (Cicer arietinum) to Hot Temperatures during the Reporductive Period. *Experimental Agriculture*, *20*(1), pp.77-93.

Tadross, M., Randriamarolaza, L., Rabefitia, Z. and Zheng, K.Y., 2008. Climate change in Madagascar; recent past and future. *World Bank, Washington, DC*, *18*.

Tanno, K.I. and Willcox, G., 2006. The origins of cultivation of Cicer arietinum L. and Vicia faba L.: early finds from Tell el-Kerkh, north-west Syria, late 10th millennium BP. *Vegetation History and Archaeobotany*, *15*(3), pp.197-204.

Tawaha, A.R., Turk, M.A. and Lee, K.D., 2005. Adaptation of chickpea to cultural practices in a Mediterranean type environment. *Res. J. Agric. Bio. Sci*, *1*, pp.152-157.Tesfaye, K., Walker, S. and Tsubo, M., 2008. Comparison of water relations, leaf gas exchange and assimilation of three grain legumes under reproductive period water deficit. *Journal of Agronomy*.

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

Thomson, B.D., Siddique, K.H.M., Barr, M.D. and Wilson, J.M., 1997. Grain legume species in low rainfall Mediterranean-type environments I. Phenology and seed yield. *Field Crops Research*, *54*(2-3), pp.173-187.
Toker, C., 2009. A note on the evolution of kabuli chickpeas as shown by induced mutations in Cicer reticulatum Ladizinsky. *Genetic Resources and Crop Evolution*, *56*(1), pp.7-12.

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Van der Maesen, L.J.G., 1972. *Cicer L., a monograph of the genus, with special reference to the chickpea (Cicer arietinum L.), its ecology and cultivation* (Doctoral dissertation, Veenman).

Van der Maesen, L.J.G., 1987. Origin, history and taxonomy of chickpea. In *The chickpea* (pp. 11-34).

Vanderpuye, A.W., 2010. *Canopy architecture and plant density effect in short-season chickpea (Cicer arietinum L.)*(Doctoral dissertation).

Vanuytrecht, E., Raes, D. and Willems, P., 2011. Considering sink strength to model crop production under elevated atmospheric CO2. *Agricultural and Forest Meteorology*, *151*(12), pp.1753-1762.

Verghis, T.I., McKenzie, B.A. and Hill, G.D., 1999. Phenological development of chickpeas (Cicer arietinum) in Canterbury, New Zealand. *New Zealand journal of crop and horticultural science*, *27*(3), pp.249-256.

Viatcheslav, V., Kharin, V. V., Zwiers, F. W., Zhang, X., Hegerl, G. C., 2007. Temperature and precipitation extremes in IPCC ensemble of global coupled model simulations. *Journal of climate change*. 20, pp1419-1444.

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.F. and Masui, T., 2011. The representative concentration pathways: an overview. *Climatic change*, *109*(1-2), p.5.

Waha, K., Müller, C., Bondeau, A., Dietrich, J.P., Kurukulasuriya, P., Heinke, J. and Lotze-Campen, H., 2013. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change*, *23*(1), pp.130-143.

Walter, L. F., Anthony, O. E., Karuturi, P. C. R., Sridhar, R. G., 2014. Climate change: Trnsforming Rural Livelihoods. Climate change management. Illustrated edition. Published by Springer. ISBN 3319130005, 97833191 30002. 233 pages.

Wamari, O.J., Sijali, V.I., Heng, N.K., Joseph, M.M. and Esilaba, O.A., 2012. Use of Aquacrop model to predict maize yields under varying rainfall and temperature in a semi-arid environment in Kenya. *Journal of Meteorology and Related Sciences (Online)*, *6*(3), pp.23-32.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Whish, J., Sindel, B., Jessop, R. and Felton, W., 1999. Integrated weed management in chickpea: how much do we know?. In *12th Australian Weeds Conference, Papers and Proceedings, Hobart, Tasmania, Australia, 12-16 September 1999: Weed management into the 21st century: do we know where we're going?* (pp. 183-186). University of Tasmania.

Chapter 3

Effect of planting date on chickpea (*Cicer arietinum*) flower and pod abortion.

Abstract

The objective was to determine the effect of planting date on flower retention, pod abortion and number of pods per plant of five chickpea genotypes grown under different water regimes in 2014 and 2015, and to investigate the relationship between grain yield with flower retention, pod abortion and number of pods per plant. Two separate field experiments were laid out in a split-plot design, with main plots comprising of planting date (1st of May being the early planting, 14th of May as the control/normal planting and 28th of May as the late planting) and chickpea genotypes as sub-plot factor. The genotypes were four desi types (Range 1, Range 3, Range 4 and Range 5) sown in 2014 and the 4 desi types and one Kabuli type (ICCV99010) sown in 2015. Experiment one was well watered (received total of 430 & 435 mm in 2014 & 2015, respectively), and experiment two was watered three times (at planting (60 mm), flowering (58 mm) and pod formation 57 mm). Number of pods per

plant varied with planting date, genotype and year of planting, whilst flower retention and pod abortion varied significantly with genotype and year but was not affected by the main effects of planting date or by the interaction between the treatments in experiment one. In contrast, flower retention and pod abortion were affected by interaction between planting date and genotype and planting date and year of planting and genotype and year in experiment two. Clearly early planting date may be the most suitable sowing date for chickpea in this environment but this may vary with availability of moisture.

3.1 Introduction

Grain yield in chickpea is determined by the number of flowers retained per plant, level of podding or fruit set, number of seeds per pod and number of pods per plant (Zaiter and Barakat, 1995; Niharika, 2013). The plant produces many flowers and pods but the final number of mature seed at harvest maturity is comparably lower than the produced flowers and pods. Flower retention in chickpea ranges from 40 to 95% depending on genotype, environmental conditions and different levels of crop management, and pod abortion has been observed to range from 54 to 73% in moisture stressed crop and 42-67% in well-watered chickpea crop (Nayyar, 2005; Fang *et al.,* 2010; Kumar *et al*., 2010). Indeed, most of the flowers and pods abort before physiological maturity. Abortion and abscission rate of flowers and pods depends on factors such as temperature stress (Siddique and Sedgley, 1986; Singh *et al.*, 1989; Clarke and Siddique, 2004; Wang *et al.,* 2006; Thakur *et al.,* 2010; Devasirvatham *et al.,* 2012), photoperiod (Verghis *et al*., 1999), genotype (Siddique and Sedgeley, 1986), light intensity (Verghis *et al*., 1999), cloudiness (Dahiya *et al*., 1987), rainfall (Varma and Kumari, 1978) and moisture stress (Tay, 1992; Leport *et al.,* 2006).

The physiological effects of temperature and water stress that lead to flower abortion and poor pod set are known (Clark and Siddique, 2004; Nayyar, 2005; Kumar *et al*., 2010; Leport *et al*., 1999; Leport *et al*., 2006). High temperature (> 32^{o}C) causes anther indehiscence, reduced pollen production, as well as shrunken stigma, style and ovary (Devasirvatham *et al.*, 2012), and chilling temperature stress causes egg and secondary nucleus in ovules to disintegrate before fertilization takes place (Kumar *et al*., 2010). Also, water stress causes impairment of stigma, pollen or pistil function in chickpea (Fung *et al.,* 2010; Leport *et al.*, 2006), thus causing flower and pod abortion. Therefore selection of a planting period in which a crop germinates, grows and develops to produce seed yield whilst minimising temperature and water stress conditions that cause flower and pod abortion may increase yield.

In the North Eastern part of South Africa, where chickpea is grown during winter, early planting normally results in average daily mean temperatures of around 13 ^{o}C and 17 ^{o}C during vegetative and reproductive stage, respectively. In contrast, late planting leads to an average daily mean temperature of around 14 ^{o}C and 19 ^{o}C at vegetative and reproductive stage, respectively. However, Clarke and Siddique (2004) reported that temperatures for chickpea during reproductive stage should be above 15 ^{o}C, which is comparable to optimum temperatures of 20 ^{o}C to 26 ^{o}C which had been observed much earlier (Summerfield, 1984). Therefore, there is a variation of 3 ^{o}C to 4 ^{o}C between the average daily mean temperatures of the study area and the reported optimum temperatures for reproduction stage in chickpea. Whether this variation in temperature is significant to affect flower and pod losses and hence grain yield is not known and needs investigating. Nonetheless, there is evidence suggesting that even a 1 ^{o}C variation in temperature may cause variation in grain yield (Kalra *et al*., 2008).

Moreover, although the current study was conducted during winter season when there is no rainfall in the region, with the exception of rain drizzle which is often insignificant for crop growth and development, winter sowing is usually done soon after the summer rainfall, and thus early plantings may benefit from residual moisture during seedling emergence and early vegetative growth. In contrast, late planting could be affected by moisture stress unless there is supplementary irrigation. It is clear from the foregoing that the negative effects of temperature and moisture stress on flower retention, pod abortion and grain yield may be ameliorated through management strategies such as manipulation of planting date and genotype selection (Dhima *et al*., 2015; Silim *et al.,* 1990; Saxena, 1981).

However, the response of flower retention and pod abortion to different sowing dates under contrasting water regimes has hardly been reported in literature. We hypothesised that both moisture stress and high temperature stress would affect flower retention and pod abortion at flowering and pod development stage. Consequently, we instituted two experiments, one well-watered throughout the growth period, and the other watered only three times (at planting, first flowering and first podding stage). This design was meant to help in distinguishing whether the effect of sowing time on flower retention and pod abortion was due to temperature or water stress. Therefore our objective was to determine the (i) effect of planting date and genotype on flower retention and pod abortion, and (ii) association of this effect with grain yield of chickpea grown under different water regimes.

3.2 Materials and Methods

3.2.1 Study site

The study was conducted at the University of Venda's experimental farm in Thohoyandou (22°58.08´S and 30°26.4´E, and 595m above sea level), South Africa during 2014 and 2015 winter seasons. The area receives an annual rainfall of ± 500 mm that falls predominantly in summer. However, this study was conducted during winter season when there is no rainfall, with the exception of rain drizzle which is often ineffective for crop growth and development. The total drizzle received during the growth period of the crop was 0.21 mm (2014 and 0.29 mm (2015). The average maximum and minimum temperatures for the site are 31 and 18°C, respectively (Tadross *et al*., 2006). The site is characterised by a deep well-drained clay soil, classified as Leptic Cambisols (Fey, 2010), and low pH, low levels of organic carbon, total carbon (C), nitrogen (N), available phosphorus (P), low C:N ratio (Lusiba et al.,2016). A crop rotation system that includes maize, cassava and legume is normally practised on the farm.

3.2.2 Experimental design

Two separate experiments were laid out in a split-plot design, with main plots replicated three times and comprising of planting date (1st of May being the early planting, 14th of May as the control / normal planting, and 28th of May being the late planting date). These planting dates were selected based on previous studies (Mathews *et al*., 2009). Chickpea genotypes, four desi genotypes (Range 1, Range 3, Range 4 and Range 5) in 2014, and 4 desi types and one Kabuli genotype (ICCV99010) in 2015, were used as sub-plot factor. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV9901 are medium maturing and have an erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structure, respectively. The selected genotypes ensured we had different maturity groups with contrasting canopy structures.

Experiment one was well watered throughout the season, and experiment two was watered three times (at planting, flowering and pod formation). The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment one and 175 mm in experiment two, whilst 435 mm and 235 mm was applied in Experiment one and two, respectively in 2015. The variation in the total amount of water applied in 2014 and 2015 was caused by differences in initial soil moisture.

Sowing was done manually in rows that were 30 cm apart to achieve a planting density of thirty-three plants per m^{-2} (Thangwana and Ogola, 2012) in both experiments and seasons. Nitrogen (N) was applied in the form of Limestone Ammonium Nitrate (LAN 28 % N) at a rate of 40 N kg ha^{-1} and phosphorus (P) was applied in the form of Single Superphosphate (SSP 20.3 % P), at a rate of 50 kg P ha^{-1} (Madzivhandila *et al.,* 2012). The experiments were kept free from weeds throughout the season.

3.2.3 Measurements

3.2.3.1 Weather records

An automatic weather station that is already established at the experimental site (approximately 100 m from the experiments) was used to record rainfall (mm), maximum and minimum air temperatures (°C), solar radiation (MJ m^{-2} d^{-1}), vapour pressure deficit (VPD) and reference evapotranspiration (mm) for each day during the trial period in both seasons.

3.2.3.2 Number of pods per plant

All plants from a 2.4 m^2 quadrant of the two innermost rows of each experimental unit were cut at ground level at harvest maturity. The pods were manually removed from a sub-sample of 10 plants from each plot and counted; the data was then used to determine the number of pods per plant.

3.2.3.3 Flower retention and pod abortion

At flowering stage, three plants from the innermost two rows, in each experimental unit were randomly selected (and tagged) and the date of start and end of the flowering stage for each plant was recorded. All new and visible flowers from the selected plants were counted and tagged (by red colour string) daily between 10 00 h and 12 00 h until end of flowering stage. Flower retention was determined at the end of flowering stage by counting all red strings tied to flowers, including those red strings tagged to newly developing pods. A flower position which had a red string tied to it but with no flower was considered as an aborted flower. Flower retention was calculated using equation 1 (Vergihs *et al*., 1999).

$$\textit{Flower Retention (\%)} = \frac{Total\ number\ of\ retained\ flowers\ per\ plant}{Total\ number\ of\ flowers\ per\ plant}\ x100 \qquad 3.1$$

At podding stage, all new pods were tagged daily with a white string. Pod abortion, defined as all pods that were shed off from the plant or those which were not fertile (Leport *et al.,* 2006), was determined at physiological maturity according to equation 2 (Vergihs *et al*., 1999). Infertile pods consisted of small pods (diameter less than 2mm) with small, or no seed or large pods with no seed (Leport *et al.,* 2006). Total number of pods that were shed off from the plant was determined by counting all white string positions where the pods were missing. At harvest maturity, all pods from the selected 3 plants were harvested and partitioned into pod wall and seeds. The partitioned samples were weighed and the number of seeds per pod were counted and used to determine infertile pods. Mechanical flower and pod abscission was negligible and hence ignored.

$$\textit{Pod Abortion (\%)} = \frac{Total\ number\ of aborted\ pods\ per\ plant}{Total\ number\ of\ pods\ per\ plant}\ x100 \qquad 3.2$$

3.2.3.4 Crop phenology

Days to 50% flowering was determined by counting days from date of crop emergence until the onset of flowering period (Purushothaman *et al*., 2014). Onset of flowering was identified in each plot when 50% or more of the plants had at least one open flower (Vergihs *et al*., 1999). There was an overlap in flowering and podding in all plots because the genotypes used in the study were indeterminate. Therefore end of flowering date was identified as the date when 50% of plants in any plot had mature pods (Vergihs *et al*., 1999). Physiological maturity was recorded on the day when at least 50% of pods in a plot had turned yellow (Purushothaman *et al*., 2014).

3.2.4 Data analysis

Analyses of variance were performed using the GenStat statistical software version 14. The analysis model was Planting date * Genotype * Year. Each experiment was analysed separately. Significant differences between treatments were determined at 5% level using the standard error of differences of means (SED). Grain yield data has been reported elsewhere (Mubvuma et al., 2018). Also, regression plots of grain yield against flower retention, pod abortion and number of pods per plant were developed to quantify the magnitude of the relationships.

3.3 Results

3.3.1 Weather data

The mean temperature was around 19.45 ^oC in 2014 and 20.12 ^oC in 2015 (Fig.3.1 and 3.2). Lowest mean temperature was 15.0 ^oC and 17.27 in 2014 and 2015, respectively. There were variations in maximum and minimum temperatures experienced during vegetative and reproduction stages by different planting date treatments over the growing seasons in the two experiments. In experiment I, the late planting date experienced lowest mean temperatures (17.5 ^oC & 19.0 ^oC, respectively in 2014 and 2015), and early planting experienced highest mean temperatures (18.6 ^{o}C in 2014 and 19.0 ^{o}C in 2015) during the vegetative stage (Fig. 3.1 & 3.2). During the reproductive stage, in contrast, early planting experienced lowest mean temperature (17.5 ^{o}C and 18.8 ^{o}C, respectively in 2014 and 2015), and late planting experienced highest mean temperature (18.1 ^{o}C and 20.2 ^{o}C in 2014 and 2015, respectively) (Fig.3.1 and 3.2).

In experiment two, late planting experienced lowest mean temperatures (17.6 ^{o}C and 18.0 ^{o}C in 2014 and 2015, respectively), and early planting experienced highest mean temperatures (19.5 ^{o}C and 19.4 ^{o}C, respectively in 2014 and 2015) at the vegetative stage (Fig. 3.1 and 3.2). In contrast, early planting experienced lowest mean temperatures (20.0 ^{o}C and 18.5 ^{o}C, respectively in 2014 and 2015), and late planting date experienced highest mean temperature (21.0 ^{o}C and 19.3 ^{o}C in 2014 and 2015, respectively) during the reproductive stage (Fig. 3.1 and 3.2). On average, maximum temperatures at reproduction stage were ≤30 ^{o}C in 2014 and ≤33 ^{o}C in 2015 in both experiments. Similarly, mean minimum temperatures at reproduction stage were ≤12 ^{o}C (2014) and ≤10 ^{o}C (2015) in both experiments.

We divided the reproductive stage into flowering and podding stages in order to be able to analyse the prevailing temperature regimes during these critical stages of growth. During the podding stage, highest maximum temperatures were recorded in late planted crop in experiment one (33.2 ^{o}C) and experiment two (33.1 ^{o}C) (Table 3.1). The early planting date had the lowest maximum temperature of 29.2 ^{o}C and 28.5 ^{o}C in experiment one and two, respectively. The lowest minimum temperatures in experiment one and two, respectively ranged from 13.5 ^{o}C to 13.8 ^{o}C in early planted crops, and 11.0 ^{o}C to 11.9 ^{o}C in late planted crop. The mean temperatures were highest in late planted crop, being 22.6 ^{o}C in experiment one and 22.1 ^{o}C in experiment two. In contrast, lowest mean temperatures were 21.4 ^{o}C and 21.2 ^{o}C for experiments one and two respectively, recorded in early planted crop.

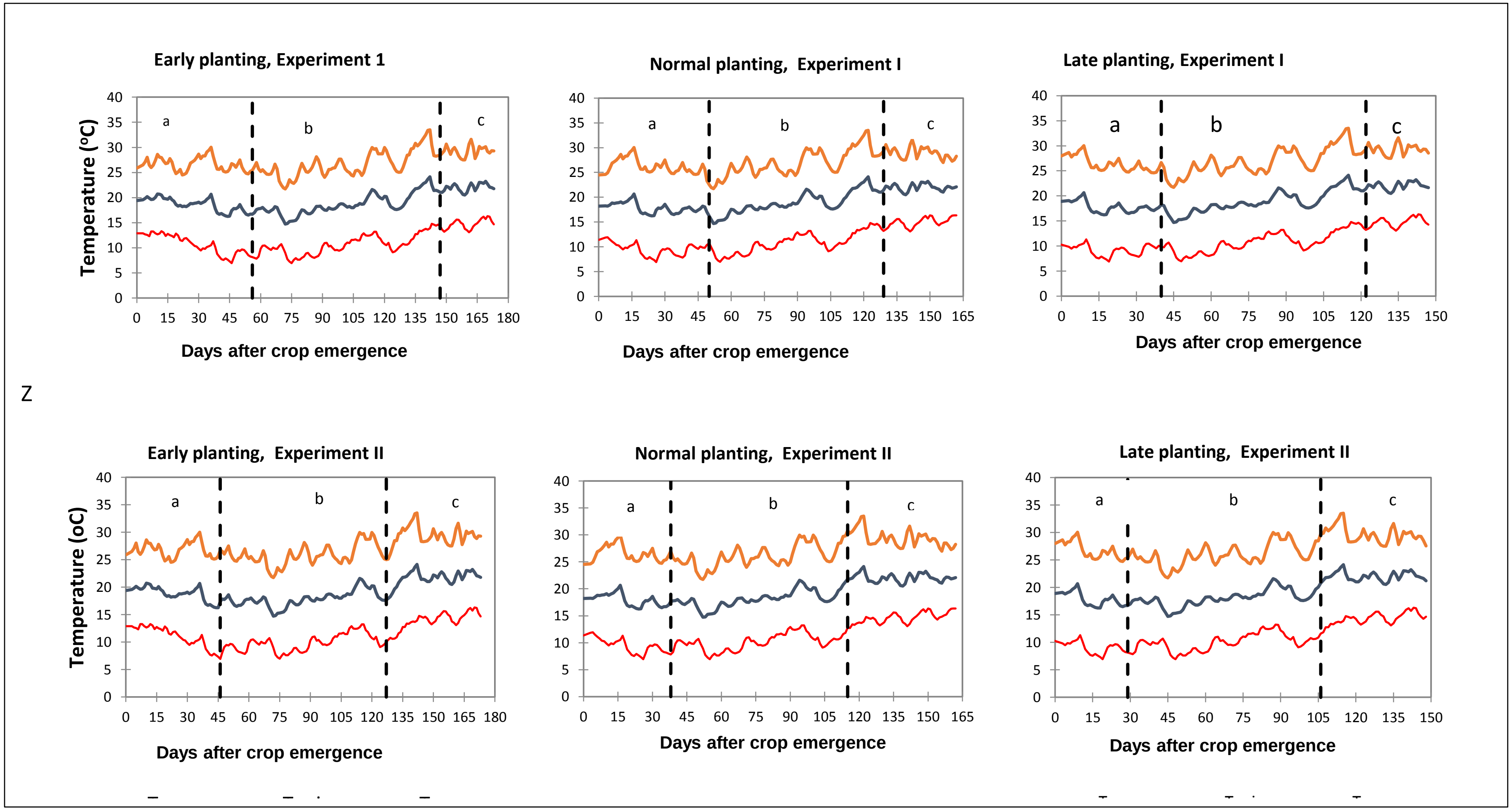


Fig 3.1 Temperature variations experienced at vegetative and reproductive stages in season 1. a, b and c, respectively are vegetative, reproduction and maturity stages of crop growth

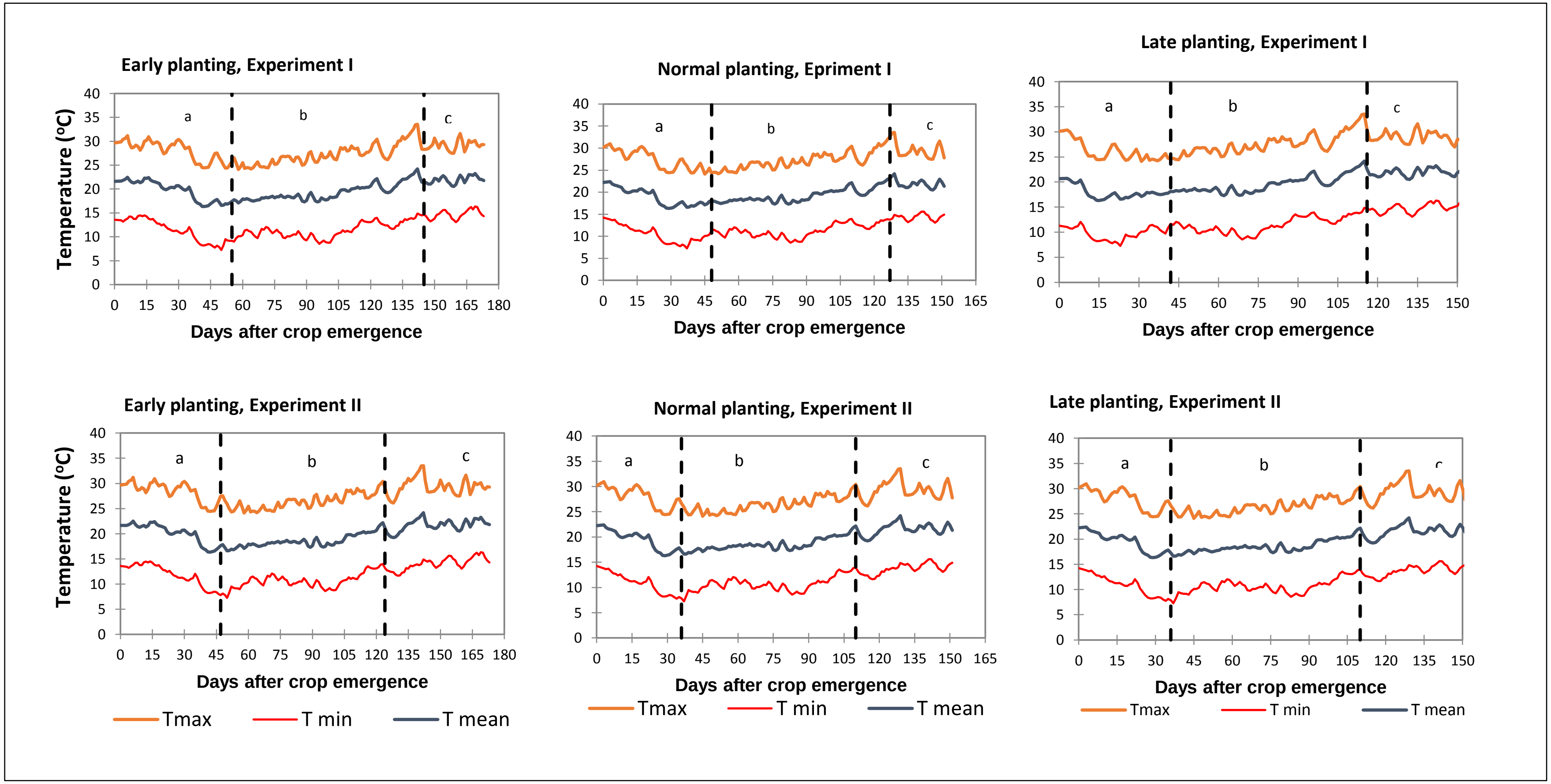


Fig 3.2 Temperature variations experienced at vegetative and reproductive stages in season 2. a, b and c, respectively are vegetative, reproduction and maturity stages of crop growth

3.3.2 Flower retention

Flower retention varied significantly with genotype (G) and year (Y) in the well-watered experiment (Table 3.2). The cultivar ICCV 9901 had the highest (54.7%), and Range 1 the lowest (33.5%) flower retention. Flower retention was more than 2-fold greater in 2014 (57.5%) compared to 2015 (26.4%) (Table 3.1).

In experiment II which was irrigated only 3 times, in contrast, planting date, PD ($p<0.001$), G ($p<0.01$), Y ($p<0.001$), PD x G ($p<0.01$), PD x Y ($p<0.001$) and G x S ($p<0.01$) affected flower retention (Table 3.2). With normal planting, no significant differences were observed amongst the genotypes (Fig. 3.3a). However, ICCV9901 recorded the highest flower retention with both early and late planting, and Range 4 and Range 3 the lowest at early and late planting, respectively (Fig. 3.3a). Flower retention was lower in 2015 compared to 2014 but the decrease in flower retention in 2015 was greater with early planting compared to normal and late planting (Fig.3.3b). Although flower retention was, on average, greater in 2014 compared to 2015, the decrease in flower retention in 2015 varied with genotypes (Fig.3.3c). Also, flower retention was greater (by 44.8%) in Experiment I compared to Experiment II.

3.3.3 Pod abortion

Pod abortion was greater in 2015 (15.1%) compared to 2014 in the well-watered experiment but the effect of planting date and genotype was not significant (Table 3.2). On average, pod abortion was 96.6%) greater in experiment two compared to experiment one (Table 3.1).

In the limited irrigation experiment in contrast, pod abortion was significantly affected by planting date ($p<0.001$), year ($p<0.01$), PD x G ($p<0.001$), PD X Y ($p<0.01$) and G x Y ($p<0.01$); relative to the control, early sowing decreased pod abortion by 0.27% day^{-1}, and late sowing sowing increased pod abortion by 0.29% day^{-1} (Table 3.2). However, the effect of planting date on pod abortion was also subject to an interaction with genotype and year. There was no significant difference in pod abortion amongst the genotypes at normal and late planting date but Range 4 recorded the highest and ICCV9901 the lowest pod abortion at early planting date (Fig. 3.4a). Similarly, there was no significant difference in pod abortion between the years at late planting but pod abortion was greater in 2015 compared to 2014 at both normal and early planting (Fig. 3.4b). Pod abortion did not vary with year in Range 3 but was greater in 2015 compared to 2014 for the rest of the genotypes; pod abortion was greater by 32.2% (Range 4) to 132.7% (Range 1) in 2015 compared to 2014 (Fig. 3.4c).

Table 3.1 Effect of Planting date and Genotype on flower retention (%), pod abortion (%) and total number of pods per plant at harvest maturity.

Experiment	Treatment										P (F-ratio)						
	EPD	**NPD**	**LPD**	**R1**	**R3**	**R4**	**R5**	**ICCV9901**	**S1**	**S2**	**PD**	**G**	**S**	**PD X G**	**PD x S**	**G x S**	**PD x G x S**
Flower retention (%)																	
Exp I	45.2	39.3	41.3	33.5^{d}	45.4^{b}	39.6^{c}	36.5^{cd}	54.7^{a}	57.5^{a}	26.4^{b}	ns	**	***	ns	ns	ns	ns
Exp II	36.8^{a}	27.1^{b}	23.3^{c}	28.5^{c}	27.9^{c}	22.2^{d}	31.6^{b}	35.8^{a}	41.6^{a}	16.5^{b}	***	**	***	**	***	**	ns
Pod abortion (%)																	
Exp I	13.6	10.8	12.6	12.1	11.8	12.4	12.0	13.5	9.6^{b}	15.1^{a}	ns	ns	***	ns	ns	ns	ns
Exp II	20.4^{c}	24.2^{b}	28.2^{a}	25.3	24.5	27.1	24.33	20.15	19.3^{b}	29.2^{a}	***	ns	***	**	**	**	ns
Total number of pods per plant																	
Exp I	74.7^{a}	66.8^{c}	70.4^{b}	70.6^{b}	68.4^{b}	71.9^{b}	68.6^{b}	80.5^{a}	74.6^{a}	69.3^{b}	**	**	**	ns	ns	ns	ns
Exp II	65.6^{a}	59.5^{b}	56.2^{c}	58.7^{c}	67.8^{a}	63.8^{b}	63.4^{b}	49.4^{d}	59.7	61.2	**	***	ns	**	***	ns	ns

SED (experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
Flower Retention	20.1	4.19	5.42	3.42	9.37	5.93	7.65	13.25
Pod abortion	16.5	1.43	1.85	1.17	3.20	2.03	2.62	4.53
Number of pods per plant	15.2	3.13	4.04	2.55	6.99	4.42	5.71	9.88
SED (experiment II)								
Flower Retention	17.4	2.92	3.60	2.38	6.52	4.12	5.33	9.29
Pod abortion	22.9	3.13	4.04	2.55	6.99	4.42	5.71	9.88
Number of pods per plant	12.8	2.48	3.21	2.03	5.55	3.51	4.53	7.85

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively
† EPD, NPD and LPD means Early planting date, Normal planting date and Late planting date respectively.
‡, PD and G means Planting date and Genotype Respectively. R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties.

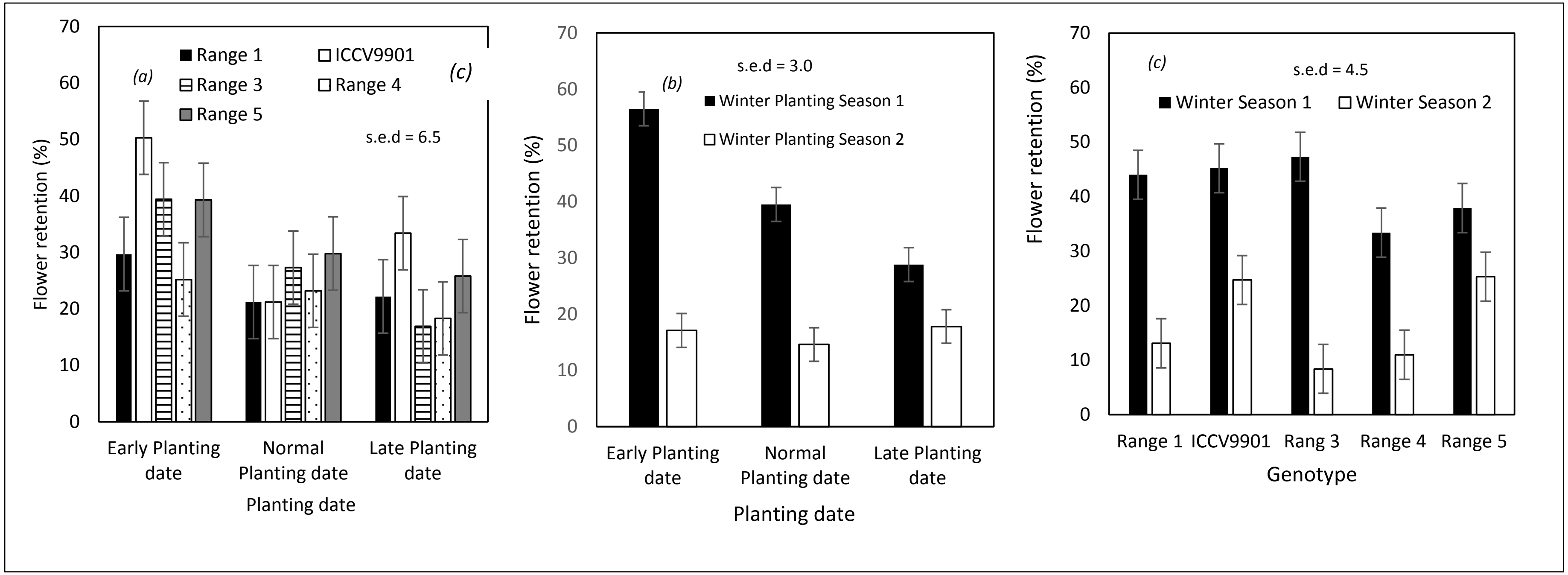


Fig 3.3 Effect of the interaction between planting date and genotype (a), planting date and season (b) and genotype and season (c) on flower retention in experiment II.

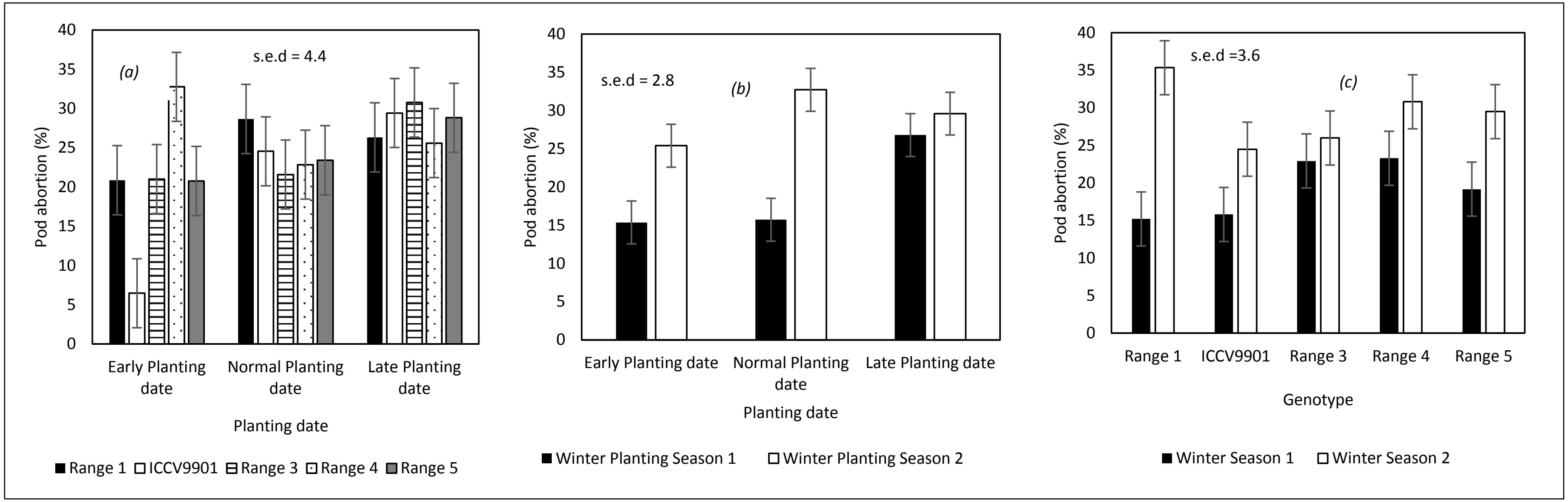


Fig 3.4 Effect of the interaction between planting date and genotype (a), planting date and season (b) and genotype and season (c) on pod abortion in experiment II.

3.3.4 Number of pods per plant.

Number of pods per plant varied significantly with planting date ($p<0.01$), genotype ($p<0.01$) and planting season ($p<0.01$) in experiment one (Table 3.2). Number of pods per plant was greater at early (74.7) compared with the control (66.8) and late (70.4) planting. However, the difference in number of pods per plant between the control and late planting was not significant. The number of pods per plant was, on average, greater in ICCV9901 (80.5) compared with the rest of the genotypes (69.9) which did not differ significantly amongst each other (Table 3.2). Number of pods per plant was greater in 2014 (74.6) compared to 2015 (69.3) planting season (Table 3.1).

In experiment II, the number of pods per plant was affected by PD ($p<0.01$), G ($p<0.001$), PD x G ($p<0.01$) and PD x Y ($p<0.001$) but the main effect of year was not significant (Table 3.2). Relative to the control, the average number of pods per plant was greater with early and lower with late planting (Table 3.2). In contrast to experiment I, the number of pods per plant in was lower in ICCV9901 compared with the other genotypes (Table 3.2). The interaction between planting date and genotype on number of pods per plant was such that there was no significant difference in number of pods per plant amongst the genotypes at early and late plantings but with the control, the number of pods per plant varied from 34.4 (ICCV9901) to 73.3 in Range 3 (Fig. 3.5a). Also, the number of pods per plant was subject to an interaction between planting date and year; there was no significant difference between the years at the normal planting date, number of pods per plant was lower in 2015 (60.8) compared to 2014 (70.3) with early planting, but it was greater in 2015 (64.4) compared to 2014 (48.0) with late planting (Fig. 3.5b).

3.3.5 Correlations and regression relationships amongst grain yield, flower retention and pod abortion and total number of pods per plant

Grain yield had a strong linear relationship with flower retention (R^2 = 0.879 & 0.714), pod abortion (R^2 = 0.893 & 0.792) and total number of pods per plant (R^2 = 0.783 & 0.644) in experiments I & II, respectively (Fig. 3.6a & 3.6b). This linear relationship was positive for flower retention (r = 0.838*** & 0.623*) and total number of pods per plant (r = 0.742* & 0.650*) but negative for pod abortion (r = 0.881*** & 0.686*), respectively in experiment I & II (Fig. 3.6a & 3.6b).

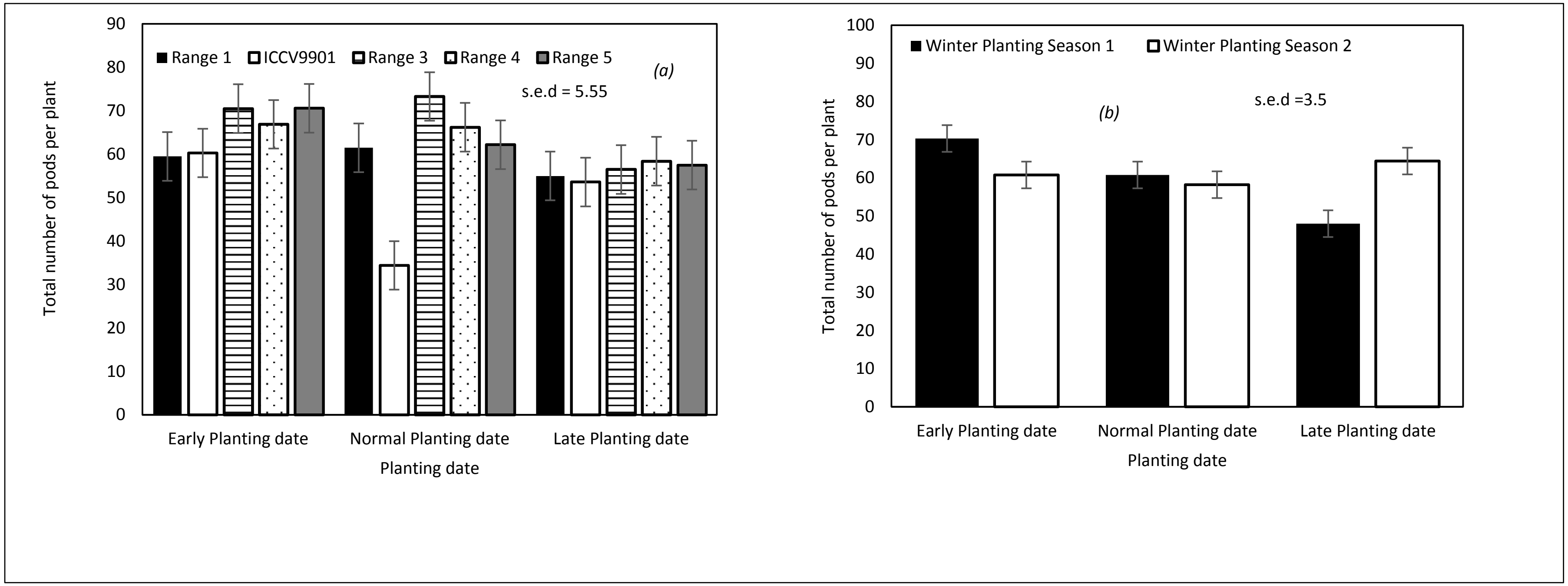


Fig 3.5 Effect of the interaction between planting date and genotype (a), planting date and season (b) on number of pods per plant in experiment II.

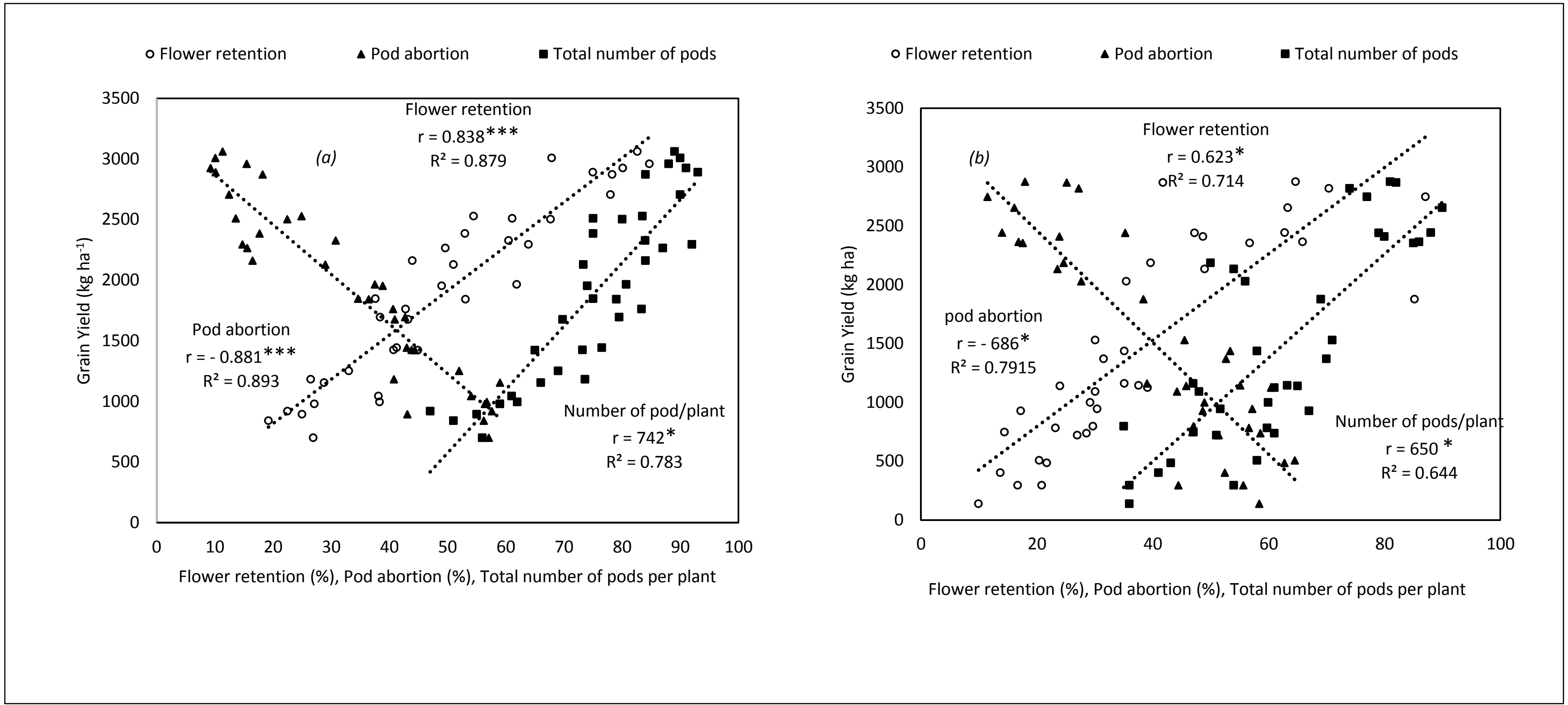


Fig 3.6 Correlations and regression relationships between grain yield and flower retention, pod abortion and total number of pods per plant. (a); experiment 1, (b); experiment II. * P ≥ 0.05, *** P ≥ 0.001.

3.4. Discussion

3.4.1 Flower retention

Flower retention varied with genotype in the well-watered experiment (Experiment one); this could be attributed partly to the variation in days to physiological maturity amongst the genotypes. The medium to late maturing kabuli cultivar, ICCV9901, had the highest flower retention, while the lowest flower retention was observed in Range 1 which is an early maturing desi cultivar. Previously, low flower retention in early maturing chickpea genotypes was attributed to low levels of putrescine (Songstad et al., 1990; Shen et al., 2000; Nayyar, 2005). However, we did not determine levels of putrescine in the current study and this needs further investigation. Our results and earlier findings (e.g., Nayyar 2005; Shen et al., 2000) suggest that days to physiological maturity may be an indirect indicator of flower retention amongst chickpea genotypes.

In contrast to genotype, planting date did not affect flower retention in experiment one suggesting that exposure of chickpea crop to high temperature conditions during the reproductive growth may not have a negative impact on flower retention if sufficient water is available to the crop, probably because the crop is able to maintain a relatively high canopy temperature depression (Purushothaman *et al*., 2014).

Flower retention was more than two-fold greater in 2014 compared to 2015; this variation in flower retention between the years was perhaps, in part, due to the variation in maximum and minimum temperatures during the reproductive stage between the two years. Maximum temperature at reproduction stage was ≤30 ^{o}C and ≤33 ^{o}C in 2014 and 2015, respectively across all the planting dates and genotypes in both experiments. In support of this, (Devasirvatham *et al*. (2012) reported that temperature greater than 32 ^{o}C may reduce flower retention in chickpea. Maximum temperature during reproductive growth in 2014 was clearly below this threshold.

In the limited irrigation experiment, i.e., experiment II, the interaction between planting date and genotype affected flower retention suggesting that the response of flower retention to planting date was not consistent among the genotypes when water was limiting. This inconsistent response could be attributed to a combination of environmental factors and plant physiological factors such as the level of plant hormones (Diby and Harshal, 2014), chemical inhibitors (Pang *et al*., 2017), gas exchange and limitations in photosynthates (Behboudian *et al*., 2001); these physiological factors are genotype-specific as well as temperature-dependent. It is apparent from our findings that the differences in maximum and minimum temperatures observed between planting dates affected the genotypes in a dissimilar manner suggesting a likely variation in thermotolerance amongst the genotypes used in the study (Nayyar and Chander, 2004; Srinivasan *et al.,* 1999). However, this apparent variation in thermotolerance amongst the genotypes was only observed where water was limiting. Therefore the negative impacts of planting date on flower retention in this region may be ameliorated through supply of sufficient moisture to the chickpea crop, especially during the reproductive stage of growth, and hence ensure the crop maintains a relatively high canopy temperature depression (Purushothaman *et al*., 2014).

Flower retention was lower in 2015 compared to 2014 but the decrease in flower retention in 2015 was greater with early planting compared to normal and late planting. The greater flower retention in 2014 compared to 2015 was probably to lower average and maximum ambient temperature across all genotypes during flowering in 2014 (21.0 ^{o}C & 30.7 ^{o}C) compared to 2015 (21.8 ^{o}C & 31.4 ^{o}C), respectively (Table 1). However, the decrease in flower retention in 2015 was greater with early planting compared to normal and late planting probably because of the greater decrease in average and maximum ambient temperature, respectively experienced by the early (1.4 ^{o}C & 2.1 ^{o}C) compared to the normal (0.5 ^{o}C & 0.6 ^{o}C) and late (0.5 ^{o}C & 0.4 ^{o}C) sown crop (Table 1).

The well-watered (430 mm in 2014 and 435 mm in 2015) experiment had greater flower retention compared with the limited irrigation (175 mm and 235 mm in 201 & 2015, respectively). In contrast, Experiment two was only irrigated three times (at planting, flowering and podding) giving a total of 175 mm in season one, and 235mm in season two. Although experiment II was irrigated at flowering and at podding, it is likely that the variation in flower retention between the two experiments was due to differences in water management at vegetative stage (Verghis, *et al*., 1999). The results do not contradict earlier findings that water stress during the reproductive stage leads to high flower abortion in chickpea (Tay, 1992; Leport *et al.,* 2006).

Grain yield had a strong positive linear relationship with flower retention in line with previous findings (Zaiter and Barakat, 1995). However, this relationship was stronger in the well-watered (R^2 = 0.879) compared to the limited irrigation (R^2 = & 0.714) experiment (Fig. 6a) thus suggesting that any management strategy that improves flower retention may also improve grain yield.

3.4.2 Pod abortion

2015 recorded greater (by 54.3%) pod abortion compared to 2014 in the well-watered experiment possibly due to differences in ambient temperature during the podding stage between the two years. For example, average maximum temperature during the podding stage was lower in 2014 (31.3 ºC) compared to 2015 (31.9 ºC) across all treatments (Table 1). It is likely that the higher maximum temperature in 2015 led to greater pod shedding. In support of this, Devasirvatham *et al*. (2012, 2013) reported that the critical temperature affecting pod set was ≥37 °C for heat-tolerant genotypes and >33 °C for heat-sensitive genotypes.

Although planting pod abortion was generally lower in early compared with normal and late sowings, this effect was not consistent among the genotypes. For example, there was no significant difference in pod abortion amongst the genotypes in normal and late sowings but with early sowing pod abortion was lowest in the kabuli genotype, ICCV9901 and highest in the desi genotype, Range 4. However, we expected the late maturing genotypes (Range 4 & 5) to benefit from early sowing, and to be affected negatively by late planting (Hankison, 2015). This was based on the hypothesis that late planting would reduce growing season length, resulting in late maturing genotypes failing to reach physiological maturity. Consequently, immature pods would abort, resulting in high rate of pod abortion. The possible cause of these unexpected results and needs further more in-depth investigation.

Pod abortion was generally greater in 2015 compared to 2014 but this effect varied with planting date and genotype. There was no significant difference in pod abortion between the years at late planting but pod abortion was greater in 2015 compared to 2014 at both normal and early planting. The greater pod abortion in 2015 was probably due to the 10% greater ambient temperature during podding stage in 2015 compared with 2014 (Table 1). The significant interaction between planting date and year on pod abortion could be attributed to the variation in temperature experienced at the podding stage by the different planting dates with years (Mirshekari *et al*., 2012; Tsimba *et al*., 2013). For example, the maximum temperatures experienced by early planting during the podding stage was greater by 3.3 ºC in 2015 compared to 2014. In contrast the ambient temperature difference experienced by the late sowing between 2014 and 2015 was only 0.3 ºC (Table 1). The results clearly show the advantage of early planting whilst penalising late planting. Similarly, Siddique and Sedgley, (1986) reported a 38% increase in pod abortion due to late planting.

Pod abortion had a strong negative linear relationship with grain yield but the relationship was weaker in the limited-irrigation experiment. This may suggest that the effect of pod abortion on grain yield may be influenced by factors such as moisture availability.

3.4.3 Number of pods per plant

The number of pods per plant is influenced by both flower retention and pod abortion (Zaiter and Barakat, 1995). In our study, the variations in number of pods per plant amongst planting dates mirrored the variations observed in flower retention amongst planting dates. Number of pods per plant was greater at early compared with the control and late planting, and could partly be attributed to lower ambient temperatures of 2 ^{o}C and 3 ^{o}C, respectively recorded in early planting compared with control and late planting (Verghis *et al*., 1999). Similar results have been reported in chickpea (Sivakumar and Singh, 2008; Kumar *et al.,* 2012) and other legumes (Chijioke *et al.,* 2010).

The greater number of pods per plant in 2014 compared to 2015 could be attributed partly to the lower mean temperature in 2014 (19.5 °C) compared with 2015 (20.1 °C). Mean daily temperatures at or exceeding 15 °C have been reported to cause flower abortion (Clarke & Siddique, 1998). Therefore it is likely that the greater flower abortion in 2015, resulting in lower number of pods per plant, was due to the mean ambient temperature being much greater than 15 °C in 2015.

The kabuli genotype, ICCV9901, recorded 15.2% (on average) greater number of pods per plant compared with the rest of the genotypes which did not differ significantly amongst each other in the well-watered experiment. This variation is likely due to a similar variation in flower retention with genotypes; ICCV9901 recorded 30.4% greater flower retention compared with the mean of all genotypes. Earlier, Thangwana and Ogola (2012) reported variation in number of pods per plant with chickpea genotypes at the site of the current study but did not give possible reasons for this variation. Other researchers concluded that the effect of genotype on number of pods per plant in chickpea could be due to differences in yield potential amongst the genotypes (Chijoke *et al*, 2010; Hasan and Deb, 2017).

In the limited irrigation experiment, the number of pods per plant also varied with planting date but this variation was influenced by genotype such that there was no significant difference in number of pods per plant amongst the genotypes at early and late plantings but with the control, the number of pods per plant was lower in the kabuli genotype, ICCV9901, compared to the desi ones. It is not clear why ICCV9901 had lower number of pods per plant at the normal planting date but it could perhaps be due to similar lower flower retention. Though non-significant, ICCV9901 recorded lower flower retention compared to the rest of the genotypes at the normal sowing (Fig. 3a).

Grain yield had a strong positive linear relationship with flower retention total number of pods per plant in experiments but the strength of the relationship was weaker in the limited irrigation experiment. These results clearly suggest that manipulation of any management strategy that improves number of pods per plant will lead to greater grain yield in chickpea.

3. 5 Conclusion

The study tested the hypothesis that planting date affects flower retention, pod abortion and number of pods per plant, and hence grain yield of five chickpea in two experiments subjected to contrasting moisture regimes. The hypothesis has not been disapproved. Flower retention and number of pods per plant were greater, and pod abortion lower with early planting in both experiments. However, in the limited irrigation the effect of planting date was subjected to an interaction with genotypes and year. Also, there was a significant positive linear relationship between grain yield and flower retention as well as number of pods per plant, and a negative relationship between grain yield and pod abortion. Therefore manipulation of planting date may be an important tool for improving grain yield of chickpea in this region. However, we recommend further more in-depth investigations using a wider range of sowing dates.

References

Auld, D.L., Bettis, B.L., Crock, J.E. and Kephart, K.D., 1988. Planting date and temperature effects on germination, emergence, and seed yield of chickpea. *Agronomy Journal*, *80*(6), pp.909-914.

Behboudian, M.H., Turner, N.C. and Palta, J.A., 2001. Gas exchange by pods and subtending leaves and internal recycling of CO 2 by pods of chickpea (Cicer arietinum L.) subjected to water deficits. *Journal of Experimental Botany*, *52*(354), pp.123-131.

Chijioke, O.B., Ifeanyi, U.M. and Blessing, A.C., 2010. Comparative study on growth and development of some accessions of local Germplasm of Bambara groundnut (Vigna subterrenea L. Verdc.) of Nigeria in two cropping seasons. *Journal of Crop Science and Biotechnology*, *13*(1), pp.21-27.

Clarke, H.J. and Siddique K.H.M., 1998. Growth and development. In: Loss S, Brandon N, Siddique K.H.M (eddition), The chickpea. Western Australia Agriculture Bulletin 1326. Department of Western Australia Agriculture.

Clarke, H.J. and Siddique, K.H.M., 2004. Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research*, *90*(2-3), pp.323-334.

Dahiya, B.S., Kumar, R. and Waldia, R.S., 1987. Thermoinsensitivity in chickpea. *International Chickpea Newsletter17*, *37*.

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Tokachichu, R.N., Trethowan, R.M. and Tan, D.K., 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology*, *39*(12), pp.1009-1018.

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Raju, T.N., Trethowan, R.M. and Tan, D.K., 2013. Reproductive biology of chickpea response to heat stress in the field is associated with the performance in controlled environments. *Field Crops Research*, *142*, pp.9-19.

Dhima, K., Vasilakoglou, I., Stefanou, S. and Eleftherohorinos, I., 2015. Effect of cultivar, irrigation and nitrogen fertilization on chickpea (Cicer arietinum L.) productivity. *Agricultural Sciences*, *6*(10), p.1187.

Diby, P and Lade, H., 2014. Plant-growth-promoting rhizobacteria to improve crop growth in saline soils: a review. *Agronomy for Sustainable Development*, *34*(4), pp.737-752.

Fang, X., Turner, N.C., Yan, G., Li, F. and Siddique, K.H., 2009. Flower numbers, pod production, pollen viability, and pistil function are reduced and flower and pod abortion increased in chickpea (Cicer arietinum L.) under terminal drought. *Journal of experimental botany*, *61*(2), pp.335-345.

Hasan, M.T. and Deb, A.C. 2017. Stability analysis of yield and yield components in chickpea (*Cicer arietinum* L). *Horticulture international Journal,* 1, pp. 1-12.

Hankinson, M.W., 2015. *Planting Date and Starter Fertilizer Effects on Soybean Growth and Yield* (Doctoral dissertation, The Ohio State University).

Hernandez, L.G. and Hill, G.D., 1983. Effect of plant population and inoculation on yield and yield components of chickpea (Cicer arietinum L.). In *Proc. Agron. Soc. NZ* (Vol. 13, pp. 75-79).

Kabir, A.F., Bari, M.N., Karim, M.A., Khaliq, Q.A. and Ahmed, J.U., 2009. Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed condition. *Bangladesh Journal of Agricultural Research*, *34*(2), pp.335-342.

Kalra, N., Chakraborty, D., Sharma, A., Rai, H.K., Jolly, M., Chander, S., Kumar, P.R., Bhadraray, S., Barman, D., Mittal, R.B. and Lal, M., 2008. Effect of increasing temperature on yield of some winter crops in northwest India. *Current science*, pp.82-88.

Kumar, S., Nayyar, H., Bhanwara, R.K. and Upadhyaya, H.D., 2010. Chilling stress effects on reproductive biology of chickpea. *Journal of SAT Agricultural Research*, *8*, pp.1-14.

KUMAR, N., Nandwal, A.S., Yadav, R., Bhasker, P., Kumar, S., Devi, S., Singh, S. and Lather, V.S., 2012. Assessment of chickpea genotypes for high temperature tolerance. *Indian J. Plant Physiol*, *17*(3&4), pp.225-232.

Leport, L., Turner, N.C., Davies, S.L. and Siddique, K.H.M., 2006. Variation in pod production and abortion among chickpea cultivars under terminal drought. *European Journal of Agronomy*, *24*(3), pp.236-246.

Leport, L., Turner, N.C., French, R.J., Barr, M.D., Duda, R., Davies, S.L., Tennant, D. and Siddique, K.H.M. 1999. Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. *European Journal of Agronomy* ,11, pp. 279–291.

Madzivhandila, T., Ogola, J.B.O. and Odhiambo, J.J.O., 2012. Growth and yield response of four chickpea cultivars to phosphorus fertilizer rates. *J. Food, Agric. Environ*, *10*, pp.451-455.

Mathews, C., Ogola, J.B.O., Gaur, P.M., Lengwati, M.D. and Gwata, E.T. 2009. Yield response of six chickpea genotypes to varying planting dates in Mpumalanga, South Africa. *Combined Congress 2009*. Book of Abstracts page 223.

MIRSHEKARI, M., MAJNOUNHOSSEINI, N., AMIRI, R., MOSLEHI, A. and ZANDVAKILI, O.R., 2012. Effects of sowing date and limited irrigation water stress on spring safflower (Carthamus tinctorius L.) quantitative traits.

Nayyar, H., 2005. Putrescine increases floral retention, pod set and seed yield in cold stressed chickpea. *Journal of agronomy and crop science*, *191*(5), pp.340-345.

Nayyar, H. and Chander, S., 2004. Protective effects of polyamines against oxidative stress induced by water and cold stress in chickpea. *Journal of Agronomy and Crop Science*, *190*(5), pp.355-365.

Pang, J., Turner, N.C., Khan, T., Du, Y.L., Xiong, J.L., Colmer, T.D., Devilla, R., Stefanova, K. and Siddique, K.H., 2016. Response of chickpea (Cicer arietinum L.) to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seed set. *Journal of experimental botany*, *68*(8), pp.1973-1985.

Purushothaman, R., Upadhyaya, H.D., Gaur, P.M., Gowda, C.L.L. and Krishnamurthy, L., 2014. Kabuli and desi chickpeas differ in their requirement for reproductive duration. *Field Crops Research*, *163*, pp.24-31.

Savithri, K.S., Ganapathy, P.S. and Sinha, S.K., 1980. Sensitivity to low temperature in pollen germination and fruit-set in Cicer arietinum L. *Journal of Experimental Botany*, *31*(2), pp.475-481.

Saxena, M.C., 1984, March. Agronomic studies on winter chickpeas. In *Proceedings of the Workshop on Ascochyta and Winter Sowing of Chickpea, Aleppo 4–7 May 1981* (pp. 123-137).

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Silim, S.N., Saxena, M.C. and Erskine, W., 1991. Effect of sowing date on the growth and yield of lentil in a rainfed Mediterranean environment. *Experimental Agriculture*, *27*(2), pp.145-153.

Singh, K.B., Malhotra, R.S. and Saxena, M.C., 1989. Chickpea evaluation for cold tolerance under field conditions. *Crop Science*, *29*(2), pp.282-285.

Sivakumar, M.V.K. and Singh, P., 1987. Response of chickpea cultivars to water stress in a semi-arid environment. *Experimental Agriculture*, *23*(1), pp.53-61.

Srinivasan, A., Saxena, N.P. and Johansen, C., 1999. Cold tolerance during early reproductive growth of chickpea (Cicer arietinum L.): genetic variation in gamete development and function. *Field Crops Research*, *60*(3), pp.209-222.

Soil Classification Working Group. 1991. Soil Classification: a taxonomic system for South Africa. Department of Agricultural Development, Pretoria, South Africa page 257.

Summerfield, R.J., Hadley, P., Roberts, E.H., Minchin, F.R. and Rawsthrone, S. 1984. Sensitivity of chickpea (*Cicer arietinum* L.) to hot temperatures during the reproductive period. *Experimental Agriculture*, 20, pp. 77-93.

Summerfield, R.J., Minchin, F.R., Roberts, E.H. and Hadley, P. 1980. The effects of photoperiod and air temperature on growth and yield of chickpea *(Cicer arietinum* L.). Proceedings of the International Workshop on Chickpea Improvement, Hyderabad, 28 February-2 March. Patancheru, ICRISAT 121-149.

Tadross, M.A., Gutowski, W.J., Jr, Hewitson, B.C., Jack, C.J. and New, M. 2006. MM5 simulations of inter-annual change and the diurnal cycle of southern African regional climate. *Theory and Applications of Climate*, 86, pp. 63-80.

Tay, U.J., 1992. Seeding date effects on faba bean yields in two agroecological areas of southern Chile [Vicia faba]. *FABIS*.

Thakur, P., Kumar, S., Malik, J.A., Berger, J.D. and Nayyar, H., 2010. Cold stress effects on reproductive development in grain crops: an overview. *Environmental and Experimental Botany*, *67*(3), pp.429-443.

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

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Varma, S.K. and Kumari, P., 1978. Nature, extent, periodicity and intensity of flower and pod shedding in gram (Cicer arietinum L.). *Legume research*.

Verghis, T.I., Hill, G.D. and McKenzie, B.A., 1993. Effect of sowing date, nitrogen and rhizobium inoculation on flowering and development of yield in chickpeas. In *Proceedings Agronomy Society of New Zealand* (Vol. 23, pp. 93-98).

Verghis, T.I., McKenzie, B.A. and Hill, G.D., 1999. Phenological development of chickpeas (Cicer arietinum) in Canterbury, New Zealand. *New Zealand journal of crop and horticultural science*, *27*(3), pp.249-256.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Zaiter, H.Z. and Barakat, S.G., 1995. Flower and pod abortion in chickpea as affected by sowing date and cultivar. *Canadian Journal of Plant Science*, *75*(2), pp.321-327.

Chapter 4

Effect of planting date and genotype on biomass and yield of chickpea

Abstract

Manipulation of planting date and genotype selection are important management practices for improving chickpea yield. This study assessed the effect of planting date (PD), genotype on biomass accumulation and grain yield of five chickpea genotypes grown under different water regimes. Two experiments were laid out in a split-plot design, with main plots comprising of planting date (1st of May being the early planting, 14th of May as the control/normal planting, and 28th of May being the late planting date) and chickpea genotypes as the sub-plot factor. (Range 1, Range 3, Range 4 and Range 5) planted in 2014 and (Range 1, Range 3, Range 4 and Range 5, ICCV9901) planted in 2015 cropping season. Experiment I was well watered throughout the season, and experiment II was watered three times (at planting, flowering and pod formation. Grain yield varied from 1.33 t ha^{-1} (late planting to 1.99 t ha^{-1} (early planting) in well-watered experiment and from 0.81 t ha^{-1} (Late planting) to 1.32 t ha^{-1} (early planting) in the limited irrigation experiment. Range 4 & 5 had similar grain yield (1.75 t ha^{-1}) & (1.73 t ha^{-1}) which was higher, respectively compared to Range 1(1.61 t ha^{-1}) & (1.07 t ha^{-1}), Range 3 (1.62 t ha^{-1}) & (1.05 t ha^{-1}) and ICCV9901 (1.39 t ha^{-1}) & (0.90 t ha^{-1}) in experiment I & II, respectively. Biomass was higher in early sowing (4.83 t ha^{-1}) & (3.70 t ha^{-1}) compared with late sowing (4.04 t ha^{-1}) & (2.69 t ha^{-1}) in experiment I & II, respectively. Range 4 & 5 had similar biomass (4.92 t ha^{-1}) & (1.15 t ha^{-1}) which was higher, respectively compared to Range 1(4.35 t ha^{-1}) & (2.72 t ha^{-1}) , Range 3 (4.24 t ha^{-1}) & (2.82 t ha^{-1}) and ICCV9901 (4.01 t ha^{-1}) & (2.48 t ha^{-1}) in experiment I & II. The results clearly indicated that early planting date is the optimum sowing date for chickpea in the region. However, further evaluation of this date is important to make definite conclusions.

4.1 Introduction

Chickpea *(Cicer arietinum. L)*, also known as garbanzo (Saxena and Singh, 1987; Van der Maesen, 1987), is an important grain legume that is ranked third amongst legumes after dry bean *(Phaseolus vulgaris)* and field pea *(Pisum sativum)* (FAO, 2016). The diploid legume belongs to the genus *Cicer*, tribe *Cicereae*, family Fabaceae, and subfamily papilonaceae (Saxena and Singh, 1987; Singh and Diwakar, 1995). The crop is grown in about 63 countries (FAO, 2016) and now constitutes 20% of the world pulses production. India is the largest producer, followed by Australia and Pakistan (FAO, 2016). In the year 2016, chickpea was grown on 12.2 million ha worldwide, with a total production of 11. 3 million tonnes (FAO, 2016). The average seed yield per hectare varies with production regions but it ranges from 0.6 to 2.3 t ha^{-1}. The world average seed yield is 0.86 t ha^{-1} (FAO, 2016). This yield is low compared with average seed yield that has been reported from research trials across the world (Siddique and Sedgeley, 1986; Kabir, 2009; Thangwana and Ogola, 2012). The biggest challenge facing chickpea researchers is to improve chickpea grain yield at farm level to the levels that have been reported in research trials.

The low seed yield in chickpea may be a result of several factors such as temperature stress (Krishnamurthy et al., 2011; Devasirvatham et al., 2012), poor fertilizing, pest and diseases, moisture stress (Leport et al*.,* 2006) and genotype (Siddique and Sedgeley, 1986). Use of optimum planting date is one management option that may lead to (Tsimba et al., 2013; Fiwa, 2015) improved grain yield through environment x genotype interaction. Several studies have reported the significance of planting date and genotype selection on biomass and grain yield of chickpea (Bahal et al., 1984, Dixit et al*.,* 1993, Hussain et al*.*, 1997, Kabir 2009). For example, in Bangladesh, Kabir et al*.* (2009) observed that sowing time had a significant effect on chickpea growth parameters, yield and yield components. Similar reports have been given across the world and in different crops (Tsimba et al., 2013; Fiwa, 2015). Planting date affects acquisition and utilisation of resources such as water and radiation in crops (Andrade et al., 1993; Soltani et al., 2006), and influences crop source – sink balance and the progression of how available assimilates from plant leaves (source) are translocated to flowers or growing pods (sink) (Tsimba, et al., 2013).

Variation in planting dates may expose crops to different environmental conditions (temperature, photoperiod and moisture) at various stages of growth and consequently affect biomass accumulation and partitioning. For example, an early planting date in Southern Africa during winter may expose the crop to extremely low temperatures (less than 8 ^{o} C) during the early reproductive stage (Nayyar, 2005; Viatcheslav et al*.,* 2007) which may affect flower retention and pod abortion. In contrast, late planting of chickpea during the winter season may result in flowering stage coinciding with high temperatures during early reproduction period which may affect fruit set and hence chickpea yield (Wang et al*.,* 2006). Moreover, exposure to high temperatures in late planting will reduce chickpea growing season length as potential evapotranspiration exceeds plant available water and because chickpea phenology is often highly temperature responsive (Devasirvatham et al. 2012; 2013). Reduced growing season length is likely to reduce yield. Furthermore, high temperatures coupled with increasing day length may reduce growing cycle period by shortening vegetative and reproduction stages (Veghis et al., 1999).

Studies also show that planting date determines the period when critical stages will take place in plants, for example when to flower or when the crop switches over to podding stage (Veghis et al., 1999). Knowledge of optimum planting date that minimises extreme temperature and water stress conditions during reproduction period may increase yield. Production of high and stable seed yield strongly depends on maximising yield components with a stable harvest index (HI) (Veghis et al., 1999). However, HI for chickpea has been reported to vary considerably with genotype and cultivars (Veghis et al., 1999) due to genetic instability, emanating from genotype by environment interaction (Chijoke et al, 2010; Krishnamurthy et al., 2011). Because of this instability, yield components such as number of pods per plant, pod weight and 100 seed weight have remained low. Whether manipulation of planting date may stabilize HI, improve yield components and increase biomass and grain yield is not known. Although a number of studies have reported on the effect of planting date on biomass accumulation and partitioning in chickpea in different regions (Chetia and Kumar, 2005; Singh et al., 2005; Tenguria and Tikle, 2005; Confalone et al., 2009), hardly any study has reported optimum planting date for chickpea that may improve and stabilize grain yield in the region. Where planting date has been reported to affect chickpea yield (Tenguria and Tikle, 2005; Confalone et al., 2009), it has been difficult to separate whether the effects were caused by temperature stress, water stress, genotype or normal seasonal variations. We hypothesised that planting date may affect chickpea grain yield and yield components indirectly by influencing the level of moisture and temperature conditions during crop growth. Thus, this study was designed with two separate experiments (Exp I and II), one well-watered and the other one watered only three times (at planting, first flowering and first podding stage). The overall objective was to assess the effect of planting date and genotype on biomass and yield of chickpea crop under different water regime.

4.2 Materials and methods

The study site, experimental design, treatments that were evaluated and agronomic practices are described in detail in Chapter 3. In summary, two separate experiments were conducted over two consecutive seasons at the University of Venda's experimental farm, which is situated at Thohoyandou (22° 58.081'S, 30° 26,411'E and 595 m asl), Limpopo Province, South Africa.

4.2.1 Experimental design

Two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1st, 14th and 28th of May for early, control and late planting date, respectively). Chickpea genotypes were assigned to sub-plots; four desi genotypes (Range 1, Range 3, Range 4 and Range 5) in 2014, and 4 desi types and one Kabuli genotype (ICCV99010) in 2015 season. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV9901 are medium maturing and have erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structure, respectively.

Experiment one was well watered throughout the season, and experiment two was watered three times (at planting, flowering and pod formation). The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment one and 175 mm in experiment two, whilst 435 mm and 235 mm was applied in 2015 in Experiment one and two, respectively. Variation in the total amount of water applied in 2014 and 2015 was caused by differences in initial soil moisture.

4.2.2 Data collection

The following parameters were determined: grain yield, aboveground biomass, harvest index, 100 seed weight, and pod weight per plant.

Aboveground biomass was measured at 14-days interval starting from 28 days after crop emergence (DAE) until harvest maturity (HM) using destructive sampling method. At each sample collection, all the plants from a quadrat of 0.36 m^2 were cut at ground level, chopped, and oven dried at 80°C for 48 hours before recording sample dry weight (kg m^{-2}).

For grain yield, all the plants from the two innermost rows of each experimental unit (2.4 m^2) were harvested (cutting the main steam at ground level) at harvest maturity and pods were manually removed from all the harvested plants and weighed using a digital scale, to determine pod weight per plant. The pods were subsequently threshed by hand and the seeds were air-dried, cleaned and weighed to determine grain yield (kg ha^{-1}). Sub-samples of the seeds for each treatment were used to determine 100 seed weight (100-SW). Harvest index was determined at harvest maturity as the ratio of grain yield to total aboveground biomass.

Sub-samples of the seeds for each treatment were used to determine 100 seed weight (100-SW).

All data were subjected to analyses of variance (ANOVA) using GenStat 16th Edition. Significant difference between treatments was determined at 5% level, using Standard error of means (S.E.D).

4.3 Results

4.3.1 Weather data: Weather data was presented in paragraph 3.3.1

4.3.2 Pod weight

Planting date ($P< 0.001$), genotype ($P< 0.001$) and season ($P< 0.001$) affected pod weight in the well-watered experiment (Table 1.3). Pod weight was 43.8% and 15% greater, respectively in early planting compared to normal and late planting in experiment I (Table 4.1). Pod weight was lower in ICCV9901 (14.2 g plant^{-1}) compared with Range 1 (17.0 g plant^{-1}) and Range 3, 4 & 5 (average of 19.5 g plant^{-1}), and season I had 14.7% greater pod weight compared with season 2 (Table 4.1). Similarly, the effect of planting date ($P< 0.001$) and season ($P< 0.001$) on pod weight was significant in the drier experiment (Table 4.1). Pod weight was 16.9% and 46.8% greater, respectively in early compared to normal and late sowing, and season I had 30% greater pod weight compared with season 2 (13.4 vs 10.3 g plant^{-1}) in experiment II (Table 4.1). Neither genotype nor the interaction between treatments affected pod weight in experiment II (Table 4.1).

4.3.3 100 seed weight.

Planting date ($P< 0.001$), genotype ($P< 0.001$) and season ($P< 0.001$) affected 100 seed weight (100-SWT) in the well-watered experiment but in the drier experiment only the effect of season was significant (Table 4.1). 100-SWT varied from 17.7 (late sowing) to 21.0 g plant^{-1} (early sowing), 15.3 (ICCV9901) to 19.5 g plant^{-1} (Range 4), and 17.2 (2015) to 19.8 g plant^{-1} (2014) in experiment I, and from 14.0 (2015) to 17.5 g plant^{-1} (2014) in experiment II (Table 4.1).

Table 4.1 Effect of planting date and genotype on Pod weight per plant (grams) and 100 seed weight (grams) of chickpea.

Experiment	Treatment									P(F-ratio)						
	EPD	NPD	LPD	R1	R3	R4	R5	ICCV9901	S1	S2	PD	G	S	PD X G	PD x S	G x S	PD x G x S
Pod weight per plant (grams)																	
Exp I	23.0^{a}	16.0^{c}	20.0^{b}	17.0^{b}	19.0^{a}	19.0^{a}	20.0^{a}	14.2^{c}	20.3^{a}	17.7^{b}	***	***	**	ns	ns	ns	ns
Exp II	13.8^{a}	11.8^{b}	9.4^{c}	10.7	11.1	11.9	11.5	9.8	13.4^{a}	10.3^{b}	**	ns	***	ns	ns	ns	ns
100 seed weight (grams)																	
Exp I	21.0^{a}	19.6^{b}	17.7^{c}	18.4^{b}	19.2^{a}	19.5^{a}	19.4^{a}	15.3^{c}	19.8^{a}	17.2^{b}	**	***	***	ns	ns	ns	ns
Exp II	17.4	17.2	15.5	17.1	17.3	18.3	18.0	17.0	17.5^{b}	14.0^{a}	ns	ns	***	ns	ns	ns	ns

S. D. E

(experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
100 seed weight	16.2	1.34	0.42	2.57	4.73	3.38	3.56	9.47
Pod weight	22.6	2.34	1.25	2.10	3.35	4.71	5.83	12.08
(experiment II)								
100 seed weight	21.1	1.67	1.74	2.80	6.45	4.61	8.27	10.79
Pod weight	19.4	1.78	2.60	2.97	4.28	6.85	3.70	9.22

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties
Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively.

4 .3.4 Aboveground biomass.

The effect of planting date ($P< 0.001$), genotype ($P< 0.001$) and season ($P< 0.001$) on aboveground biomass was significant but the interaction between the treatments was not significant in both experiments I & II. Biomass was higher (by 4.3% and 19.8%), respectively in early sowing (4.83 t ha^{-1}) compared with the control (4.63 t ha^{-1}) and late sowing (4.04 t ha^{-1}) in experiment I (Table 4.2). Similarly, early sowing produced greater crop biomass (3.70 t ha^{-1}) compared with control (2.99 t ha^{-1}) and late (2.69 t ha^{-1}) sowing in experiment II (Table 4.2). Range 4 & 5 had 13.1%, 16.0% and 22.7%, respectively greater biomass (average of 4.92 t ha^{-1}) compared to Range 1 (4.35 t ha^{-1}), Range 3 (4.24 t ha^{-1}) and ICCV9901 (4.01 t ha^{-1}) in experiment I. Similarly, aboveground biomass varied with genotype in experiment II from 2.48 t ha^{-1} (ICCV9901) to 3.38 t ha^{-1} (Range 5) (Table 4.2).

4.3.5 Grain yield

Grain yield varied with planting date ($P< 0.05$), genotype ($P< 0.001$) and season ($P< 0.05$) in both experiments. Grain yield was higher in early sowing (1.99 t ha^{-1} & 1.32 t ha^{-1}) compared with control (1.91 t ha^{-1} & 0.96 t ha^{-1}) and late sowing (1.33 t ha^{-1} & 0.81 t ha^{-1}) respectively, in experiment I & II (Table 4.2). ICCV9901 recorded the lowest grain yield in experiment I & II (1.39 t ha^{-1} & 0.90 t ha^{-1}, respectively), and Range 4 & 5 had highest yield in experiment I (average of 1.75 t ha^{-1}) and experiment II (1.16 t ha^{-1}) (Table 4.2). Grain yield decreased by 68% (2.81 vs 1.67 t ha^{-1}) and 63% (1.34 vs 0.82 t ha^{-1}) in experiment I & II, respectively in 2015 compared with 2014 (Table 4.2). The interaction between the treatments did not affect grain yield in both experiments (Table 4.2).

4.3.6 Harvest index

The effect of planting date ($P< 0.01$) and season ($P< 0.01$) on harvest index (HI) was significant in both experiments (Table 4.2). HI was greater in early sowing (43 & 36%) compared with the control (39 & 32%) and late sowing (38 & 30%) in experiment I & II, respectively, and in 2014 (44 & 34%) compared with season 2015 (34 & 30%), respectively in experiment I & II (Table 4.2). Neither genotype nor the interaction between the treatments affected HI (Table 4.2).

Table 4.2 Effect of planting date and genotype on aboveground biomass (kgha^{-1}) and grain yield (kgha^{-1}) of chickpea crop.

Experiment	Treatment										P (F-ratio)						
	EPD	NPD	LPD	R1	R3	R4	R5	ICCV9901	S1	S2	PD	G	S	PD X G	PDxS	G xS	PD x G x S
Grain Yield (t ha^{-1})																	
Exp I	1.99^{a}	1.91^{b}	1.33^{c}	1.62^{b}	1.61^{b}	1.76^{a}	1.74^{a}	1.39^{c}	1.91^{a}	1.67^{b}	*	***	*	ns	ns	ns	ns
Exp II	1.32^{a}	0.96^{b}	0.81^{c}	1.07^{b}	1.05^{b}	1.16^{a}	1.15^{a}	0.90^{c}	1.34^{a}	0.82^{b}	*	***	*	ns	ns	ns	ns
Biomass (t ha^{-1})																	
Exp I	4.83^{a}	4.63^{b}	4.04c	4.35^{b}	4.24^{b}	4.89^{a}	4.94^{a}	4.01^{b}	4.58^{a}	3.13^{b}	*	*	***	ns	ns	ns	ns
Exp II	3.70^{a}	2.99^{b}	2.69.^{c}	2.72^{b}	2.82^{b}	3.24^{a}	3.38^{a}	2.48^{bc}	3.23^{a}	2.14^{b}	***	***	***	ns	ns	ns	ns
Harvest Index (%)																	
Exp I	43^{a}	39^{b}	38^{b}	39	38	41	40	37	42^{a}	34^{b}	**	ns	**	ns	ns	ns	ns
ExpII	36^{a}	32^{b}	30^{c}	36	36	38	39	35	34^{a}	30^{b}	**	ns	**	ns	ns	ns	ns

		S. D. E						
(Experiment I) S	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x**
Grain Yield (t ha^{-1})	17.3	0.07	0.11	0.20	0.54	0.31	0.44	0.76
Above ground biomass (t ha^{-1})	25.1	0.12	0.37	0.26	0.64	0.45	0.52	0.90
Harvest Index %	13.1	3.0	5.0	6.0	8	11	15	10
SED (Experiment II)								
Grain Yield (t ha^{-1})	15.5	0.14	0.07	0.12	0.28	0.20	0.23	0.41
Above ground biomass (t ha^{-1})	18.3	0.23	0.31	0.33	0.89	0.57	0.73	0.12
Harvest Index %	12.8	1.5	7.0	3.0	12	16	11	13

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties. Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively

4.4 Discussion

4.4.1 Grain yield

Grain yield varied with planting date in both the well-watered and the limited irrigation experiments but the magnitude of the variation was not consistent across the experiments. Delayed sowing led to a yield penalty of 41.4 kg ha^{-1} d^{-1}, and early sowing led to a yield gain of 5.5 kg ha^{-1} d^{-1}, relative to the control in the well-watered experiment. In contrast, delayed sowing led to a yield penalty of 10.6 kg ha^{-1} d^{-1} (74% lower than the well-watered experiment), and early sowing resulted in a yield gain of 26.2 kg ha^{-1} d^{-1} (3.8 times greater than the well-watered experiment) in the drier experiment. These results suggest that the benefits of early sowing, relative to the control, at the site of the current study are relatively greater in water-limited compared with well-watered situations while the penalty for late sowing is more severe under more moist conditions. The variation in grain yield with planting date was associated with a similar variation in harvest index in line with previous studies that show that grain yield in chickpea and other pulses is a function of dry matter accumulation and partitioning (Davies et al., 2000; Fotiadis et al., 2017). The early sowing resulted into larger leaf canopy, longer growing season, greater cumulative intercepted radiation and thermal time which likely led to higher dry matter accumulation, and lower ambient temperatures during the reproductive stage of growth which was associated with greater flower retention. Earlier, Thangwana and Ogola (2012) observed huge differences in grain yield between winter and summer sowings which was attributed mainly to differences in the length of the growing season between the two sowings. In addition, the lower grain yield in late sowings could partly be attributed to higher respiration losses since the ambient temperatures during the reproductive were higher in late sowings (Evans, 1993; Fotiadis, et al., 2017). Our results are comparable to the findings of Fotiadis et al. (2017) that planting date may affect crop biomass by affecting the crop growth rate (CGR) and the length of the growing season. Earlier, Tollenaar and Dwyer (1999) reported that the total annual dry matter accumulation of a crop canopy is equal to the sum of the daily CGR during the growing season.

The greater grain yield observed in Range 4 & 5 compared to the rest of the genotypes could be attributed to their longer growing season and hence longer duration of dry matter accumulation (Davies et al., 2000; Fotiadis et al., 2017). Range 4 & 5 are late maturing cultivars, and they recorded greater accumulated degree days, total intercepted radiation, and larger leaf canopy during the reproductive stage compared to the rest suggesting that Range 4 & 5 not only accumulated dry matter over a longer duration but they also had higher dry matter accumulation during the reproductive growth stage. Similarly, Fotiadis et al. (2017) concluded that dry matter accumulation after the onset of seed filling appears to be crucial in determining the overall dry matter of chickpea at maturity. Genotypic variation in grain yield of chickpea has previously been reported at the site of the current study (Madzivhandila et al., 2012; Thangwana and Ogola, 2012).

Grain yield was greater in 2014 compared to 2015, possibly because of lower ambient temperatures and hence longer growth duration in 2014 compared to 2015 (Turner et al., 2005; Regan et al., 2006; Kalra et al., 2008; Thangwana and Ogola, 2012). Grain yield was greater in the well-watered (432.5 mm) compared with the drier (205 mm) experiment across the two seasons as expected.

4.4.2 Aboveground biomass

Aboveground biomass was affected by planting date and season in experiment II. Biomass production was reduced with delayed planting, whilst early planting improved aboveground biomass. The low biomass in late planting may have been due to shortened growing season length which resulted in plants accumulating inadequate temperature for biomass accumulation (Chijioke et al., 2010). For example, the plants from late planting had lower canopy cover, fewer sink sites and lower pod weight, indicating a hastened growth and development process (Chaturvedi and Dua, 2003). Even their grain yield and weight of 100 seeds was low, clearly suggesting the penalty of delayed planting on biomass accumulation. In support of this, similar reports were given by Singh et al., (2005) and (2011), who suggested that lower biomass in late planting may be a consequence of short growing season length.

The variation in aboveground biomass with genotype in both experiments was possibly caused by variation in physiological days to maturity between genotypes. For instance the greater aboveground biomass observed in late maturing Range 4 & 5 genotypes compared to early maturing Range 1, and medium maturing Range 3 and ICCV9901 in experiment I & II was probably caused by their differences in growing season length. Genotypes with a longer growing season length have been reported to accumulate greater biomass (Chaturvedi and Dua, 2003).

The variation in aboveground biomass with season may possibly have been due to variation in temperature between the two seasons. Season 2 experienced 10% higher maximum temperatures than season 1 and this may have caused variation in yield. Indeed, variation in aboveground biomass with temperature has been reported extensively in literature (Singh et al., 2005; Wang et al., 2006; Kalra et al., 2008; Singh et al., 2011; Devasirvatham et al. (2012; 2013).

4.4.3 Harvest index

Harvest index was affected by planting date in both experiments, possibly because of the differences in grain yield and biomass that was observed amongst planting dates. For example, the lower harvest index in late planting compared to early and normal planting may have been caused by greater biomass and lower grain yield. Even the pod weight and 100 seed weight in late planting was low, clearly indicating lower grain yield per total dry matter. In contrast, early planting had higher harvest index and this was supported by greater pod weight and grain yield in early planting. In support of the study results, Ganguly and Bhattacharya (2000) reported variation in harvest index as a result of staggering planting dates and suggested the the greater grain yield to be responsible for higher harvest index. Indeed, a positive association of harvest index with grain yield have been reported (Sign, 1976), clearly suggesting that improvement in chickpea grain yield will improve harvest index. Likewise, improvement in pod weight and 100 seed weight will improve grain yield and hence harvest index.

Harvest index was also affected by planting season in both experiments possibly because of variation in temperatures experienced by the crops in season 1 and in season 2. Season 2 experienced maximum temperatures that were ≥33 ^{o}C, whilst season 1 had ≥30 ^{o}C. Temperatures greater than 32^{o}C have been reported to affect flowering and pot setting (Devarstrasthratum et al., 2012), whilst subnormal temperature has been reported to affect harvest index (Prasad et al., 2006).

The variation in harvest index between experiment I and experiment II could partly be due to moisture variation between the two experiments. Experiment I had large plants with greater biomass and many primary and secondary branches with reproductive sink sites, capable of sustaining a larger grain yield. Similar findings have been reported in studies where contrasting water regime has been evaluated in chickpea (Veghis et al., 1999; Anwar et al., 2003).

Harvest index results in this study are comparable with earlier studies in chickpea (Veghis et al., 1999) and in other crops (Prasad et al., 2006). This validate the results and make them possibly a correct finding. However, the low harvest index observed in the study confirms the behavior of legumes of having sufficiently high aboveground biomass, but very low grain yield (Hay, 1995). The variation of harvest index across planting date and season clearly indicate the instability in the parameter and suggest the existence of inconsistences in partitioning of assimilates to the sink areas. However, the fact that genotype did not affect harvest index rules out genetic instability amongst the genotypes. Moreover, the results seem to indicate that early planting date is the optimum date for chickpea in the region so as to improve harvest index in both well-watered and moisture stress conditions. However, further evaluation of this date is important to make definite conclusions.

4.5 Conclusion

This study aimed at determining the effect of planting date and genotype on biomass and yield of chickpea crop under different water regime. In agreement with the study hypothesis, planting date affected chickpea grain yield and yield components. Grain yield was higher in early planting compared to normal and late planting in both experiments. Season 1 had greater biomass, grain yield and harvest index compared to season 2 in both experiments. Genotype and interaction between treatments did not affect grain yield in both experiment I and experiment II. Furthermore, aboveground biomass was affected by planting season in experiment I, whilst in experiment II, it was affected by planting date and season. Harvest index was higher in early planting compared to normal and late planting in both experiments. This study identified early planting date as the optimum date for planting chickpea in the region so as to improve grain yield, pod weight and harvest index in both well-watered and limited moisture conditions. However, aboveground biomass may not have optimum planting date in the region and so is 100 seed weight as they were not affected by planting date.

References

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 2003. The effect of irrigation and sowing date on crop yield and yield components of Kabuli chickpea (Cicer arietinum L.) in a cool-temperate subhumid climate. *The Journal of Agricultural Science*, *141*(3-4), pp.259-271.

Bahl, P.N., Singh, K.P. and Singh, D., 1984. Evaluation of tall chickpea genotypes for normal and late sowings. *Indian Journal of Agricultural Sciences*.

Chaturvedi, S.K. and Dua, R.P., 2003, January. Breeding chickpea for late sown conditions in northern India. In *International Chick pea Conference, January* (pp. 20-22).

Chijioke, O.B., Ifeanyi, U.M. and Blessing, A.C., 2010. Comparative study on growth and development of some accessions of local Germplasm of Bambara groundnut (Vigna subterrenea L. Verdc.) of Nigeria in two cropping seasons. *Journal of Crop Science and Biotechnology*, *13*(1), pp.21-27.

Confalone, A., Lizaso, J.I., Ruiz-Nogueira, B., López-Cedrón, F.X. and Sau, F., 2010. Growth, PAR use efficiency, and yield components of field-grown Vicia faba L. under different temperature and photoperiod regimes. *Field crops research*, *115*(2), pp.140-148.

Desta, F., Bissa, M. and Korbu, L., 2015. Crop water requirement determination of chickpea in the central vertisol areas of Ethiopia using FAO CROPWAT model. *African Journal of Agricultural Research*, *10*(7), pp.685-689.

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Tokachichu, R.N., Trethowan, R.M. and Tan, D.K., 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology*, *39*(12), pp.1009-1018.

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Raju, T.N., Trethowan, R.M. and Tan, D.K., 2013. Reproductive biology of chickpea response to heat stress in the field is associated with the performance in controlled environments. *Field Crops Research*, *142*, pp.9-19.

Dixit, J.P., Pillai, P.V.A. and Namdeo, K.N., 1993. Response of chickpea (Cicer arietinum) to planting date and irrigation schedule. *Indian Journal of Agronomy*, *38*, pp.121-121.

FAO.,2016. Production Yearbook. Food and Agricultural Organization of the United Nations, Rome. Volume 58.

Fiwa, L., 2015. Improving rainfed cereal production and water productivity in Malawi: Modelling field management options in response to current and future climatic conditions..

Ganguly, S.B. and Bhattacharya, A., 2000. Harvest index in late sown chickpea: effect of physio-chemical traits in developing grains. *Legume Research*, *23*(4), pp.222-226.

Hay, R.K.M., 1995. Harvest index: a review of its use in plant breeding and crop physiology. *Annals of applied biology*, *126*(1), pp.197-216.

Hussain, A., Nawaz, M. and Chaudhry, F.M., 1998. Radiation interception and utilization by chickpea (Cicer arietinum L.) at different sowing dates and plant populations. *Journal of Agricultural and Marine Sciences [JAMS]*, *3*(2), pp.21-25.

Kabir, A.F., Bari, M.N., Karim, M.A., Khaliq, Q.A. and Ahmed, J.U., 2009. Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed condition. *Bangladesh Journal of Agricultural Research*, *34*(2), pp.335-342.

Kalra, N., Chakraborty, D., Sharma, A., Rai, H.K., Jolly, M., Chander, S., Kumar, P.R., Bhadraray, S., Barman, D., Mittal, R.B. and Lal, M., 2008. Effect of increasing temperature on yield of some winter crops in northwest India. *Current science*, pp.82-88.

Krishnamurthy, L., Gaur, P.M., Basu, P.S., Chaturvedi, S.K., Tripathi, S., Vadez, V., Rathore, A., Varshney, R.K. and Gowda, C.L.L., 2011. Large genetic variation for heat tolerance in the reference collection of chickpea (Cicer arietinum L.) germplasm. *Plant Genetic Resources*, *9*(1), pp.59-69.

Leport, L., Turner, N.C., Davies, S.L. and Siddique, K.H.M., 2006. Variation in pod production and abortion among chickpea cultivars under terminal drought. *European Journal of Agronomy*, *24*(3), pp.236-246.

Nayyar, H., 2005. Putrescine increases floral retention, pod set and seed yield in cold stressed chickpea. *Journal of agronomy and crop science*, *191*(5), pp.340-345.

Nayyar, H., 2005. Putrescine increases floral retention, pod set and seed yield in cold stressed chickpea. *Journal of agronomy and crop science*, *191*(5), pp.340-345.

Pooran Chand and Singh F. 1997 Correlation and path analysis in chickpea (*Cicer arietinum* L.). Indian Journal of Genetics and Plant Breeding 57(1) pp. 40-42.

Regan, K.L., Siddique, K.H.M., Brandon, N.J., Seymour, M. and Loss, S.P., 2006. Response of chickpea (Cicer arietinum L.) varieties to time of sowing in Mediterranean-type environments of south-western Australia. *Australian Journal of Experimental Agriculture*, *46*(3), pp.395-404.

Saxena, M.C. and Singh, K.B., 1987. *The chickpea*. Commonwealth Agricultural Bureaux International.

Siadat SA and Hemayat SS. 2009. Effect of sowing date on yield and yield components of three oilseed rape varieties. *Plant Ecophysiology,* 1, pp. 31- 35.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Singh F, Gupta PK and Singh V. 1985. Genetic association in chickpea (*Cicer arietinum* L.) Proceeding of 72nd Indian Science Congress, *Agricultural Science*. 53, pp. 31.

Singh, T.P., Deshmukh, P.S., Mishra, S.K. and Kushwaha, S.R., 2005. Effect of temperature regimes on physiological parameters in chickpea (Cicer arietinum L.). *New Botanist*, *32*(1/4), pp.225.

Singh, F. and Diwakar, B., 1995. Chickpea botany and production practices. Skill Development Series nº 16.

Soltani, A., Robertson, M.J., Rahemi-Karizaki, A., Poorreza, J. and Zarei, H., 2006. Modelling biomass accumulation and partitioning in chickpea (Cicer arietinum L.). *Journal of agronomy and crop science*, *192*(5), pp.379-389.

Tenguria RK and Tikle AN., 2005. Flowering response and seed filling sink of newly bred chickpea (*Cicer arietinum* L.) genotypes. *Flora and Fauna,* 11(1), pp. 57-60.

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

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Van der Maesen, L.J.G., 1987. Origin, history and taxonomy of chickpea. In *The chickpea* (pp. 11-34).

Verghis, T.I., McKenzie, B.A. and Hill, G.D., 1999. Phenological development of chickpeas (Cicer arietinum) in Canterbury, New Zealand. *New Zealand journal of crop and horticultural science*, *27*(3), pp.249-256.

Viatcheslav, V., Kharin, V. V., Zwiers, F. W., Zhang, X., Hegerl, G. C., 2007. Temperature and precipitation extremes in IPCC ensemble of global coupled model simulations. *Journal of climate change,* 20, pp. 1419-1444.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Yadav, V.S., Yadav, S.S. and Panwar, J.D.S., 1998. Effect of planting time on physiological attributes and grain yield in desi and kabuli chickpca gcnotypes. *Indian Journal of Plant Physiology*, *3*, pp.292-295.

Chapter 5

The response of water use and water use efficiency of five genotypes of chickpea (C*icer arietinum* l.) to planting date

Abstract

This study assessed the effect of planting date and genotype on water use (WU) and water use efficiency of grain yield (WUE_g) and biomass (WUE_b) production of chickpea. Two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1, 14 & 28 May being early, control/normal, and late planting date, respectively) and chickpea genotypes (Range 1, Range 3, Range 4, Range 5 and ICCV99010) as the sub-plot factor. Experiment I was well watered throughout the season, and experiment II was watered three times (at planting, flowering and pod formation). In comparison to the control, late sowing decreased grain yield (by 41.4 and 10.6 kg ha^{-1} d^{-1}), and WUE_g (by 1.1 and 1.7 kg ha^{-1} mm^{-1}) in experiment I & II, respectively. However, WU was, on average, 16% greater in late sowing compared with the control in the well-watered experiment but this response varied with genotype and season. In contrast, grain yield and WUEg was, on average, greater with early sowing (1.7 t ha^{-1} & 7.7 kg ha^{-1} mm^{-1}) compared with the control (1.1 t ha^{-1} & 7 kg ha^{-1} mm^{-1}), respectively but the differences were more pronounced in the well-watered experiment. Clearly, sowing at the beginning of the month of May has potential of improving chickpea productivity in this environment but there is need to investigate the possibilities of earlier sowings.

Keywords: Planting date; Chickpea, Water use, Water use efficiency; Grain yield.

5.1 Introduction

Chickpea grain yield is affected by availability of moisture at various stages of growth and development (Siddique and Sedgley, 1986; Leport et al., 2006), and the effects of moisture stress on chickpea and other legumes vary with genotype (Siddique et al., 2001) and planting date (Anwar et al., 2003a). Planting chickpea early or late in the season may result in crops experiencing variation in moisture regime depending on the daily pattern of weather elements such as temperature, Vapour Pressure Deficit (VPD) and evapotranspiration (Siddique and Sedgley, 1986). For example, in NE South Africa where chickpea is grown during winter, a delay in sowing, coupled with high temperatures may retard canopy growth and promote high evaporation early in the season at the expense of transpiration during the late stages of plant growth (Siddique et al., 2001). In contrast, early planting may allow the crop to take advantage of residual soil moisture and promote a faster and early canopy growth.

Therefore moisture availability for crop transpiration may potentially be increased through early sowing which is likely to lead to a dense canopy early in the season that reduces direct evaporation of water from the soil beneath the crop canopy (E_{sc}). A decrease in $E_{sc,}$ and a concomitant increase in transpiration, is likely to lead to increase in grain yield and water use efficiency (Ogola et al., 2002 & 2005). However, the effect of planting time on canopy growth, yield formation and water use efficiency may vary with genotypes (Ogola et al., 2013; Ogola and Thangwana, 2013) and their interaction with the environment (Tsimba et al., 2013) partly due to variation in canopy structures and rooting depth with genotypes (Zhang et al., 2000). Also, planting date may affect root length density and rooting pattern and this is likely to affect soil water extraction (Benjamin and Nielsen, 2006).

Moreover, canopy and root growth as well as sink-source balance in chickpea genotypes with indeterminate growth are generally more complicated than in determinate ones because vegetative growth continues during reproductive development and young vegetative tissues compete with developing seeds for assimilate supply (Turner et al., 2005). Furthermore, manipulation of planting date provides crops with an opportunity to adapt to environmental moisture challenges by either allowing the crops to escape, avoid or tolerate moisture stress without a compromise on final grain yield. Also, temporal variation in assimilate supply and partitioning, which depends on plant development and environment, has been reported in chickpea (Turner et al., 2005; Fotiadis et al., 2017). Indeed, early maturing chickpea genotypes may escape or avoid heat and water stress during seed filling, through better timed crop phenology, with early sowing resulting into greater grain yield (Siddique et al., 2001).

However, water extraction, water use and water use efficiency in any crop may vary with season. For example, cooler and more humid seasons with greater VPD may lead to a decrease in crop water use and an increase in grain yield and water us efficiency (Ogola et al., 2002). Therefore it is important to isolate the effect of planting date and genotype on water use and water use efficiency of chickpea from the seasonal effect.

Planting date has been shown to be an important agronomic practice affecting chickpea growth and development (Anwar et al., 2003b), productivity (Saxena et al., 1990; Singh et al., 1997; Fotiadis et al., 2017), seed size (López-Bellido et al., 2008), and water use and water use efficiency (Anwar et al., 2003a) in the Mediterranean regions. However, there is a dearth of information on the response of chickpea yield and water productivity to sowing time in the sub-tropics where the crop is grown during the dry winters. Also, quantitative information regarding the effects of chickpea planting date on soil water extraction patterns by the crop, especially under different watering regimes is limited. Moreover, it is expected that plants sown at different planting dates will be exposed to different temperature and moisture regimes during the critical periods of growth. However, the documented studies (i) did not analyse the effects of these variations on patterns of soil moisture extraction, cumulative crop water use and the efficiency by which the crop utilizes water, and (ii) were based solely on kabuli chickpea types.

Therefore we hypothesised that moisture regime and temperature pattern would affect water use and water use efficiency. Thus we designed the study to have two separate experiments, one well-watered and the other one watered only three times (at planting, first flowering and first podding stage) repeated over two seasons. This study investigated the effect of planting date on water use and water use efficiency of 4 desi and 1 kabuli chickpea genotypes grown under well-watered and dryland conditions in NE South Africa.

5.2 Materials and method

5.2.1 Study site

The study was conducted at the University of Venda's experimental farm in Thohoyandou (22^{o}58.08´S and 30^{o}26.4´E, and 595m above sea level), South Africa during 2014 and 2015 winter seasons. The area receives an annual rainfall of ± 500 mm that falls predominantly in summer; and only rain drizzle during winter which is often insignificant for crop growth and development. The total rainfall received during the growth period of the crop was 0.21 mm (2014) and 0.29 mm (2015). The average maximum and minimum temperatures are 31 and 18°C, respectively (Tadross et al., 2006). The site is characterised by a deep well-drained clay soil, classified as Leptic Cambisols (Fey, 2010), and low pH, low levels of organic carbon, total carbon (C), nitrogen (N), available phosphorus (P), low C:N ratio (Lusiba et al.,2016). A crop rotation system that includes maize, cassava and legume is normally practised on the farm.

5.2.2 Experimental design

Two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1st of May being the early planting, 14th of May as the control / normal planting, and 28th of May being the late planting date). These planting dates were selected based on previous studies (Mathews et al., 2009). Chickpea genotypes were used as sub-plot factor; four desi genotypes (Range 1, Range 3, Range 4 and Range 5) were sown in 2014, and the 4 desi types and one Kabuli genotype (ICCV99010) were sown in 2015 season. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV9901 are medium maturing and have an erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structures, respectively.

Experiment I was well watered throughout the season, and experiment II was watered three times (at planting, flowering and pod formation). The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment I and 175 mm in experiment II, whilst 435 mm and 235 mm was applied in 2015 in Experiment I and II, respectively. Variation in the total amount of water applied in 2014 and 2015 was caused by differences in initial soil moisture in the soil.

Sowing was done manually in rows that were 30 cm apart to achieve a planting density of 33 plants m^{-2} (Thangwana and Ogola, 2012) in both experiments and seasons. Nitrogen (N) was applied in the form of Limestone Ammonium Nitrate (LAN 28 % N) at a rate of 40 N kg ha^{-1} and phosphorus (P) was applied in the form of Single Superphosphate (SSP 20.3 % P), at a rate of 50 kg P ha^{-1} (Madzivhandila et al., 2012). The experiments were kept free from weeds throughout the season.

5.2.2 Measurements

5.2.2.1 Weather records

An automatic weather station that is approximately 100 m from the experiments was used to record relative humidity (%), rainfall (mm), maximum and minimum air temperatures (°C), reference evapotranspiration (mm) and solar radiation (MJ m^{-2} d^{-1}), for each day during crop growing season. These recorded data were compared with long term average climate data for the area. Vapour Pressure Deficit (kPa) was calculated from relative humidity and the maximum and minimum air temperatures (°C) (Allen et al., 1998) and was used to normalise WU with the aim of eliminating the effects of different seasons (Tolk and Howell, 2009). The normalisation equations used in the study are presented in Table 5.1.

5.2.2. 2 Soil water extraction, water use and water use efficiency

Volumetric soil water content (V_Θ): In both experiments, soil moisture content was measured at 7 days interval between 28 and 105 days after crop emergence (DAE) in 2014, and 28 and 102 days DAE in 2015. Measurements were conducted using a neutron probe (Model 503DR Hydroprobe, CPN International, and Martinez, California, USA). On each occasion, the neutron probe was lowered into the access tubes that were inserted centrally in each plot at a depth of 1.2 m. Count readings (16 seconds) were taken at soil depth of 30, 60 90 and 120 cm. Standard counts were taken before and after taking measurements and was used to determine count ratios. V_Θ was calculated using the site-specific calibration equations (Ogola and Thangwana, 2016) as shown below:

$$0.30 \text{ m depth: } V_\Theta = 0.0818\,x + 0.0268 \quad (5.1)$$

$$0.60 \text{ m depth: } V_\Theta = 0.3227\,x - 0.2733 \quad (5.2)$$

$$0.90 \text{ -1.20 m depth: } V_\Theta = 0.3736\,x - 0.3297 \quad (5.3)$$

Where x is the count ratio.

Soil moisture extraction: Soil moisture extraction was determined following the method used by Djaman and Irmak (2012). The method assumes that in the absence of heavy rainfall and irrigation, water extraction is indicated by the behavioural pattern of soil moisture content during the growing period. A sudden change in soil moisture content within the root zone depth may indicate water being extracted by plant roots. Thus in the study soil moisture extraction was calculated at weekly time step, for each soil layer (0-30 cm, 30 – 60 cm, 60-90 cm and 90 – 120 cm) by calculation the differences between two successive weekly soil moisture content recordings. The computed weekly soil moisture extraction values were then summed up throughout the growing season to determine the seasonal total soil water extraction, and was expressed as a percentage of the soil layer.

Water use (WU): Water use was determined using the standard water balance equation:

$$WU = \Delta S + P + I + U - D - R \quad (5.4)$$

Where ΔS is the change in storage (difference in volumetric water content of the entire profile between the first and last neutron probe readings), P is precipitation (mm), I is irrigation (mm), U is upward capillary, D is drainage and R is the surface runoff (Allen et al., 1998; Anwar et al*.,* 1999). Considering the flatness of the field (less than 2% slope), negligible rainfall and earlier studies from the same site (Ogola & Thangwana*,* 2013; Ogola, et al*.,* 2013), rate of infiltration, drainage, capillary rise and surface runoff were assumed to be negligible. Therefore, WU was estimated as a function of change in storage, irrigation and precipitation. The total amount of water applied in 2014 was 430 mm in experiment I and 230 mm in experiment II, whilst 435 mm and 235 mm were applied in 2015, in Experiment I and II, respectively.

Vapour Pressure Deficit (VPD) was used to normalise water use values (Table 5.2). VPD for each planting date was defined as the average VPD measured during peak biomass accumulation (Tolk and Howell, 2009); daily VPD values were regressed against interpolated daily water use values to give the equations and the corresponding R^2 values shown in Table 5.1.

Table 5.1**.** Equations and R^2 values from regression of VPD against interpolated daily WU

Experiment		**Regression equation**	**R^2**
2014	Experiment I	WU = 2.1762 VPD -1.823	0.9999
2014	Experiment II	WU = 2.0964 VPD +7.893	0.9921
2015	Experiment I	WU = 2.2955 VPD -4.0004	0.9915
2014	Experiment II	WU = 2.2788 VPD -3.635	0.9830

Water use efficiency of grain yield and of biomass (WUE_g) and (WUE_b), respectively were determined using equation 5 and 6.

$$WUE_g = \frac{Grain\ Yield}{WU} \qquad (5.5)$$

$$WUE_b = \frac{Total\ biomass}{WU} \qquad (5.6)$$

All the collected data (soil moisture content, WU, and WUE) were subjected to analyses of variance (ANOVA) using GenStat 17th edition, and significant differences between treatments were evaluated at 5% level, using the Standard error of means (S.E.D). Graph plots of water extraction were determined by excel software. Pearson's product moment correlation and linear regression analysis using AXLSTAT software (Addinsoft 1995-2018) was used to evaluate the relationship between grain yield and WUE_g and WUE_b and WU.

5.3 Results

5.3.1 Summary of weather data at Thohoyandou, during the winter 2014 and 2015 cropping seasons.

The 2014 and 2015 temperature and relative humidity data for the experimental station did not show major deviations with long term historical average, but there was a significant decrease in rain-drizzle (90% in 2014 and 86% in 2015) over the past 24 years (Table 5.2). During the growth period of the crop, the average maximum temperature was 27 ^{o}C and the lowest temperature was 10 ^{o}C in the two years of study. Average VPD for the two seasons was 2.24 kPa and 2.17 kPa in 2014 and 2015, respectively.

Table 5.2 Weather data recorded during the trial period (May –October 2014 and 2015), compared with 24 year average historical weather data for the trial station.

Month	Temp (ºC)	Rainfall (mm)	Solar) radiation (MJm^{-1} day^{-1}	Wind speed (ms^{-1})	VPD (kPA)
2014					
May	19.56	0.02	16.98	0.43	2.23
June	17.59	0.00	15.72	0.49	2.24
July	16.81	0.03	13.88	0.43	1.91
August	19.17	0.02	17.78	0.67	2.31
September	21.49	0.37	20.89	0.78	2.54
October	22.06	0.83	23.75	0.88	2.25
2015					
Month					
May	21.11	0.00	14.84	0.36	2.14
June	17.27	0.03	12.48	0.40	1.98
July	18.36	0.02	13.05	0.53	1.99
August	19.77	0.05	15.22	0.59	2.26
September	21.63	0.75	17.98	0.45	2.27
October	22.58	0.90	17.98	0.45	2.38
1983-2007					
Month					
May	18.95	0.53	-	-	2.19
June	18.16	0.46	-	-	2.12
July	16.53	0.45	-	-	1.97
August	18.33	0.25	-	-	2.26
Sept	20.63	0.75	-	-	2.35
October	22.18	2.22	-	-	2.30

The total amount of water applied in 2014 was 430 mm in experiment I and 230 mm in experiment II, whilst 435 mm and 235 mm were applied in 2015, in Experiment 1 and II, respectively.*Temperature was presented as the mean temperature for the month; rainfall was presented as cumulative totals.

5.3.2 Soil water extraction

Planting date (PD) affected the pattern of soil water extraction in both experiments over the two seasons (Fig 5.1 and 5.2). The late sowing extracted greater soil water (by 4% and 7.2%), respectively compared with early sowing and the control in the 0-30cm soil layer, whilst in the 30-60cm soil layer, early sowing recorded greater soil water extraction (by 4.8% and 4%), respectively compared to normal and late sowing in experiment in both seasons (Fig 5.1a&c). In contrast, PD did not affect water extraction in the 60-90 cm and 90-120 cm soil layers in experiment I in both seasons (Fig 5.1a&c). In the drier experiment, late planting and the control extracted 4% greater water from the 0-30 cm soil layer than the early planting (Fig 5.1b&d) in both seasons. In contrast, the early planting extracted 4.5% and 2.9% more water in the 30-60 cm soil layer, and 3.5% and 4.5% in the 60-90 cm soil layer, respectively compared to normal and late planting (Fig 5.1b&d). PD did not affect soil moisture extraction at the 90-120 cm depth (Fig 5.1a-d). The drier experiment extracted more water from the 30-120 cm depths compared with the well-watered experiment (Fig 5.1a-d).

The effect of genotype (G) on soil water extraction varied with soil depths in both experiments in 2014. Range 1 and Range 3 extracted more water than Range 4 & 5 in the 0-30 cm (by 4%) and 30-60 cm (by 3.5%) soil layers (Fig 5.2a&b). In contrast, in the 60-90 cm (by 5%) and 90-120 cm (by 3.5%) soil layer Range 4 & 5 cultivars extracted greater water compared to Range 1 & 3 cultivars in season (Fig 5.2a&b). In the limited irrigation in 2015, Range 1 extracted 3% greater amount of water compared with ICCV9901, Range 3, 4 & 5 in the 0-30 cm soil layer (Fig 5.2d). In contrast, in the 30-60 cm soil depth, Range 4 & 5 extracted 3.5% more water than Range 1, 3 and ICCV9901, and in the 60-90 cm soil depth, Range 3, 4 & 5 extracted 3.5% more water compared to Range 1 and ICCV9901 (Fig 5.2d).

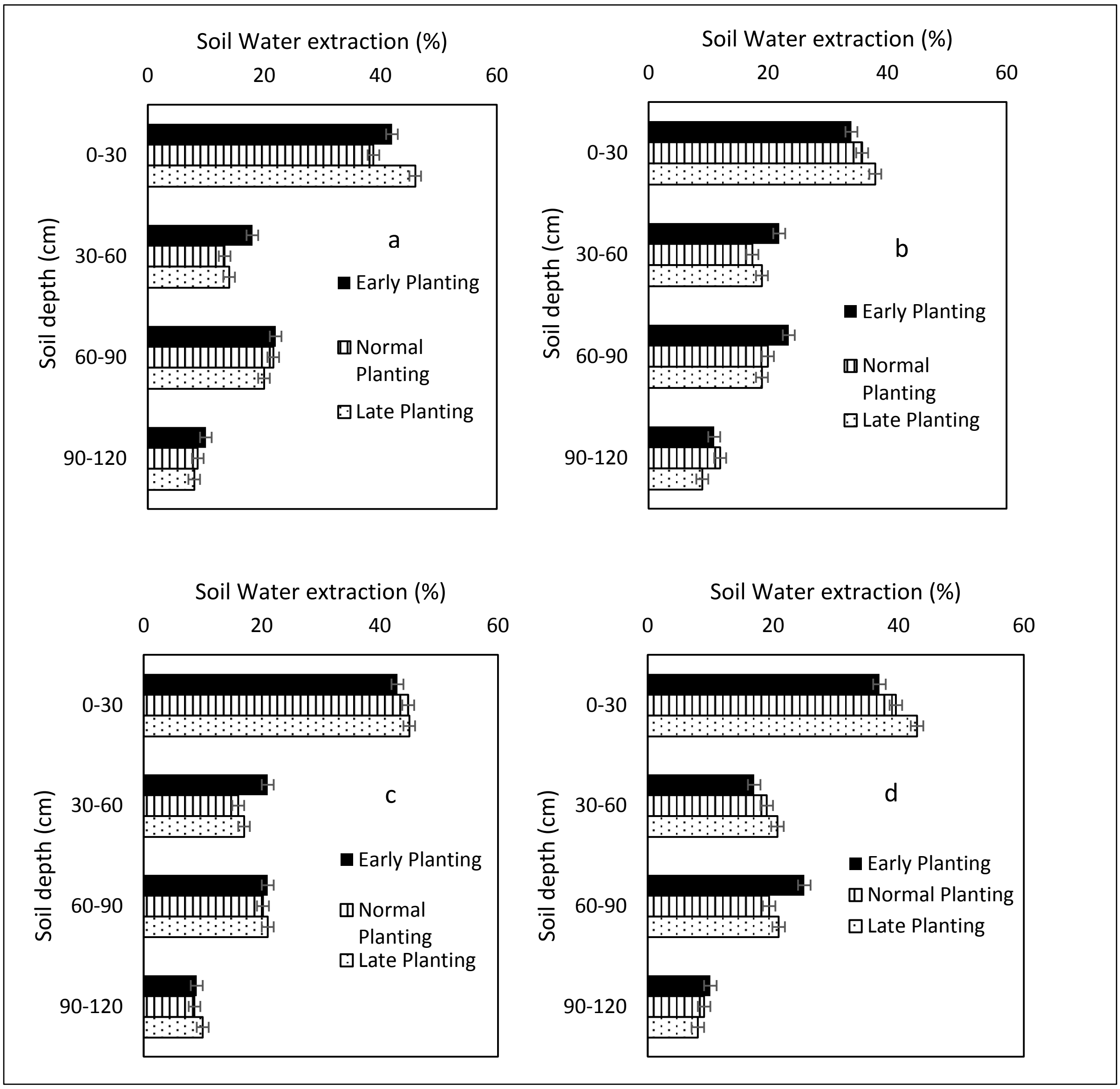


Fig 5.1 Effect of planting date on soil water extraction. a) Season 1, experiment I, b) season 1, experiment II, c) season 2, experiment I, d) season 2, experiment II

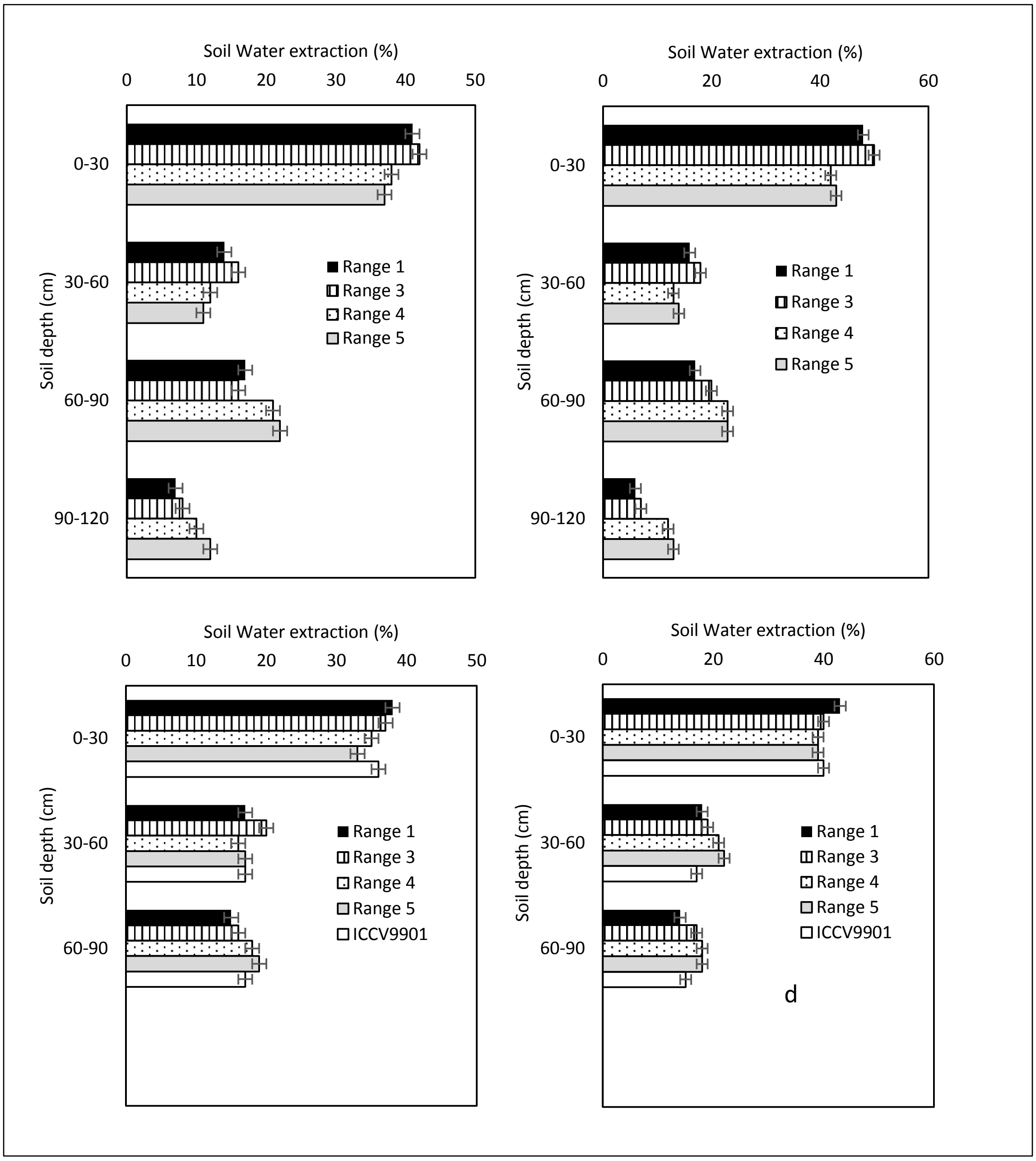


Fig 5.2 Effect of genotype on soil water extraction. a) Season 1, experiment I, b) season 1, experiment II, c) season 2, experiment I, d) season 2, experiment II

5.3.3 Crop water use

Cumulative crop water use was affected by PD, G, season (S) and the interaction between PD & G, PD & S, and G & S but the three way interaction (PD x G x S) was not significant in experiment I (Table 5.3). Late sowing increased WU of Range 1, 3, 4 & 5 but decreased WU of ICCV9901 relative to the control in experiment I (Fig 5.3a). Similarly, early sowing increased WU of Range 1, 3, 4 & 5 but decreased WU of ICCV9901 relative to the control in experiment I but the magnitude of the differences were lower than with late sowing (Fig 5.3a). The effect of PD on WU varied with seasons; late sowing decreased WU, relative to the control, in season I. In season II, in contrast, late sowing increased WU compared with the control (Fig 5.3b). Also, WU was greater (by 6.4%, 5.8%, 2.4% and 4.1%, respectively in Range 1, 3, 4 & 5) in season II compared to season I across all genotypes but the magnitude of the difference varied with genotypes (Fig 5.3c).

In experiment II in contrast, only main effects of PD and S had a significant effect on water use (Table 5.3). Early sowing recorded 1% greater WU (237 mm) compared with the control and late sowing (Table 5.3). Also, WU was 13.9% greater in 2014 (254 mm) compared with 2015 (223 mm) (Table 5.3).

5.3.4 Water use efficiency of grain yield.

WUE_g varied with PD, G, S, and the PD x S and G x S interaction in experiment I (Table 5.3). WUE_g was 11% greater in the control compared with late sowing in 2014 but there was no significant difference in WUE_g between the control and late sowing in 2015 experiment I (Fig 5.4a). Also, early sowing increased WUE_g by 68% compared with the control in 2015 but not in 2014 (Fig 5.4a). Genotype affected WUE_g in experiment I but this effect varied with season; WUE_g decreased in season 2 in all genotypes but the magnitude of the decrease was greater in Range 1 (110%) compared to the rest (Fig 5.4 b).

In contrast, only G and S affected WUE_g in experiment II; WUE_g was much lower in ICCV9901 (3.0 kg ha^{-1} mm^{-1}) compared with the rest of the genotypes (average 7.7 kg ha^{-1} mm^{-1}), and WUE_g was 83% greater in 2014 compared with 2015 (Table 5.3).

Table 5.3 Effect of planting date and genotype on water use efficiency of grain and biomass production

Experiment	Treatment										P (F-ratio)						
2014 S	**EPD**	**NPD**	**LPD**	**R1**	**R3**	**R4**	**R5**	**ICCV9901**	**S1**	**S2**	**PD**	**G**	**S**	**PD X G**	**PD x S**	**G x S**	**PD x G x S**
WU (mm)																	
Exp I	174^{b}	162^{c}	188^{a}	179^{ab}	182^{a}	182^{a}	178^{b}	……	173^{b}	177^{a}	***	***	**	***	***	***	ns
Exp II	237^{b}	239^{a}	239^{a}	238	240	239	237	153	254^{a}	223^{b}	**	ns	***	ns	ns	ns	ns
WUE_g (kg ha^{-1} mm^{-1})																	
Exp I	8.0^{a}	6.8^{b}	5.7^{c}	7.3^{a}	7.0^{b}	7.3^{a}	7.1^{b}	……	7.9^{a}	5.8^{b}	**	**	***	ns	**	***	ns
Exp II	7.4	7.2	5.5	7.14^{a}	8.3^{a}	7.3^{a}	8.0^{a}	3.0^{b}	5.5^{b}	3.0^{a}	ns	**	***	ns	ns	ns	ns
WUE_b (kg ha^{-1} mm^{-1})																	
Exp I	18.9	19.6	16.4	20.7	17.8	16.6	16.6	……	18.2	18.3	ns	ns	ns	ns	ns	ns	ns
Exp II	11.8	10.8	8.3	11.8^{a}	12.4^{a}	11.0^{a}	11.9^{a}	4.6^{b}	13.9^{a}	8.7^{b}	ns	**	***	ns	ns	ns	ns

		S. D. E						
(experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
WU	5.3	2.38	3.07	1.94	5.32	3.36	4.34	7.52
WUE_g	12.4	0.75	0.18	0.61	1.67	1.06	1.36	2.36
WUE_b	25.6	1.68	2.17	1.37	3.76	2.38	3.07	5.32
(experiment II)								
WU	11.3	0.78	1.01	0.64	1.75	1.10	1.43	2.47
WUE_g	21.6	1.07	1.38	0.87	2.39	1.51	1.95	3.37
WUE_b	22.8	1.73	2.23	1.41	3.87	2.45	3.16	5.47

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties

Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively.

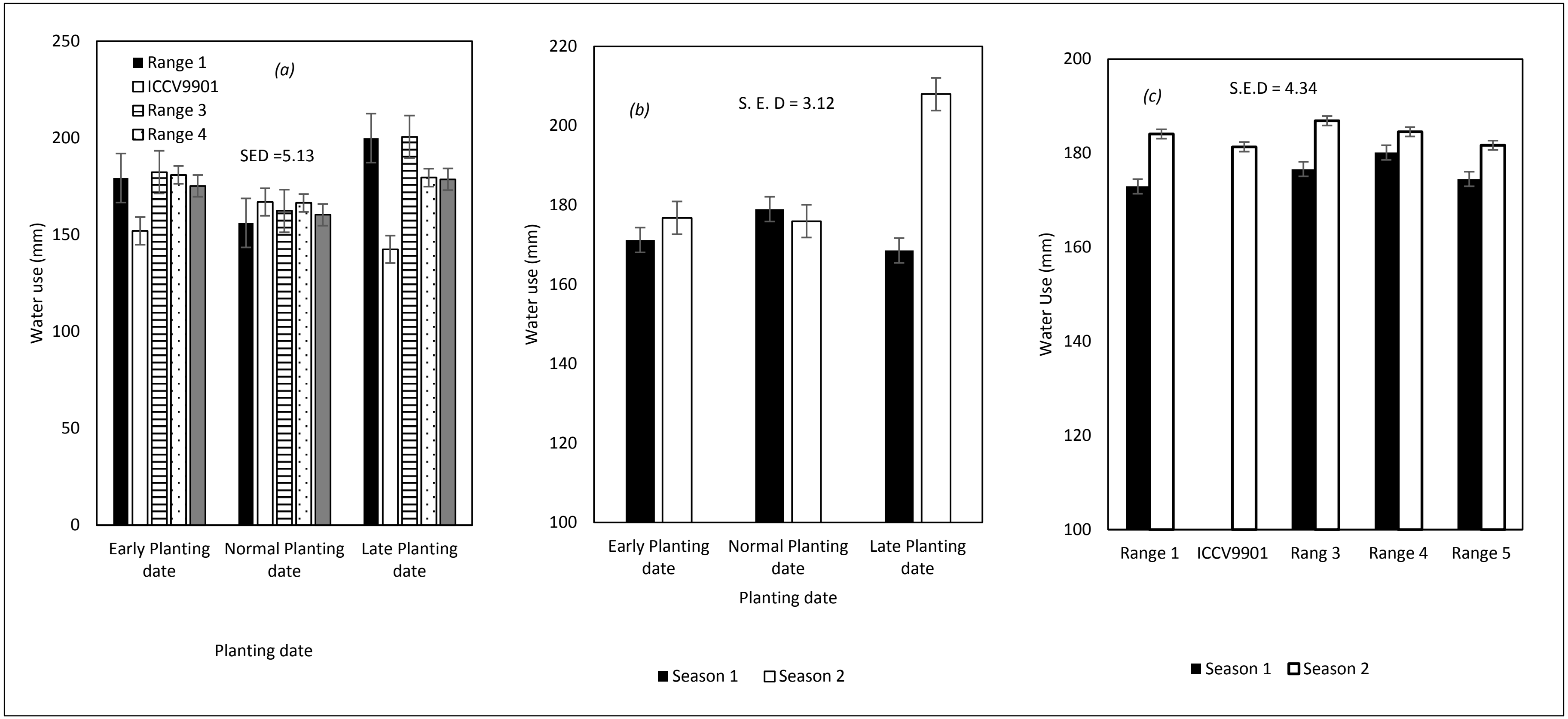


Fig 5.3.The effect of planting date x genotype (a), planting date x season (b), genotype x season (c) on cumulative WU in experiment I.

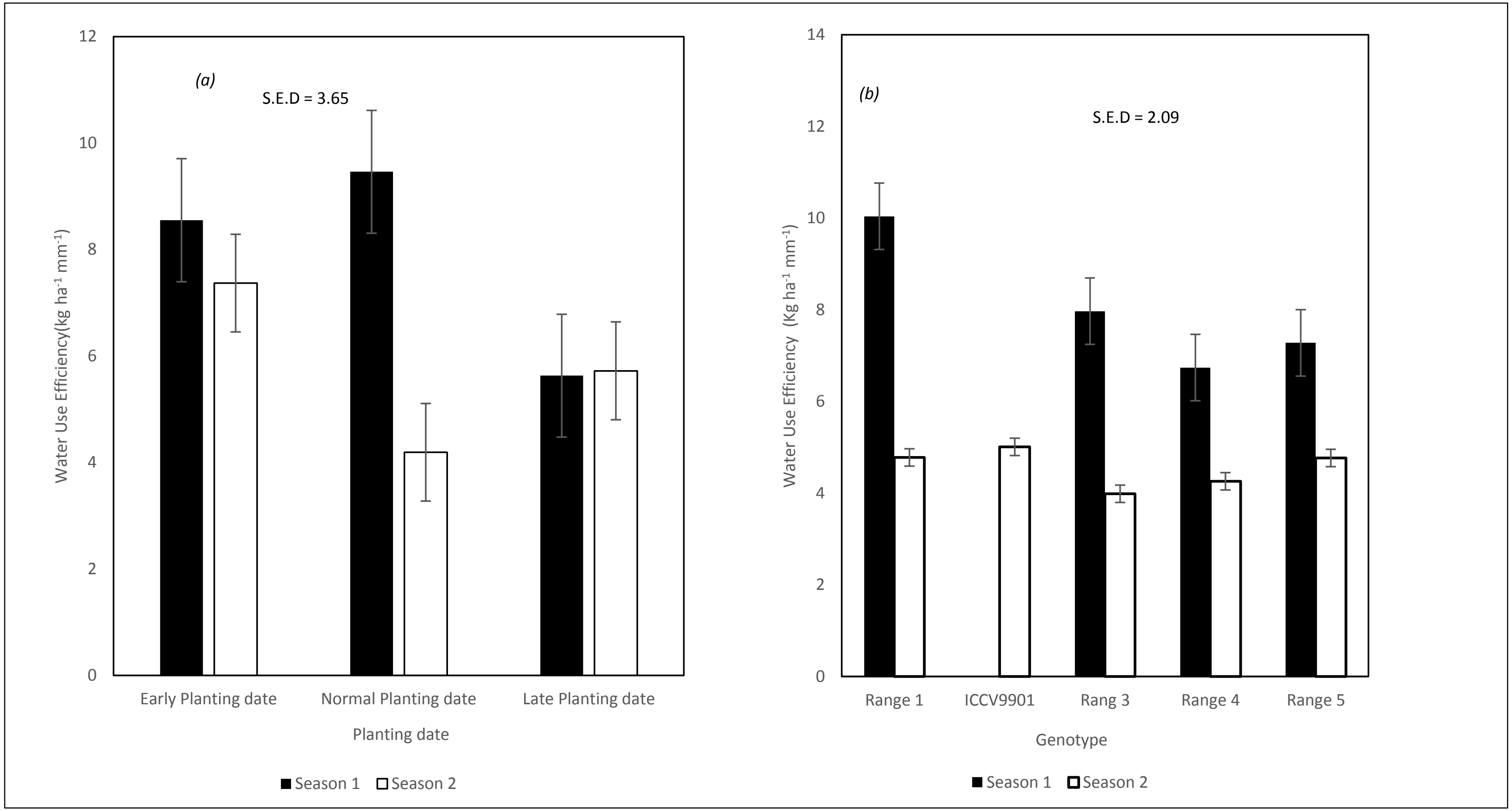


Fig 5.4.The effect of planting date x season (a), genotype x season (b) on WUE_g in experiment I.

5.3.5 Water use efficiency of biomass production.

Water use efficiency of biomass production (WUE_b) was not affected by PD, G and S in experiment I (Table 5.3). In experiment II in contrast, WUE_b was lower in ICCV9901 (4.6 kg ha^{-1} mm^{-1}) compared with the rest of the genotypes (11.0 to 12.4 kg ha^{-1} mm^{-1}), and 60% greater in season I compared with season II (Table 5.3).

5.3.6 Correlations and regression relationships amongst grain yield, water use and water use efficiency of biomass.

Grain yield and water use efficiency of grain yield and of biomass showed a strong positive correlation, whilst water use had no correlation in both experiments I and II (Table 5.4). Similarly, the linear regression analysis showed that grain yield had a strong relationship with water use efficiency of grain yield and biomass. However, the strength of the relationships were stronger in well-watered experiment compared with experiment II (limited irrigation) Table 5.4).

Table 5.4 Person's correlation and linear correlation analysis between grain yield and WU, WUEb and WUEg under different planting dates.

Treatments	Experiment I		Experiment II	
Relationship	r	R^2	r	R^2
WU	ns	-0.503	ns	-0.567
WUE_b	0.980**	0.960	0.606**	0.662
WUE_g	0.948**	0.899	0.679**	0.712

Person's correlation is denoted by r and linear correlation by R^2. * 0.05, ** 0.01, 0.001***

5.4 Discussion

5.4.1 Water extraction between planting dates

Soil water extraction followed a normal conical shape, particularly in the well-watered experiment. The greater soil water extraction in late planting compared to early and normal planting in the soil layer 0-30 cm was probably due, in part, to greater E_{sc} since late planting had lower canopy cover during early crop growth and indeed throughout the crop growth period. Although water use was not partitioned into transpiration (T) and E_{sc} in the current study, the association of larger leaf canopy with lower Esc has been reported in chickpea (Choma et al., 2018) and other crops (Ogola et al., 2002; 2005). In contrast to the 0-30 cm soil depth, soil water extraction was greater in early sowing compared with the control and late sowing in the 30-90 cm soil depth in both experiments, albeit more pronounced in the well-watered experiment. The greater biomass and canopy cover recorded in early planting clearly suggests that more water was required for greater dry matter accumulation (Ogola et al. 2013; Ogola and Thangwana 2013). Soil water extraction did not vary with planting date and was comparatively lower in the 90-120 cm in probably due to lower root density down the profile (Merrill and Rawlins, 1979; Benjamin and Nielsen, 2006) and lower specific free energy of the water near the surface that makes it more available than water deep in the profile (Durieux et al., 1994).

It is not clear why Range 1 & 3 (early and medium maturing) extracted more water from the 0-30 cm depth compared to the late maturing genotypes, Range 4 & 5 as this could not be explained by the variation in crop canopy cover. Range 1 & 3 had greater canopy cover early in the season (up to about 49 DAE), while Range 4 & 5 had greater canopy from 63 DAE until physiological maturity. However, the greater water extraction from the 60-90 cm soil depth in Range 4 & 5 could be attributed partly due the larger crop canopy during the period of maximum biomass accumulation (Ogola et al. 2013; Ogola and Thangwana 2013).

5.4 3 Water use

Cumulative crop water use varied with PD, G & S in the well-watered experiment but the effect of PD was not consistent across genotypes and seasons. With the exception of ICCV9901, WU was greater with both early and late sowing compared with the control in the rest of the genotypes. The greater cumulative water use in early sowing was likely due to the observed greater extraction of moisture from the 30-90 cm soil depth which has been attributed to large crop cover over a long duration (Miao et al., 2016) as well as the greater biomass. In contrast, the increase in WU in late sowing relative to the control was probably due, in part, to the observed greater soil water extraction in the 0-30 cm soil depth which was associated to greater E_{sc} since late planting had lower canopy cover during early crop growth and indeed throughout the crop growth period. Indeed, any management practice that increases E_{sc}, T or both E_{sc} and T increases crop WU (Ogola et al., 2002).

The greater water use in late sowing in season 2015 compared to 2014 was probably due to lower crop canopy cover in the late sowing in 2015 suggesting that there was greater loss of water through E_{sc} (Ogola et al., 2002; 2005). In support of this, both grain yield and total crop biomass was lower in late sowing compared with the control despite the greater WU. The non-consistent variation in WU with genotype over the two seasons could also be partly attributed to variation in canopy cover; although all genotypes had greater WU in season 1 compared to season 2, the late maturing genotypes (Range 4 & 5) which had larger crop canopy cover recorded minimum WU between the two seasons. Variation in WU with planting dates (Anwar, et al., 2003a), genotypes (Ogola et al., 2013; Ogola and Thangwana, 2013) and seasons (El-Mageed and Semid, 2015) have been reported in literature.

5.4 4 Water use efficiency of grain yield (WUE_g) and biomass (WUE_b)

The relationship between biomass accumulation or grain yield and water use (Equation 5.5 & 5.6), and the assumption that the two components of WU, T and E_{sc}, are independent and additive (Denmead, 1973) shows that WUE may be increased by increasing: the amount of dry matter or grain yield produced per unit of water transpired; the amount of water transpired relative to E_{sc}; and/or the total amount of water used to produce extra growth or yield provided that this results in increased transpiration rather than simply increasing E_{sc} (Sinclair et al 1984; Ogola et al., 2002). In the current study, late sowing increased WUEg, relative to the control, in 2014 but not in 2015 in the well-watered experiment. This interactive effect was probably because late sowing increased grain yield in both seasons, increased WU enormously in 2014, and decreased WU slightly in 2015. This suggests that the increase in WU due to late sowing was largely due to the increase in the wasteful E_{sc} rather than T (Ogola et al., 2002). Although the effect of planting date on WUEg in the drier experiment was statistically non-significant, WUEg generally increased with early sowing, and decreased with late sowing relative to the control; this could be attributed to the respective increase and decrease in grain yield in early and late sowing, which was accompanied by a decrease in WU in early sowing and no effect in late sowing, compared with the control.

The generally greater WUE_g across all genotypes in 2014 compared to 2015 was likely due to the similarly greater grain yield and lower WU in 2014. However, there was greater decrease in WUEg in Range 1 in 2015 compared with 2014 which was likely due to the relatively higher increase in WU in Range 1 compared with the rest of the genotypes. The lower WUEg in ICCV9901 compared with the rest of the genotypes in the drier experiment could be attributed partly to the observed 18.7% lower grain yield in ICCV9901 compared with the other genotypes, which was however, not accompanied by any genotypic differences in WU (Table 5.3). ICCV9901 is a kabuli and the other genotypes are desi chickpea types. Although only one kabuli compared to 4 desi genotypes were evaluated in the current study, the lower productivity of ICCV9901 particularly under water deficit, was probably due to relatively shorter vegetative growth time (calendar days), lower shoot biomass and a less developed root due to the less adaptability of kabuli genotypes to tropical environments (Purushothaman et al., 2014). However, Ogola and Thangwana (2013) reported greater WUEg in kabuli than desi genotypes at the site of the current study.

5.5 Conclusion

This study evaluated the effect of planting date and genotype on water use and water use efficiency of grain yield and biomass production of five chickpea genotypes. Water use, WUE_g and WUE_b varied with planting date, genotype and season but the effect of planting date on WU was not consistent across genotypes and seasons. Clearly, manipulation of management practices like sowing time and genotype selection may improve water and crop productivity of chickpea.

References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome*, *300*(9), p.D05109.

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 2003a. The effect of irrigation and sowing date on crop yield and yield components of Kabuli chickpea (Cicer arietinum L.) in a cool-temperate subhumid climate. *The Journal of Agricultural Science*, *141*(3-4), pp.259-271.

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 2003b. Phenology and growth response to irrigation and sowing date of Kabuli chickpea (Cicer arietinum L.) in a cool-temperate subhumid climate. *The Journal of Agricultural Science*, *141*(3-4), pp.273-284.

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 1999. Water use efficiency of chickpea (Cicer arietinum L.) cultivars in Canterbury: effect of irrigation and sowing date. *Agronomy New Zealand*, *29*, pp.1-8.

Benjamin, J.G. and Nielsen, D.C., 2006. Water deficit effects on root distribution of soybean, field pea and chickpea. *Field crops research*, *97*(2-3), pp.248-253.

Choma H, Ogola JBO. 2018. Water use and water use efficiency of chickpea. A dissertation submitted for the requirements of BSc honours in Agriculture. University of Venda. February 2018.

Davies, S.L., Turner, N.C., Palta, J.A., Siddique, K.H.M. and Plummer, J.A., 2000. Remobilisation of carbon and nitrogen supports seed filling in chickpea subjected to water deficit. *Australian Journal of Agricultural Research*, *51*(7), pp.855-866.

Denmead, O.T., 1973. Relative significance of soil and plant evaporation in estim ating evapotranspiration. In *Plant Response to Climatic Factors Proceedings of theuppsala Symposium*.

Djaman, K. and Irmak, S., 2012. Soil water extraction patterns and crop, irrigation, and evapotranspiration water use efficiency of maize under full and limited irrigation and rainfed settings. *Transactions of the ASABE*, *55*(4), pp.1223-1238.

Durieux, R.P., Kamprath, E.J., Jackson, W.A. and Moll, R.H., 1994. Root distribution of corn: the effect of nitrogen fertilization. *Agronomy Journal*, *86*(6), pp.958-962.

Evans, L.T., 1993. Crop evolution, adaptation, and yield. Cambridge Univ. Press, Cambridge, UK. *Crop evolution, adaptation, and yield. Cambridge Univ. Press, Cambridge, UK.*

Sumner, M., 2015. Soils of South Africa: Their distribution, properties, classification, genesis, use and environmental significance. *Soil Science Society of America Journal*, *79*(4), pp.1265-1265.

Fotiadis, S., Koutroubas, S.D. and Damalas, C.A., 2017. Sowing Date and Cultivar Effects on Assimilate Translocation in Spring Mediterranean Chickpea. *Agronomy Journal*, *109*(5), pp.2011-2024.

Kalra, N., Chakraborty, D., Sharma, A., Rai, H.K., Jolly, M., Chander, S., Kumar, P.R., Bhadraray, S., Barman, D., Mittal, R.B. and Lal, M., 2008. Effect of increasing temperature on yield of some winter crops in northwest India. *Current science*, pp.82-88.

Leport, L., Turner, N.C., Davies, S.L. and Siddique, K.H.M., 2006. Variation in pod production and abortion among chickpea cultivars under terminal drought. *European Journal of Agronomy*, *24*(3), pp.236-246.

López-Bellido, F.J., López-Bellido, R.J., Khalil, S.K. and López-Bellido, L., 2008. Effect of planting date on winter kabuli chickpea growth and yield under rainfed Mediterranean conditions. *Agronomy journal*, *100*(4), pp.957-964.

Lusiba, S., Odhiambo, J. and Ogola, J., 2017. Effect of biochar and phosphorus fertilizer application on soil fertility: soil physical and chemical properties. *Archives of Agronomy and Soil Science*, *63*(4), pp.477-490.

Lusiba, S., Odhiambo, J. and Ogola, J., 2018. Growth, yield and water use efficiency of chickpea (Cicer arietinum): response to biochar and phosphorus fertilizer application. *Archives of Agronomy and Soil Science*, *64*(6), pp.819-833.

Madzivhandila, T., Ogola, J.B.O. and Odhiambo, J.J.O., 2012. Growth and yield response of four chickpea cultivars to phosphorus fertilizer rates. *J. Food, Agric. Environ*, *10*, pp.451-455.

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

Merrill, S.D. and Rawlins, S.L., 1979. Distribution and Growth of Sorghum Roots in Response to Irrigation Frequency 1. *Agronomy Journal*, *71*(5), pp.738-745.

Miao, Q., Rosa, R.D., Shi, H., Paredes, P., Zhu, L., Dai, J., Gonçalves, J.M. and Pereira, L.S., 2016. Modeling water use, transpiration and soil evaporation of spring wheat–maize and spring wheat–sunflower relay intercropping using the dual crop coefficient approach. *Agricultural Water Management*, *165*, pp.211-229.

Ogola, J.B.O., Wheeler, T.R. and Harris, P.M., 2005. Water use of maize in response to planting density and irrigation. *South African Journal of Plant and Soil*, *22*(2), pp.116-121.

Ogola, J.B.O. and Thangwana, N.M., 2013. Water use efficiency of summer sown chickpea in a tropical environment: Response to genotype and planting density. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.2689-2695.

Ogola, J.B., Madzivhandila, T. and Odhiambo, J.J., 2013. Water use of chickpea (Cicer arietinum L.): Response to genotype and phosphorus fertilizer rates in winter and summer sowings. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.1341-1347.

Ogola, J.B.O., Wheeler, T.R. and Harris, P.M., 2002. Effects of nitrogen and irrigation on water use of maize crops. *Field Crops Research*, *78*(2-3), pp.105-117.

Purushothaman, R., Upadhyaya, H.D., Gaur, P.M., Gowda, C.L.L. and Krishnamurthy, L., 2014. Kabuli and desi chickpeas differ in their requirement for reproductive duration. *Field Crops Research*, *163*, pp.24-31.

Regan, K.L., Siddique, K.H.M., Brandon, N.J., Seymour, M. and Loss, S.P., 2006. Response of chickpea (Cicer arietinum L.) varieties to time of sowing in Mediterranean-type environments of south-western Australia. *Australian Journal of Experimental Agriculture*, *46*(3), pp.395-404.

Saxena, M.C., Silim, S.N. and Singh, K.B., 1990. Effect of supplementary irrigation during reproductive growth on winter and spring chickpea (Cicer arietinum) in a Mediterranean environment. *The Journal of Agricultural Science*, *114*(3), pp.285-293.

Siddique, K.H.M., Regan, K.L., Tennant, D. and Thomson, B.D., 2001. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. *European Journal of Agronomy*, *15*(4), pp.267-280.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Sinclair, T.R., Tanner, C.B. and Bennett, J.M., 1984. Water-use efficiency in crop production. *Bioscience*, *34*(1), pp.36-40.

Singh, K.B., Malhotra, R.S., Saxena, M.C. and Bejiga, G., 1997. Superiority of winter sowing over traditional spring sowing of chickpea in the Mediterranean region. *Agronomy Journal*, *89*(1), pp.112-118.

Tadross, M.A., Gutowski, W.J., Hewitson, B.C., Jack, C. and New, M., 2006. MM5 simulations of interannual change and the diurnal cycle of southern African regional climate. *Theoretical and Applied Climatology*, *86*(1-4), pp.63-80.

Thangwana MN, Ogola JBO 2016. Calibration of a neutron probe in a clay soil in Thohoyandou. Combined Congress 2016. Book of Abstracts. 250.

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

Tolk, J.A. and Howell, T.A., 2009. Transpiration and yield relationships of grain sorghum grown in a field environment. *Agronomy journal*, *101*(3), pp.657-662.

Tollenaar, M. and Dwyer, L.M., 1999. Physiology of maize. In *Crop yield* (pp. 169-204). Springer, Berlin, Heidelberg.

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Turner NC, Davies SL, Plummer JA Siddique, KHM. 2005. Seed filling in grain legumes under water deficits, with emphasis on chickpeas. *Advances in Agronomy*, 87, pp. 211–250.

Zhang, H., Pala, M., Oweis, T. and Harris, H., 2000. Water use and water-use efficiency of chickpea and lentil in a Mediterranean environment. *Australian Journal of Agricultural Research*, *51*(2), pp.295-304.

Chapter 6

Planting date effects. Resource use in chickpea (Cicer arietinum. L): III Radiation use efficiency.

Abstract

Radiation use efficiency is a crop parameter that may be used for analysing crop productivity across diverse environments. Two field experiments, to assess the effect of planting date on canopy cover, intercepted radiation (IR), and radiation use efficiency of grain yield (ε_g) and biomass production (ε_b) of 5 chickpea genotypes, were conducted in 2014 & 2015 in NE South Africa. Planting date (1, 14 & 28 May being early, control/normal, and late, respectively) was allocated the main plots and chickpea genotypes (Range 1, Range 3, Range 4, Range 5 and ICCV99010) the sub-plots. Experiment I was well watered (close to field capacity) throughout the season, and experiment II was watered three times (at planting, flowering and pod formation). Relative to the control, late sowing decreased total IR by 12.2% (5.1 MJ m^{-2} d^{-1}) and 3.2% (1.1 MJ m^{-2} d^{-1}) in experiment I & II, respectively. In early sowing in contrast, total IR was greater by 25.5% (10.6 MJ m^{-2} d^{-1}) in experiment I and 33.5% (11.2MJ m^{-2} d^{-1}) in experiment II compared to the control. In comparison to the control, ε_b was 13.2% lower (0.17 g MJ^{-1}) and 6.2% greater (0.08 g MJ^{-1}) in late and early sowing, respectively in experiment I. The response of ε_g to planting date varied with genotype in experiment II but was, on average, greater in early (1.06 g MJ^{-1}) compared with control (0.96 g MJ^{-1}) and late (0.90 g MJ^{-1}) sowing. ε_b varied with genotype in experiment I and was subjected to the interaction between sowing date and genotype in experiment II. On average, Range 4 & 5, had greater ε_g (0.97 g MJ^{-1}) compared to ICCV9901 (0.90 g MJ^{-1}) and Range 1 & 3 (0.84 g MJ^{-1}) in experiment I. The response of ε_g to genotype in experiment II varied with planting date but was generally greater in the late maturing varieties, Range 4 & 5. Clearly, manipulation of planting date may be used as a tool to enhance radiation interception and the efficiency of conversion of the intercepted radiation to yield of chickpea in this environment.

Keywords: Canopy cover; Chickpea Genotypes; Intercepted Radiation; Kabuli, Early and late maturing cultivars.

.

6.1 Introduction

Crop productivity may be analysed based on the relationship between yield and total intercepted radiation, or that between yield and cumulative water use, categorised as solar-driven and water-driven productivity, respectively (Steduto, 2003). Yield may be economic (grain yield) or biological (total crop biomass) yield. Albrizio and Steduto (2005) concluded that the relationship at the biomass level properly captures and synthesizes the optimisation of underlying processes occurring during growth. Chapter 5 of this study focussed on the water-driven growth. In this chapter, the focus is on solar-driven growth as illustrated in equation 1 (Ogola, 2015).

$$DM = \int Qi\varepsilon\delta t \qquad (6.1)$$

Where Q is daily incident radiation, i is fraction of incident radiation intercepted, ε is radiation use efficiency (the slope of the graph representing the relationship between crop yield and total intercepted radiation), and t is time.

It is clear from the solar driven-growth (equation 6.1) that any management practice that increases daily incident radiation, fraction of incident radiation intercepted, radiation use efficiency, and the duration of radiation interception will increase crop yield. Although ε is considered to be fairly constant for a given crop species at a given environment, huge variability in radiation use efficiency values under optimal conditions have been reported (Sinclair and Muchow, 1999) and thus there is need for more comprehensive investigations of the relationship between dry matter accumulation and radiation capture under different management and environmental conditions. Earlier, Gullagher and Biscoe (1978) reported a direct relationship between Y_i and Photosynthetically Active Radiation (PAR), harvest index (HI) and ε (equation 6.2).

$$Y_i = IR * \varepsilon * HI \qquad (6.2)$$

Although harvest index (HI) tends to be constant and genotype-dependent (Gifford et al, 1984; Hay and Walker, 1989), some studies show that manipulation of management practices affects biomass partitioning into grain yield in chickpea (Thangwana and Ogola, 2012; Fotiadis et al., 2017; Lusiba et al., 2018). Also, IR and ε can be manipulated for yield improvement using several management strategies such as the choice of planting date within a season (Tsimba, 2011). This does not contradict the conclusions of Sinclair and Muchow (1999) because changing the sowing date essentially changes the environment under which a crop grows.

Planting early or late in the season may affect radiation capture depending on climate factors such as temperature (Andrade et al., 1993; Soltani et al., 2006), rainfall and vapour pressure deficit (VPD) (Kiniry et al., 1998). For example, in the southern hemisphere, early crop growth in late sowings during winter normally coincides with winter solstice, when the sun is furthest away from the earth, sunshine hours are shortest, and temperatures are very low (Nautical Almanac office, 1999). In contrast, early sowing of chickpea may allow the crop to take advantage of available radiation when winter solstice is at least 55 days from planting date. In support of this, early plantings of chickpea in winter at the site of the current study experienced higher temperatures (by 2 ^{o}C – 3 ^{o}C) during vegetative stage compared with late plantings.

Also, earlier reports have shown that radiation capture is directly affected by temperature (Muchow et al., 1990), and that low temperatures may reduce total intercepted radiation in plants (Andrade et al., 1993; Soltani et al., 2006). Therefore manipulation of planting date not only affects the radiation regime to which a crop grows but the temperature regime as well. Furthermore, early sowing may result into longer growing season and hence a longer duration of radiation interception and allow the crop to take advantage of residual moisture in the soil (Siddique and Sedgley, 1986) and hence promote a faster and early canopy growth which ensures greater radiation capture. Also, manipulation of sowing date may affect the daily incident radiation, Q, indirectly by influencing the radiation regime to which a crop is exposed.

Despite the overwhelming evidence in literature on the relationship between radiation interception and crop growth, as illustrated in equation 6.1, large variations in ε_b have been reported (Sinclair and Muchow, 1999; Albrizio and Steduto, 2005; Ogola, 2015). Therefore there is need for further investigation of the relationship between biomass accumulation and radiation interception and the influence of various management practices on this relationship.

The study hypothesised that incident radiation, moisture regime and temperature pattern would affect radiation capture and the efficiency of utilization of the captured radiation to produce yield. Thus we designed the study to have two separate experiments, one well-watered, close to field capacity, throughout crop growth and the other one watered only three times (at planting, first flowering and first podding stage). Consequently we investigated the effect of planting date on radiation use and radiation use efficiency of five chickpea genotypes grown under (i) well-watered conditions, and (ii) deficit-irrigation.

6.2 Materials and method

6.2.1 Experimental design

Field experiments were conducted at the University of Venda's experimental farm in Thohoyandou (22º58.08´S and 30º26.4´E, and 595m above sea level), South Africa in 2014 and 2015 winter seasons. The experimental details including climatic and soil characteristics of the study location, experimental design and cultural practices have been reported in chapter 3 but a brief description of the experimental design is given below.

Two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1, 14 and 28 May representing early, control and late planting date, respectively), and four desi chickpea genotypes (Range 1, Range 3, Range 4 and Range 5) in 2014, and 4 desi and one kabuli genotype (ICCV99010) in 2015 season were assigned to sub-plots. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV9901 are medium maturing and have erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structure, respectively.

Experiment I was well-watered throughout the season with the aim of keeping the plots close to field capacity, and experiment II was watered three times (at planting, flowering and pod formation). The frequency of irrigation, and the total amount of water applied at each occasion, in experiment I was based on soil moisture content that was measured periodically using a neutron probe as explained in chapter 5. The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment I and 175 mm in experiment two, whilst 435 mm and 235 mm was applied in 2015 in Experiment I & II, respectively.

6.2.2 Measurements

6.2.2.1 Weather records

An automatic weather station that is approximately 100 m from the experiments was used to record relative humidity (%), maximum and minimum air temperatures (°C), and solar radiation (MJ m^{-2} d^{-1}), for each day during crop growing season (Table 6.1).

6.2.2.2 Biomass and grain yield

Aboveground biomass and grain yield determination are described in chapter 4.

6.2.2.3 Intercepted radiation and radiation use efficiency

The proportion of intercepted radiation (F_i) by the canopy was approximated based on the method presented by Gallagher and Biscoe (1978) as shown in equation 6.3.

$$F_i = 1.0 - T_i \qquad (6.3)$$

Where T_i is fraction of incident radiation transmitted by the canopy (equation 4):

$$T_i = 1 - \left(\frac{PAR_{below\ canopy}}{PAR_{above\ canopy}}\right) \qquad (6.4)$$

The total amount of Photosynthetically Active Radiation (PAR) intercepted (IR) was approximated using equation 5 (Anwar et al*.,* 2003; Szeic, 1974; Jahansooz et al*.,* 2007).

$$IR = F_i * Q \qquad (6.5)$$

Where Q is daily incident radiation

PAR above and below the canopy was measured mostly at 7-day intervals between 28 and 91 days after emergence (DAE) in both 2014 and 2015. The measurement dates in both years encompassed the vegetative as well as the reproductive (flowering, podding and physiological maturity) stages of crop growth. The measurements were taken between 11.00 h and 13.00 h (solar noon) on clear, cloudless days using AccuPAR ceptometer (model LP-80, Decagon Devices Ltd., Pullman, USA. When measuring PAR below the canopy, the ceptometer was positioned between the rows in such a manner that it ran perpendicular to the rows. PAR was taken as 50% of the incident solar radiation (Monteith and Unsworth, 1990).

Radiation use efficiency for biomass production (ε_b) and grain yield (ε_g) was calculated as the ratio of total above ground biomass or grain yield to total intercepted radiation (equations 6 and 7).

$$\varepsilon_b\ (g\ MJ^{-1}) = \frac{Total\ aboveground\ biomass\ (g\ m{-}2)}{Total\ intercepted\ radiation\ (MJ\ m{-}2)} \qquad (6.6)$$

$$\varepsilon_g\ (\text{g MJ}^{-1}) = \frac{Grain\ yield\ (g\ m{-}2)}{Total\ intercepted\ radiation\ (MJ\ m{-}2)} \quad (6.7)$$

6.2.3 Data analysis

Analyses of variance were performed, using the GenStat statistical package 17th edition, to assess the effect of planting date and genotype on proportion of radiation intercepted (F_i), the total amount of intercepted PAR (IR), and radiation use efficiency of biomass production and grain yield were performed. Significant differences among the treatment means were separated at 0.05 probability level using the Standard error of difference of the means (SED). Linear regression analysis was used to evaluate the relationship between intercepted radiation and biomass as well as grain yield.

6.3 Results

6.3.1 Summary of weather data at Thohoyandou, during winter 2014 and 2015 cropping seasons.

The maximum temperatures during vegetative growth in experiment I varied with planting date from 25.6 ^oC (late sowing) to 26.6 ^oC (early sowing) in 2014, and 26.4 ^oC (late sowing) to 27.5 ^oC (early sowing) in 2015. Similar trend was observed in experiment II (Table 6.1). In contrast, maximum temperatures during reproductive growth in experiment I was greater in late sowing (33.0 & 33.1 ^oC) compared with the control (30.2 & 32.4 ^oC) and early sowing (30.3 & 31.2 ^oC), respectively in 2014 and 2015. Similarly in experiment II, maximum temperatures during reproductive was greater in late sowing (33.1 ^oC & 33.8 ^oC) compared with the control (30.3 & 32.2 ^oC) and early sowing (30.4 & 31.6 ^oC) in 2014 and 2015, respectively (Table 6.1).

The average incident solar radiation during vegetative growth in experiment I was greater in late sowing (15.9 & 16.2 MJ m^{-2} d^{-1}) compared with the control (15.6 & 15.4 MJ m^{-2} d^{-1}) and early sowing (14.7 & 15.8 MJ m^{-2} d^{-1}), respectively in 2014 and 2015. Similar trend was observed in experiment II (Table 6.1). In contrast to vegetative stage, incident solar radiation during reproduction stage was lower in late sowing (15.8 MJ m^{-2} d^{-1}) compared with the control (16.2 MJ m^{-2} d^{-1}) and early sowing (16.4 MJ m^{-2} d^{-1}) in experiment I in 2014 but the converse was the case in 2015 (16.2, 16.6 & 17.3 MJ m^{-2} d^{-1}, respectively in early, the control and late sowing) (Table 6.1). In experiment II, however, incident solar radiation during the reproductive stage was lower in early sowing (14.8 & 15.9 MJ m^{-2} d^{-1}) compared with the control (16.7 & 16.4 MJ m^{-2} d^{-1}) and late sowing (15.4 & 17.1 MJ m^{-2} d^{-1}) in 2014 and 2015, respectively (Table 6.1).

Table 6.1. Maximum, and minimum temperatures recorded during vegetative and reproductive Stages of the crop.

Crop development Stage	T_{max} (°C)		T_{min} (°C)		Solar radiation ($MJm^{-2}day^{-1}$)	
2014						
Experiment	**I**	**II**	**I**	**II**	**I**	**II**
Vegetative stage						
Early planting	26.6	26.4	11.1	10.8	14.7	13.9
Normal Planting	25.9	25.9	10.9	10.6	15.6	15.4
Late Planting	25.6	25.4	10.5	10.2	15.9	15.6
Flowering and podding						
Early Planting	30.3	30.4	10.0	9.8	16.4	14.8
Normal Planting	30.2	30.3	10.5	10.3	16.2	16.7
Late planting	33.0	33.1	11.1	11.0	15.8	15.4
2015						
Experiment I						
Vegetative stage						
Early planting	27.5	26.9	11.1	10.9	15.8	15.5
Normal Planting	26.9	26.6	10.9	10.6	15.4	15.1
Late Planting	26.4	26.2	10.5	10.3	16.2	15.9
Flowering and podding						
Early Planting	31.2	31.6	10.0	9.9	16.2	15.9
Normal Planting	32.4	32.2	10.5	10.4	16.6	16.4
Late planting	33.1	33.8	11.1	10.9	17.3	17.1

6.3.2 Proportion of intercepted radiation

The proportion of intercepted radiation (F_i) varied with planting date in both experiments but the variation was more pronounced in the well-watered than the drier experiment (Fig 6.1a & b). Early sowing recorded greater F_i compared to the rest of the dates between 49 and 91 DAE in experiment I (Fig 6.1a) and between 63 and 84 DAE in experiment II (Fig 6.1b). The proportion of intercepted radiation was lowest in late sowing in both experiments (Fig 6.1a&b). The maximum F_i was recorded in early (92 and 60% in experiment I & II, respectively) compared with the control (60 and 55% in experiment I & II, respectively) and late (51 and 46% in experiment I & II, respectively) sowing (Fig 6.1a & b).

Also, genotype affected the proportion of IR in both experiments but the variation was greater in experiment I compared to experiment II; Range 4 recorded the highest peak F_i in experiment I (65%) and II (60%), and Range 1 (54%) & Range 3 (49%) the lowest peak F_i in experiment I and II, respectively (Fig 6.1c & d).

The main effect of planting date (PD), genotype (G) and year (Y) on total IR was significant in both experiments but in experiment II the effect of PD varied with year (Table 6.2). Compared to the control, total IR was 25.5% (148 MJ m^{-2}) greater in early sowing and 12.2% (71 MJ m^{-2}) lower in late sowing in experiment I (Table 6.2). Similarly, relative to the control, total IR was greater (by 33.5%; 157 MJ m^{-2}) in early sowing and lower (by 3.2%; 15 MJ m^{-2}) in late sowing in experiment II (Table 6.2). Also, in experiment II, total IR was subjected to an interaction between planting date and year; with early sowing total IR did not vary from 2014 to 2015 but with the control and late sowing, total IR was lower in 2015 compared to 2014 (Fig 6.2).

Range 4 & 5 had, on average, 19.9% (113 MJ m^{-2}) greater total IR than Range 3 and ICCV9901, and 29.1% (153.5 MJ m^{-2}) greater total IR than Range 1 in experiment I (Table 6.2). Similarly, Range 4 & 5 intercepted 9.7% (49.8 MJ m^{-2}) greater total IR compared to the rest of the genotypes in experiment II (Table 6.2). Also, total IR was greater by 9.7% (62 MJ m^{-2}) in 2014 compared to 2015 in experiment I, and by 20% (115 MJ m^{-2}) in 2014 compared to 2015 in experiment II (Table 6.2).

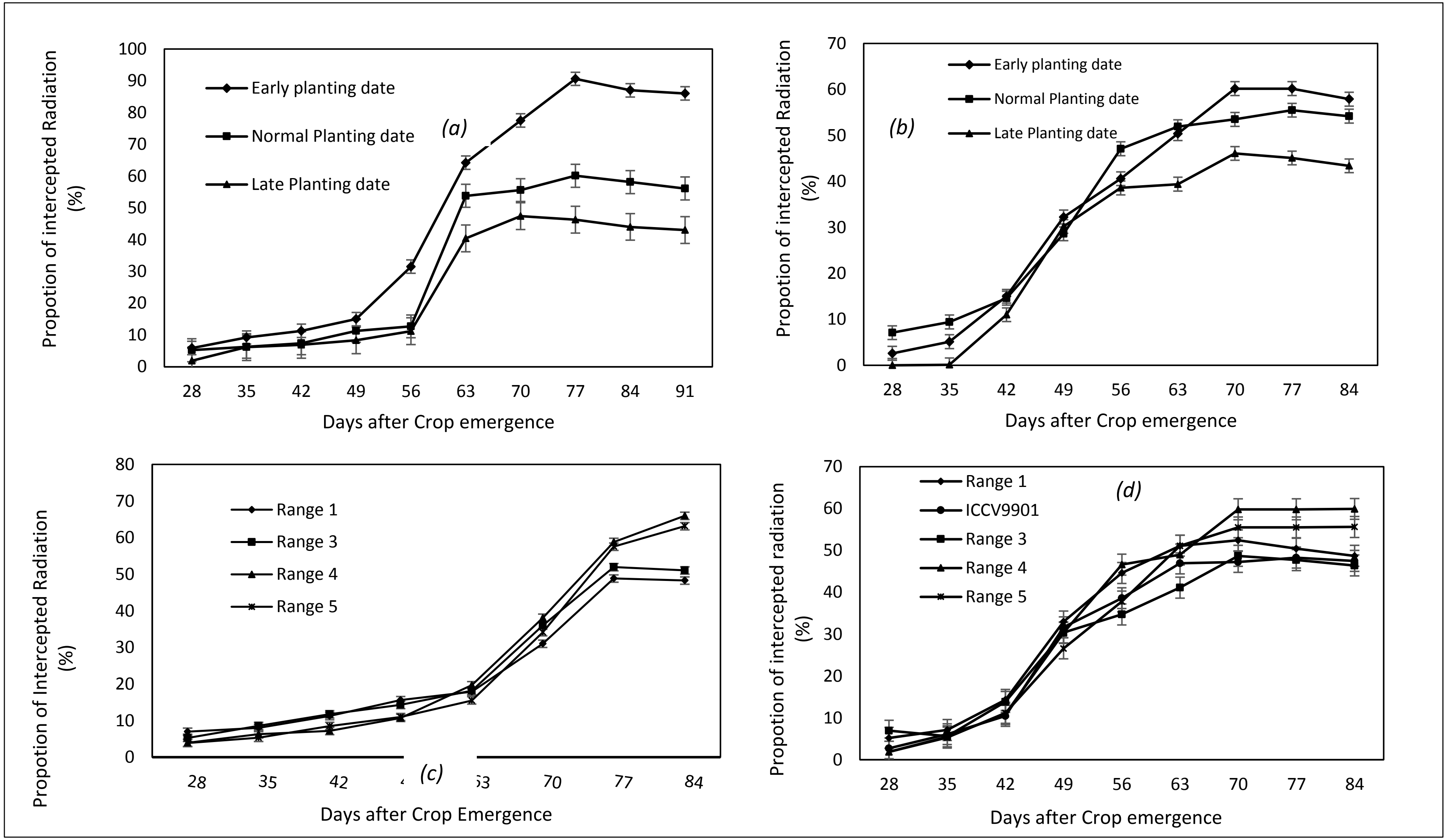


Fig 6.1 Effect of planting date and genotype on propotion of intercepted radiation. Graphs a and c are for experiment I, whilst graphs b and d are for experiment II.

6.3.3 Total intercepted radiation

The total intercepted radiation (IR) was 25.5% and 43.0% greater, respectively in early planting compared with normal and late planting in experiment I (Table 6.2). Range 4 and Range 5 had similar IR, which was however 20.7%, 18.8% and 29.0% greater, respectively compared with Range 1, Range 3 and ICCV 9901. Furthermore, season 1 had 10.8% greater IR compared with season 2.

In contrast, the interaction between planting date and season affected IR in experiment II. Season 1 and 2 had similar IR in early planting (624 MJm^{-2}) but IR was however 64.2% and 76.8% greater, respectively in season 1 compared with season 2 in normal and late planting date, respectively (Fig 6.2). In addition, the genotype Range 5 intercepted greater IR by an average of 25.1 %, 11.9 %, and 10.5 %, compared to ICCV 9901, Range 1, Range 3 and Range 4 cultivars, respectively in experiment II (Table 6.2). Experiment I had 17.7% greater IR (606 MJ m^{-2}) compared to experiment II (515 MJ m^{-2}).

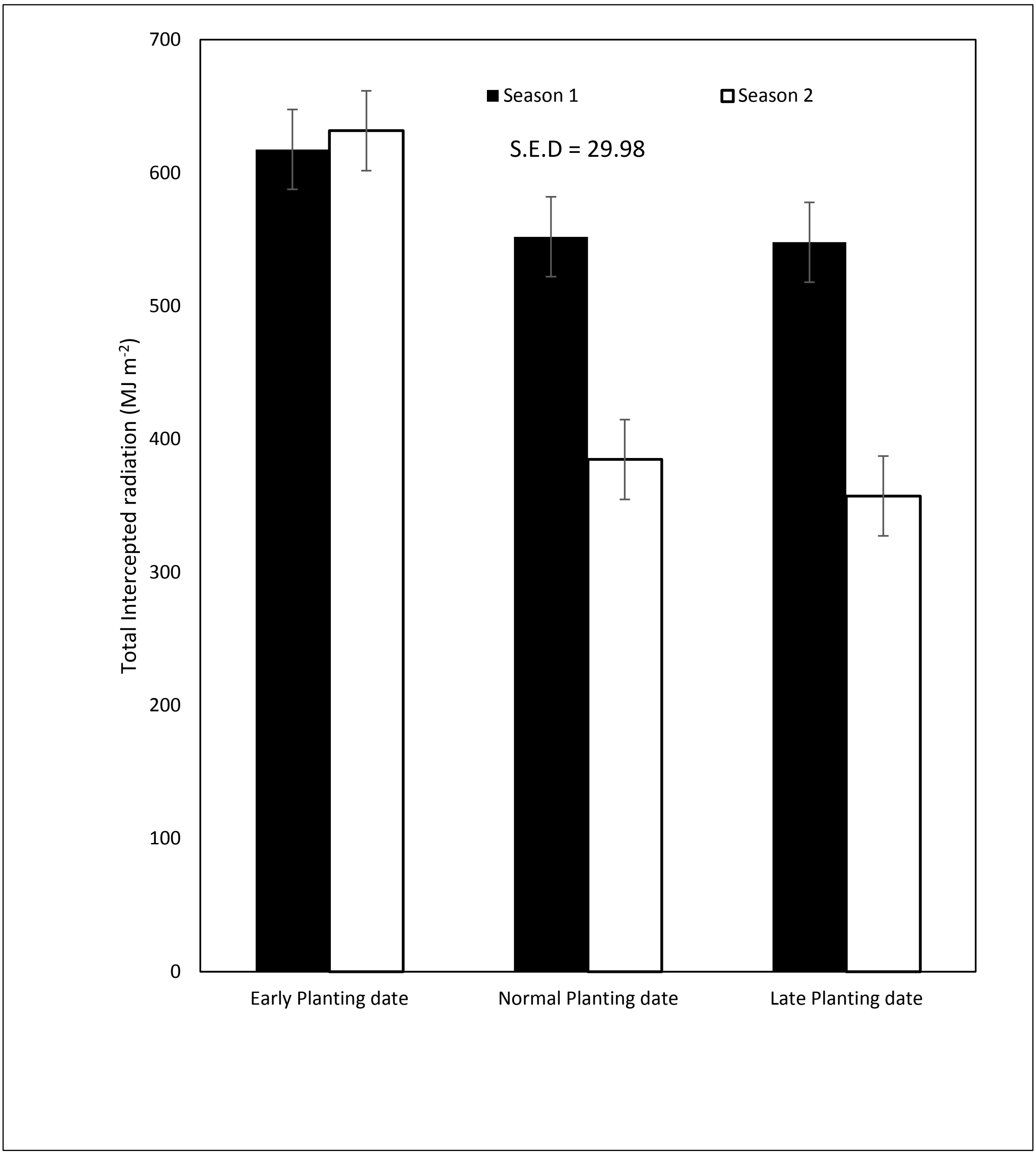


Fig. 6.2 Interactive effect of planting date and planting season on total intercepted radiation in experiment II.

6.3.4 Radiation use efficiency of biomass.

Radiation use efficiency of biomass production (ε_b) was significantly affected by the PD ($p<0.001$), G ($p<0.01$) and the PD x G interaction ($p<0.05$) in experiment I but since the main effects of PD and G were more significant than the interactive effects, only the main effects of PD and G are described. Relative to the control, ε_b was 6.2% (0.08 g MJ^{-1}) greater and 13.2% (0.17 g MJ^{-1}) lower in early and late sowing, respectively in experiment I (Table 6.2). Also, ε_b varied with genotype from 1.13 g MJ^{-1} (Range 1) to 1.44 g MJ^{-1} (ICCV9901) in experiment I (Table 6.2).

In experiment II in contrast, ε_b was subjected to the interaction between PD & G ($p<0.001$), PD & Y ($p<0.001$), and G & Y ($p<0.001$) (Table 6.2). The interaction between PD & G was such that ε_b varied from 1.09 g MJ^{-1} (ICCV9901) to 1.39 g MJ^{-1} (Range 5) in late sowing, and 1.36 g MJ^{-1} (Range 3) to 1.83 g MJ^{-1} (Range 5) in early sowing (Figure 6.3). In addition, there was no significant difference in ε_b between early sowing and the control (Figure 6.3). Also, the effect of genotype on ε_b in experiment II varied with year; Range 5 recorded greater ε_b in 2014 compared to 2015 while the converse was true for Range 3, and no significant differences in ε_b between 2014 and 2015 were observed in Range 1, Range 4 and ICCV9901 (Figure 6.4b). Also, ε_b was greater in 2014 compared to 2015 in early sowing and the control, while the converse was the case in late planting (Figure 6.4a).

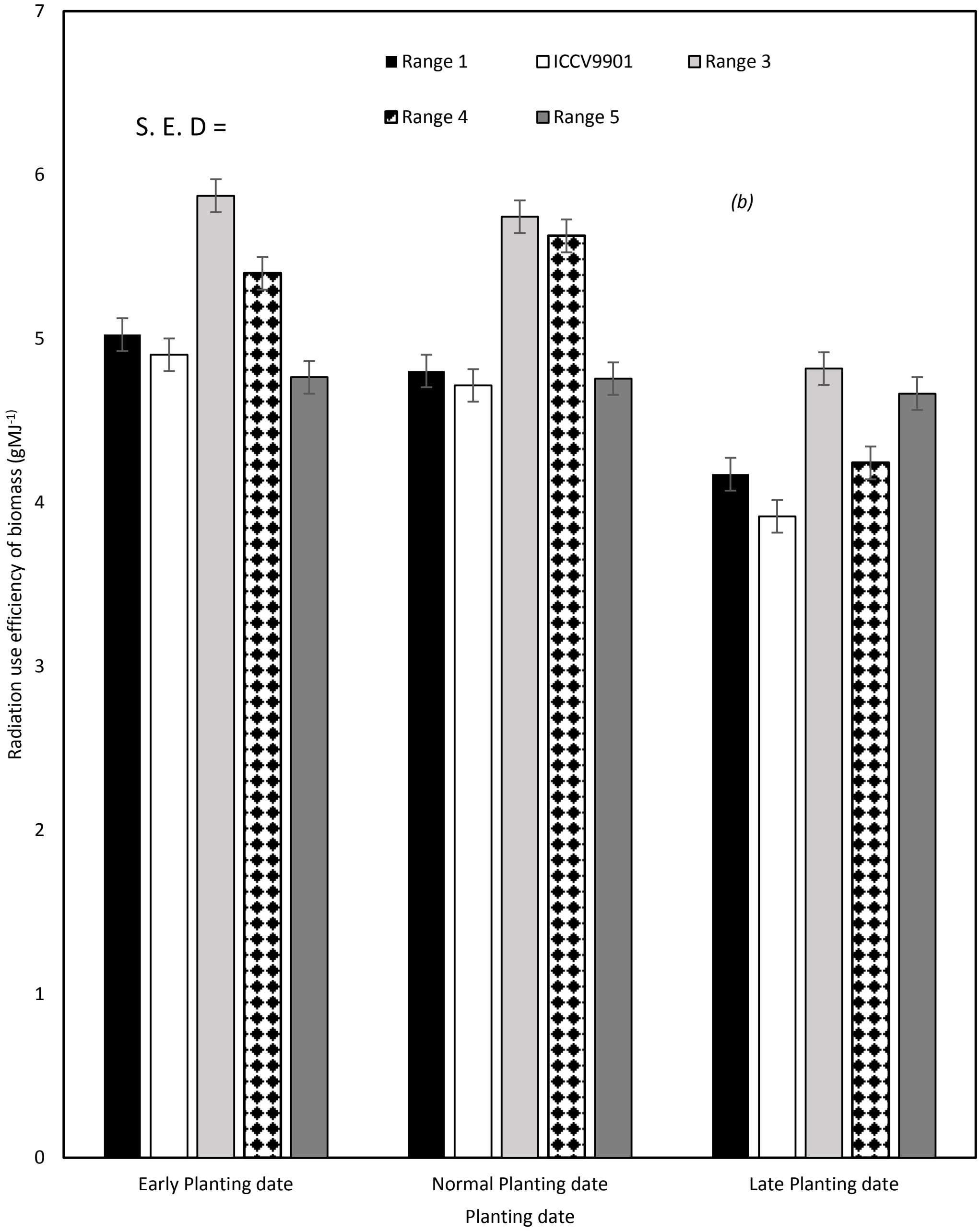


Fig 6.3 Interaction effect of planting date and genotype on radiation use efficiency of biomass

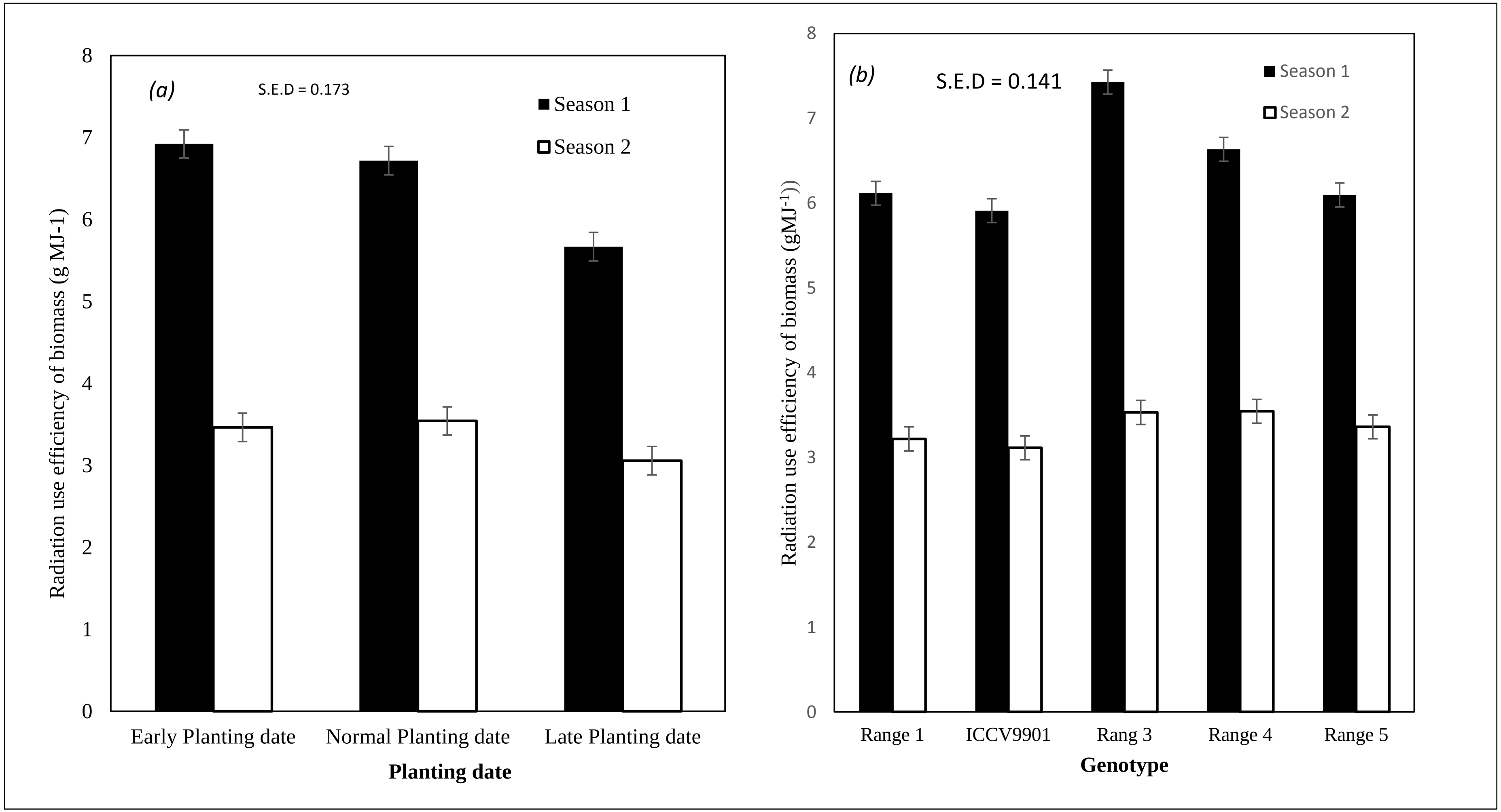


Fig 6.4 Interaction effect of planting date & season (a), genotype & season (b) on radiation use efficiency of biomass in experiment II.

6.3.5 Radiation use efficiency of grain yield (RUE_g).

Genotype and year affected radiation use efficiency of grain yield (ε_g) in experiment I (Table 6.2). Range 4 & 5 recorded the highest ε_g which was, on average, 7.2% (0.07 g MJ^{-1}) greater than ICCV9901, and 15.6% (0.13 g MJ^{-1}) greater than Range 1 & 3, and ε_g was 13.4% lower in 2015 compared to 2014 (Table 6.2). In experiment II in contrast, there was significant main effects of PD & G (Table 6.2). Across genotypes, ε_g was greater in early sowing compared to the control and late sowing (Table 6.2). The interactive effect between PD & G was such that no significant difference in ε_g among the genotypes was observed in the control and late sowings but Range 4 & 5 recorded greater ε_g compared with the rest of the genotypes in early sowing (Table 6.2).

Table 6.2. The response of total intercepted radiation, and radiation use efficiency of grain yield (ε_g) and biomass production (ε_b) to planting date and genotype in 2014 and 2015

Experiment	Treatment										P (F-ratio)						
	EPD	NPD	LPD	R1	R3	R4	R5	ICCV9901	2014	2015	PD	G	S	PD X G	PD x S	G x S	PD x G x S
IR (MJm^{-2})																	
Exp I	728^{a}	580^{b}	509^{c}	528^{c}	573^{b}	681^{a}	682^{a}	564^{b}	637^{a}	575^{b}	***	***	**	ns	ns	ns	ns
Exp II	625^{a}	468^{b}	453^{b}	505^{b}	513^{b}	558^{a}	573^{a}	529^{b}	573^{a}	458^{b}	***	***	***	ns	***	ns	ns
ε_b (b gMJ^{-1})																	
Exp I	1.37^{a}	1.29^{b}	1.12^{c}	1.13^{cd}	1.26^{bc}	1.29^{b}	1.19^{c}	1.44^{a}	1.31	1.21	***	**	ns	*	ns	ns	ns
Exp II	1.56^{a}	1.54^{a}	1.21^{b}	1.32^{c}	1.35^{c}	1.50^{b}	1.67^{a}	1.34^{c}	1.45	1.42	***	***	ns	***	***	***	ns
ε_g (g MJ^{-1})																	
Exp I	0.99	0.89	0.84	0.84^{c}	0.83^{c}	0.94^{a}	0.99^{a}	0.90^{b}	0.97^{a}	0.84^{b}	ns	***	**	ns	ns	ns	ns
Exp II	1.06^{a}	0.96^{b}	0.90^{b}	0.84^{b}	0.89^{a}	0.87^{a}	0.94^{a}	0.87^{a}	0.99	0.96	**	***	ns	ns	ns	ns	ns

		S. D. E						
(experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
IR	5.3	30.5	39.3	24.9	68.1	43.1	55.6	96.4
ε_b	20.3	0.066	0.085	0.054	0.148	0.094	0.121	1.432
ε_g	25.6	0.078	0.101	0.064	0.175	0.111	0.143	0.609
(experiment II)								
IR	11.3	21.20	27.37	17.31	47.40	29.98	38.70	67.03
ε_b	8.8	0.033	0.042	0.027	0.073	0.046	0.060	0.831
ε_g	22.8	0.083	0.080	0.068	0. 186	0.118	0.152	0.263

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties.

Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different.

*, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively.

6.3.6 Correlation and linear regression between IR and biomass and grain yield.

Aboveground biomass and IR showed a strong positive correlation in both experiment I and II (Fig.5a & b). Similarly, the linear regression analysis showed that aboveground biomass had a strong relationship with IR. However, there was a slight variation in strength of the relationships amongst the two experiments, with experiment I showing greater correlation and regression slope compared to experiment II (Fig.6.5 a & b). For example, the strength of the correlation and regression slopes as measured by r and R^2, respectively in experiment I was 0.8510 and 0.8043 in experiment I, respectively (Fig 6.5 a), and 0.606 and 0.723 in experiment II, respectively.

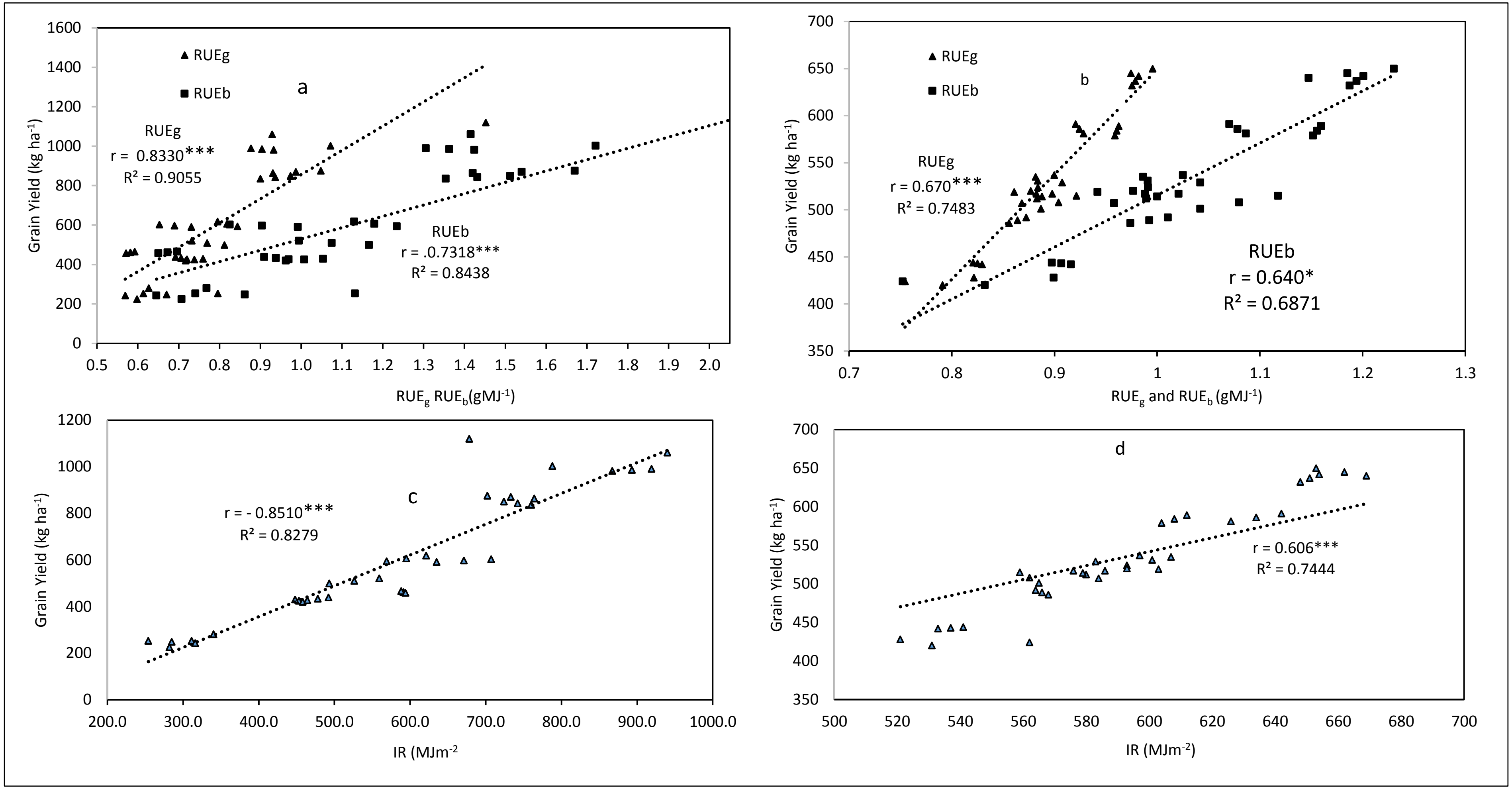


Fig 6.4 Correlations and regression relationships between grain yield and, IR, RUE_g and RUE_b. (a and c); experiment 1, (b and d); experiment two. * P ≥ 0.05, *** P ≥ 0.001.

6.4 Discussion

6.4.1 Intercepted radiation

The greater total IR observed in early compared to normal (control) and late sowing was partly due to the greater proportion of intercepted radiation that was recorded in the early sowing (Figure 6.1), and the longer growth period; both days to flowering and physiological maturity were greater in early compared to the control and late planting. The greater proportion of intercepted radiation in early sowing was perhaps, in part, due to the observed greater plant height and canopy size with early sowing. Although xcwe did not measure canopy size directly in this study, it is clear from equation 6.7, famously known as the Monsi-Saeki (1953) equation, and Figure 6.1a & b that canopy size was greater in early sowing compared to the control and late sowing. Moreover, early sowing recorded higher peak values of F_i and also reached peak values of F_i almost 14 days later than the control and late sowing, suggesting that the early sowing recorded greater leaf area duration (Albrizio and Steduto, 2005; Ogola, 2015).

$$I = I_o e^{-K_L L} \qquad (6.7)$$

Where I is light flux at any level of the canopy, I_o is light flux incident to the top of canopy, L is LAI, and K_L is the light extinction coefficient.

The study results are comparable to previous reports that IR is a function of incident solar radiation, canopy size and the duration of radiation capture (Monteith and Unsworth, 1990; Muchow et al., 1990; Haverkort, 2007). However, the early sown chickpea crop in our study was exposed to slightly lower Q compared to the control and late sown crop (Table 6.1) but this was more than offset by the considerably longer period of growth, hence radiation capture, in early sowing.

The late maturing genotypes (Range 4 & Range 5) recorded greater total intercepted radiation compared to the early (Range 1) and medium maturing (Range 3) desi genotypes as well as the medium maturing kabuli (ICCV9901) genotype. This variation in total IR was probably due to the variation in period of radiation capture, canopy size and plant height and hence variation in leaf area duration (LAD). In support of this, the late maturing genotypes reached the peak of radiation interception a week after the early and medium maturing genotypes suggesting a longer LAD in the late genotypes. The effect of management practices on LAD in chickpea has been reported previously at the site of the current study (Ogola, 2015). Earlier, Anwar et al. (2003) attributed the variation in total intercepted radiation amongst chickpea genotypes to a similar genotypic variation in days to physiological maturity.

The greater total IR in 2014 compared to 2015 was likely, in part, due to the 18.7% greater incident solar radiation (Table 6.1) and the 1.6% greater growth duration in 2014 in line with equation 6.1. Also, total IR was 44% greater in the well-watered compared to the deficit-irrigation experiment as expected. Earlier, Azam et al. (2004) reported that irrigation increased radiation interception in chickpea by 80%.

The correlation and regression slope showed that total intercepted radiation had a strong positive effect on aboveground biomass, and this confirmed earlier findings by Monteith (1977), who reported that aboveground biomass is linearly related to total intercepted radiation. The greater correlation strength observed in well-watered experiment I compared with the drier experiment that was irrigated three times only was expected and could have been due to the differences in canopy cover, which varied between the experiments. Moreover, the strength of the relationship indicated that any management strategy that improves total intercepted radiation may also improve aboveground biomass.

6.4.2 Radiation Use efficiency of grain yield (RUE_b) and of biomass (RUE_b).

Radiation use efficiency (ε_b & ε_g) was greater in the early sowing, and lower in the late sowing, compared with the control, in both experiments. This variation in ε with planting date was similar to the observed variation in cumulative IR (Table 6.2), and biomass, grain yield and harvest index with planting date. Likewise, Confalone et al. (2009) attributed the variation in ε with planting date to variation in intercepted radiation across planting dates. Our results suggest that manipulation of planting date may be a useful tool in improving grain yield of chickpea at the site of current study through its effect on cumulative intercepted radiation, the efficiency of utilization of the intercepted radiation to assimilate biomass, and the partitioning of the assimilated biomass into grain yield (Montheith, 1977, 1990; Kiniry et al., 1989) as illustrated in equation 6.1. Also, the variation in ε with planting date could partly be attributed to the variation in the number of cloudy days that the different sowings were exposed. Albrizio and Steduto (2005) concluded that the percentage of diffuse radiation, which leads to more efficient penetration of radiation into the canopy (Hammer and Wright, 1994; Sinclair and Muchow, 1999b), is higher on cloudy days. However, we did not determine the number of cloudy days each sowing date was exposed to in the current study and this needs further more comprehensive investigation in subsequent studies.

Although early sowing increased both cumulative IR and grain yield, and late sowing decreased cumulative IR and grain yield, relative to the control, no significant differences ($p \leq 0.05$) in ε_g were observed between sowing dates in the well-watered experiment. The non-significant effect of planting date on ε_g could partly be attributed to the differences in the magnitude of the effect of PD on grain yield and total IR. For example in experiment I, early sowing increased total IR by 25.5% (Table 6.2), and grain yield by only 4.2%, while late sowing decreased total IR by 12.2% (Table 6.2), and grain yield by 30.4%.

The variation in ε_g with genotype in both experiment I & II, could be attributed partly to similar variation in grain yield and cumulative IR (Table 6.2) with genotype; this is in agreement with observations from previous studies (e.g., Jha et al., 2012). However, the effect of genotype on ε_b in experiment I was in contrast to its effect on biomass and cumulative IR (Table 6.2). Although the late maturing genotypes, Range 4 & 5, had 13.1 – 22.7% greater biomass (Mubvuma et al., 2018) and 19.9 – 29.1% greater cumulative IR (Table 6.2) than the rest of the genotypes in experiment I, they did not record the highest ε_b in this study. This suggests that in the well-watered experiment, the greater cumulative IR in the late maturing genotypes (which also had greater plant height and larger crop canopy) did not translate into correspondingly greater biomass probably because part of the IR were at lower canopy levels where irradiance limited photosynthesis (Acciaresi et al., 2014; Ogola, 2015).

In experiment II, in contrast, the effect of genotype on ε_b was influenced by planting date. The late maturing genotypes (Range 4 & 5) generally had greater ε_b in early and normal sowings. In contrast, late sowing decreased ε_b of all genotypes but the decrease varied with genotype; from 2.9% (0.04 g MJ^{-1}) in Range 3 to 30.1% (0.49 g MJ^{-1}) in Range 4 and was on average (27.1%; 0.47 g MJ^{-1}) greater in late maturing genotypes. This is consistent with our observations and earlier findings in chickpea (Jha et al., 2012) and other crops (Tsimba et al., 2011) that late sowing leads to a reduction in the length of the growing season. A decrease in the length of the growing season would have greater adverse effect on the late maturing genotypes than the medium and early maturing genotypes.

The wide variation in ε_b observed across treatments and years suggests the lack of robustness in using the solar-driven productivity in crop growth models. Therefore further and more comprehensive investigations on the relationship between intercepted radiation and biomass across diverse environments are recommended. However, the linear relationship between IR and biomass accumulation (Figure 6.5), indicates the possibility of using the solar-driven growth engine to analyse the effects of various management practices on chickpea productivity.

6.4.3 Conclusion

This study investigated the effect of planting date on radiation use and radiation use efficiency of five chickpea genotypes grown under (i) well-watered conditions, and (ii) deficit-irrigation. The proportion of intercepted radiation, total intercepted radiation and radiation use efficiency varied with planting date and genotypes but these effects were not consistent across the two experiments. Early sowing and the late maturing genotypes, Range 4 & Range 5, performed better than the rest of the sowing dates, and the early and medium maturing genotypes, respectively. Clearly, manipulation of management practices like sowing time and genotype selection may improve radiation capture and utilisation of chickpea.

References

Acciaresi, H.A., Tambussi, E.A., Antonietta, M., Zuluaga, M.S., Andrade, F.H. and Guiamét, J.J., 2014. Carbon assimilation, leaf area dynamics, and grain yield in contemporary earlier- and later-senescing maize hybrids. *European journal of agronomy*, *59*, pp.29-38.

Adeboye, O.B., Schultz, B., Adekalu, K.O. and Prasad, K., 2016. Impact of water stress on radiation interception and radiation use efficiency of Soybeans (Glycine max L. Merr.) in Nigeria. *Brazilian Journal of Science and Technology*, *3*(1), p.15.

Albrizio, R. and Steduto, P., 2005. Resource use efficiency of field-grown sunflower, sorghum, wheat and chickpea: I. Radiation use efficiency. *Agricultural and Forest Meteorology*, *130*(3-4), pp.254-268.

Andrade, F.H., Uhart, S.A. and Cirilo, A., 1993. Temperature affects radiation use efficiency in maize. *Field Crops Research*, *32*(1-2), pp.17-25.

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 2003. The effect of irrigation and sowing date on crop yield and yield components of Kabuli chickpea (Cicer arietinum L.) in a cool-temperate subhumid climate. *The Journal of Agricultural Science*, *141*(3-4), pp.259-271.

Azam, M., Hussain, A., Wajid, S.A. and Maqsood, M., 2002. Effect of sowing date, irrigation and plant densities on radiation interception and its utilization efficiency in lentils. *Int. J. Agric. Biol*, *4*(2), pp.217-219.

Brown, H.E., Moot, D.J. and Teixeira, E.I., 2006. Radiation use efficiency and biomass partitioning of lucerne (Medicago sativa) in a temperate climate. *European Journal of Agronomy*, *25*(4), pp.319-327.

Cirilo, A.G. and Andrade, F.H., 1994. Sowing date and maize productivity: I. Crop growth and dry matter partitioning. *Crop science*, *34*(4), pp.1039-1043.

Confalone, A., Lizaso, J.I., Ruiz-Nogueira, B., López-Cedrón, F.X. and Sau, F., 2010. Growth, PAR use efficiency, and yield components of field-grown Vicia faba L. under different temperature and photoperiod regimes. *Field crops research*, *115*(2), pp.140-148.

Farré, I., Van Oijen, M., Leffelaar, P.A. and Faci, J.M., 2000. Analysis of maize growth for different irrigation strategies in northeastern Spain. *European Journal of Agronomy*, *12*(3-4), pp.225-238.

Fotiadis, S., Koutroubas, S.D. and Damalas, C.A., 2017. Sowing Date and Cultivar Effects on Assimilate Translocation in Spring Mediterranean Chickpea. *Agronomy Journal*, *109*(5), pp.2011-2024.

Gallagher, J.N. and Biscoe, P.V., 1978. Radiation absorption, growth and yield of cereals. *The Journal of Agricultural Science*, *91*(1), pp.47-60.

Gifford, R.M., Thorne, J.H., Hitz, W.D. and Giaquinta, R.T., 1984. Crop productivity and photoassimilate partitioning. *Science*, *225*(4664), pp.801-808.

Haverkort, A.J., 2007. Potato crop response to radiation and daylength. In *Potato Biology and Biotechnology* (pp. 353-365).

Hay, R.K. and Walker, A.J., 1989. *Introduction to the physiology of crop yield*. Longman Group UK Limited.

Hernandez, L. G and Hill, G. D., 1985. Effect of sowing date and plant population on growth and yield of chickpea (*Cicer* arietinum L.). *Proceedings Agronomy Society of NewZealand,* 15, pp. 81-85.

Jahansooz, M.R., Yunusa, I.A.M., Coventry, D.R., Palmer, A.R. and Eamus, D., 2007. Radiation-and water-use associated with growth and yields of wheat and chickpea in sole and mixed crops. *European Journal of Agronomy*, *26*(3), pp.275-282.

Jha, S.O.M.N.A.T.H., Sehgal, V.K. and Subbarao, Y.V., 2012. Effect of direction of sowing and crop phenotype on radiation interception, use efficiency, growth and productivity of mustard (Brassica juncea L.). *J Agril Physics*, *12*, pp.37-43.

Kiniry, J.R., Landivar, J.A., Witt, M., Gerik, T.J., Cavero, J. and Wade, L.J., 1998. Radiation-use efficiency response to vapor pressure deficit for maize and sorghum. *Field Crops Research*, *56*(3), pp.265-270.

Kiniry, J.R., Jones, C.A., O'toole, J.C., Blanchet, R., Cabelguenne, M. and Spanel, D.A., 1989. Radiation-use efficiency in biomass accumulation prior to grain-filling for five grain-crop species. *Field Crops Research*, *20*(1), pp.51-64.

Krishnan, P., Ramakrishnan, B., Reddy, K.R. and Reddy, V.R., 2011. High-temperature effects on rice growth, yield, and grain quality. In *Advances in Agronomy* (Vol. 111, pp. 87-206). Academic Press.

Lafitte, H. R., Edmeades, G. O., 1997. Temperature effects on radiation use and biomass partitioning in diverse tropical maize cultivars. *Field Crops Research*, 49, pp. 231-247.

Lake, L and Sadras, V. 2017. Associations between yield, intercepted radiation and radiation use efficiency in chickpea. *Crop and Pasture Sceince*, 68 (2), pp. 140-147.

Lusiba S, Odhiambo J, Ogola J., 2018. Growth, yield and water use efficiency of chickpea (Cicer arietinum): response to biochar and phosphorus fertilizer application. *Archives of Agronomy and Soil Science*, 64 (6), pp. 819-833.

Nautical Almanac office., 1999. Astronomical Almanac for the year 1999: Data for Aftronomy, space science, Geodesy, Survey, Navigation and otherapplication. pp. 008-054.

Mariscal, M., Orgaz, F., Vilalbos, F. J., 2000. Radiation use efficiency and dry matter partitioning of a young olive *(Olea europea)* orchard. *Tree* physiology, 20, pp. 65-72.

Miralles, D.J. and Slafer, G.A., 1997. Radiation interception and radiation use efficiency of near-isogenic wheat lines with different height. *Euphytica*, *97*(2), pp.201-208.

Monsi, M., 1953. Uber den Lichtfaktor in den Pflanzengesellschaften und seine Bedeutung fur die Stoffproduktion. *Jpn. J. Bot*, *14*, pp.22-52.

Monteith, J.L. and Unsworth, M.H., 1990. Principles of environmental physics, edited by: Arnold. *SE, London, UK*.

Monteith, J. L., 1977. Climate and the efficiency of crop production in Britain. Philosophical transactions of the Royal Society of London series. *Biological Sciences,* 281, pp. 277-329.

Muchow, R.C., Sinclair, T.R. and Bennett, J.M., 1990. Temperature and solar radiation effects on potential maize yield across locations. *Agronomy journal*, *82*(2), pp.338-343.

Muchow, R.C., 1990. Effect of high temperature on grain-growth in field-grown maize. *Field Crops Research*, *23*(2), pp.145-158.

Ogola, J.B., 2015. Growth and yield response of chickpea to Rhizobium inoculation: productivity in relation to interception of radiation. *Legume Research: An International Journal*, *38*(6).

Oluwasemire, K.O. and Odugbenro, G.O., 2014. Solar radiation interception, dry matter production and yield among different plant Densities of Arachis spp. in Ibadan, Nigeria. *Agricultural Sciences*, *5*(10), p.864.

Otegui, M.E., Nicolini, M.G., Ruiz, R.A. and Dodds, P.A., 1995. Sowing date effects on grain yield components for different maize genotypes. *Agronomy Journal*, *87*(1), pp.29-33.

Rahman, S.M.L., Nawata, E., Sakuratani, T. and Uddin, A.S.M.M., 2000. Ecological adaptation of chickpea (Cicer arietinum L.) to water stress. 1. Effect of water stress on leaf area development, growth, biomass accumulation and stress period of chickpea varieties collected from different agro-ecological regions. *Legume Research*, *23*(3), pp.141-145.

Sinclair, T.R. and Muchow, R.C., 1999. Radiation use efficiency. In *Advances in agronomy* (Vol. 65, pp. 215-265). Academic Press.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Sinclair, T.R. and Muchow, R.C., 1999. Radiation use efficiency. In *Advances in agronomy* (Vol. 65, pp. 215-265). Academic Press.

Singh, T.P., Deshmukh, D.S., Kumar, P., 2008. Relationship between physiological traits in chickpea under rainfed condition. *Indian Journal of Physiology*, 13 (4), pp. 411-413.

Soltani, A., Robertson, M.J., Rahemi-Karizaki, A., Poorreza, J. and Zarei, H., 2006. Modelling biomass accumulation and partitioning in chickpea (Cicer arietinum L.). *Journal of agronomy and crop science*, *192*(5), pp.379-389.

Steduto P., 2003. Biomass water-productivity. Comparing the growth-engines of crop models. In: FAO Expert Meeting on Crop Water Productivity Under Deficient Water Supply, Rome, February 26–28.

Stone, P.J., Wilson, D.R., Reid, J.B. and Gillespie, R.N., 2001. Water deficit effects on sweet corn. I. Water use, radiation use efficiency, growth, and yield. *Australian Journal of Agricultural Research*, *52*(1), pp.103-113.

Sun, H., Shao, L., Chen, S., Wang, Y. and Zhang, X., 2013. Effects of sowing time and rate on crop growth and radiation use efficiency of winter wheat in the North China Plain. *International Journal of Plant Production*, *7*(1).

Szeicz, G., 1974. Solar radiation for plant growth. *Journal of Applied Ecology*, pp.617-636.

Tesfaye, K., Walker, S. and Tsubo, M., 2006. Radiation interception and radiation use efficiency of three grain legumes under water deficit conditions in a semi-arid environment. *European journal of Agronomy*, *25*(1), pp.60-70.

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

Ting, K.C. and Giacomelli, G.A., 1987. Availability of solar photosynthetically active radiation. *Transactions of the ASAE*, *30*(5), pp.1453-1457.

Tsimba, R., 2011. *Development of a decision support system to determine the best maize (Zea mays. L) hybrid-planting date option under typical New Zealand management systems: a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Plant Science at Massey University, Palmerston North, New Zealand* (Doctoral dissertation, Massey University).

Toyota, M., Maitree, L. and Chomsang, K., 2017. Changes in radiation interception and R: FR over time and with canopy depth of two soybean cultivars with different branching characteristics. *Plant Production Science*, *20*(2), pp.205-214.

Chapter 7

Thermal time for development of chickpea (*Cicer arietinum*): response to genotype and planting date.

Abstract

Temperature is one of the most important factors affecting chickpea yield across the world. Therefore any management practices that manages the impact of extreme temperature stress may improve chickpea yield. This study aimed at evaluating the effect of planting date and genotype on thermal time for of chickpea. Two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1^{st} of May being the early planting, 14^{th} of May as the control and normal planting, and 28^{th} of May being the late planting date) and chickpea genotypes as the sub-plot factor. Chickpea genotypes comprised of four desi genotypes (Range 1, Range 3, Range 4 and Range 5) planted in 2014 and five genotypes comprising of 4 desi types and one Kabuli genotype (ICCV99010) planted in 2015 season. Experiment I was well watered throughout the season, and experiment II was watered three times (at planting, flowering and pod formation). AGDD was 14% and 27% greater, respectively in early planting compared with normal and late planting date. Highest HUE_g was observed in normal planted crops (0.99 Kg ha^{-1} MJ m^{-2}) and (1.06 Kg ha^{-1} MJ m^{-2}), whilst the late planted crops had the lowest HUE_g (0.84 Kg ha^{-1} MJ m^{-2}) and 0.90 Kg ha^{-1} MJ m^{-2}), respectively in experiments I and II. Early planting recorded 16.1% and 33.3% greater plant height, respectively compared to normal and late planting in experiment I. In contrast, plant height was affected by interaction between planting date and genotype in experiment II. Range 4 cultivar recorded 17% and 29% greater plant height, respectively in early planting compared with normal and late planting. Moreover, plant height was greater in normal compared with early and late planting in ICCV 9901 (15% and 46%, respectively), and in Range 3 (29% and 37%, respectively). Furthermore, experiment II had 29.4% greater number of primary branches compared with experiment I. Clearly, management of planting date and selection of genotype may affect thermal time of growth and fecundity in chickpea.

7.1 Introduction

Temperature is one of the most important abiotic factors that affect chickpea yield across the world (Summerfield et al*.,* 1990; Clarke and Siddique, 2004; Devasirvatham et al*.,* 2012). It is anticipated that impacts of climate change will be felt in form of extreme temperatures and these may have detrimental effects on chickpea growth and yield (Koocheki et al*.,* 2006; Singh et al*.,* 2014). Studies have shown that in semi-arid parts of South Africa, temperature is expected to increase by 1.5 to 4.8 ^{o}C by 2100 (IPPC, 2014). Such increases may substantially affect chickpea growth pattern and ontogeny (Siddique and Sedgley, 1986). Moreover, chickpea growth and development depends on a specific amount of heat units accumulated over time from emergence until physiological maturity (Parthasarathi et al*.,* 2013), thus a delay in planting chickpea could shorten its growing season length and may perhaps result in some plants accumulating insufficient thermal units to reach physiological maturity. The amount of heat energy chickpea accumulates over a period of time has been found to range from 1678-1802 ^{o}C day, respectively using a base temperature range of between 0 ^{o} C (Soltani et al*.,* 2006) and 8 ^{o} C (Thangwana and Ogola 2012; Parthasarathi et al*.,* 2013). However, the expected increase in temperature under climate change may ensure sufficient thermal units for crops to reach physiological maturity, even under late planting conditions, but high temperatures are likely to hasten chickpea life cycle, and hence lower biomass and grain yield (Summerfield et al*.,* 1984; Clarke and Siddique, 2004; Devasirvatham et al*.,* 2012; Wahid et al., 2007). The highest potential yield of chickpea crop may be achieved when growing season length is long and characterised with relatively low temperatures (Summerfield et al., 1984). Thus manipulation of planting date to improve growing season length may be one of the simplest ways of increasing chickpea yield.

Planting chickpea under different dates within the same season may expose the crop to varying temperature and water regime during critical stages of growth and development (Siddique and Sedgley, 1986). For example, late sowing in winter season (Southern Hemisphere) may be associated with effects of low soil temperatures which causes uneven and slow seedling emergence (Chaturvedi and Dua 2003), reduced plant growth and poor canopy development (Soltani et al., 2006). In contrast, early planting may expose the crop to relatively warm temperatures during early seedling emergence stage that improves seedling vigour, growth and development. Moreover, the rate of canopy development and leaf expansion during early development are influenced by ambient temperature (10^{o}C -25^{o}C) (Khanna-Chopra and Sinha, 1987). High temperatures at reproductive stage, experienced by late planted crops during winter season may reduce chickpea growing season length and consequently yield as potential evapotranspiration exceeds plant available water in the absence of irrigation water supply. However, there is dearth of information in literature on the interaction of planting date and genotypes on heat use efficient and consequently the final yield.

Tsimba et al. (2013) argued that genotypes that tolerate early temperature stress or are adapted to cool conditions may have some comparative advantage in late sowings. In addition, Siddique and Sedgley, (1986), reported variation in chickpea grain yield between early and late maturing varieties and attributed that variation to temperature and moisture conditions experienced by the crops. More recently, Chijiike et al. (2017), found that late planting was associated with insufficient thermal time for biomass accumulation because of reduced growing season length, particularly to late maturing genotypes. Thus, the interaction of planting date and genotypes may affect accumulated growing degree days and heat use efficiency in chickpea due to differences in temperature regime. Moreover, although the effect of temperature on chickpea plant height, and number of primary and secondary branches is well documented in literature (Siddique and Sedgley, 1986; Iannucci et al*.,* 2008; Keatinge et al*.,* 1998; Papastylianou et al*.,* 2011), the magnitude of the effect of temperature on chickpea crop yield sown on diverse dates within the same season has hardly been reported.

The effect of planting date and genotype on AGDD, HUE, plant height and number of primary and secondary branches has been reported in cotton (Gudadhe et al*.,* 2013), forage legumes (Papastylianou et al*.,* 2011), and wheat (Ottman et al*.,* 1997), but, there is little evidence in literature on the effects of planting date and genotype on AGDD, HUE, plant height and number of primary and secondary branches per plant in chickpea.

We hypothesised that sowing chickpea at different dates within the same winter season under different watering regimes may affect accumulation of growing degree days, heat use efficiency, plant height, number of primary and secondary branches because; (i) late planted crops are often affected by late summer high temperatures which are likely to reduce their plant height and number of primary and secondary branches; and (ii) late planted chickpea is normally affected by low temperatures at seedling stage which decreases accumulation of heat units and plant height development. Chickpea winter planting season window at the current study site is very narrow, because the crop is planted in the field that is made free soon after harvesting the summer crop in early month of April, and this leaves out end of April and the whole month of May as the possible sowing window for chickpea in the study area. Although this window appears short, a wide range of variation in mean temperatures is experienced by the crop during vegetative, and reproduction stages when planted early (1 May), normal (14 May) or late (28 May) in the study area, thus representing a good spread of temperatures for investigation. Therefore the objective of the study was to determine the effect of planting date and genotype on accumulation of growing degree days, heat use efficiency, plant height, and number of primary and secondary branches per plant of chickpea.

7.2 Materials and method

7.2.1 Background

The study site, experimental design, treatments and planting details are described in Chapter 3. In summary, two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1st of May being the early planting, 14th of May as the control / normal planting, and 28th of May being the late planting date). These planting dates were selected based on previous studies (Mathews et al., 2009). Chickpea genotypes were used as sub-plot factor; four desi genotypes (Range 1, Range 3, Range 4 and Range 5) were sown in 2014, and 4 desi types and one Kabuli genotype (ICCV99010) were sown in 2015 season. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV9901 are medium maturing and have an erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structure, respectively.

Experiment I was well watered throughout the season, and experiment II was watered three times (at planting, flowering and pod formation). The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment one and 175 mm in experiment two, whilst 435 mm and 235 mm was applied in 2015 in Experiment one and two, respectively. Variation in the total amount of water applied in 2014 and 2015 was caused by differences in initial soil moisture.

7.2.2 Experimental Data Collection

a) Weather records: An automatic weather station that is already established at the experimental site (approximately 100 m from the experiments) was used to record rainfall (mm), maximum and minimum air temperatures (^{o}C), Heat units (^{o}C day^{-1}), cold units (^{o}C day^{-1}) and relative humidity (%) for each day during the trial period.

b) Number of primary and secondary branches per plant and plant height were all determined at physiological maturity. 10 plants in each plot were selected at random for these measurements. Plant height was measured in centimetres using a garden tape measure. The measurements were conducted from the ground level up to the shoot apex (Heady, 1957).

7.2.2.1 Calculation of growing degree days

Growing degree days (GDD) was calculated using maximum and minimum temperatures recorded during the study period from a weather station established at the experiment station as shown in equation 7.1 (Allen et al*.,* 1998).

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base} \qquad (7.1)$$

Where, T_{max} is the maximum temperature for the day, and T_{min} is the minimum temperature for the day, T_{base} is the temperature below which no growth takes place and was taken as 8°C for this study (Thangwana and Ogola 2012). GDD units were calculated for each day from the date of planting until date of physiological maturity and summed up to give one cumulative heat units value (AGDD).

7.2.2.2 Calculation of heat use efficiency (HUE)

Heat use efficiency was calculated using equation 7.2 (Rao *etal*., 1999).

$$Heat\ Use\ Efficiency = \frac{Grain\ Yield\ (kg\ ha^{-1})}{Growing\ Degree\ days\ (^{o}C\ .day^{-1})} \quad (\text{Kg ha}^{-1}\ {}^{o}\text{C day}^{-1}) \qquad (7.2)$$

Grain yield data presented in chapter 4 was used use to c

7.2.3 Data analysis

Analysis of variance was performed using the GenStat statistical package 17th edition. Significant differences among the treatment means (plant height, number of primary and secondary branches, GDD, and HUE) were evaluated at $P \leq 0.05$. A Pearson's product-moment correlation test was conducted to evaluate the relationship between grain yield and plant height, number of primary and secondary branches, AGDD and HUE.

7.3 Results

7.3.1 Weather data

At flowering stage, early planting experienced lowest mean temperatures (20.2 °C and 21.4 °C, respectively in season one and season two) (Table 1), whilst late planting experienced highest mean temperature (21.8 °C and 22.5 °C in season one and season two, respectively) in experiment one. Similarly, in experiment two, early planting experienced lowest mean temperatures (20.2 °C and 21.6 °C, respectively in season one and season two), whilst late planting date experienced highest mean temperature (21.9 °C and 22.4 °C in season one and season two, respectively). Maximum temperatures at flowering stage were ≤30 °C in season one, whilst in season two they were ≤33 °C in both experiments. Similarly, mean minimum temperatures at flowering stage were ≤11 ^{o}C in early planting, whilst in late planting they were ≤10 ^{o}C in both experiments.

During the podding stage, highest maximum temperatures were recorded in late planted crop in experiment one (33.2 ^{o}C) and experiment two (33.1 ^{o}C) (Table 1). The early planting date had the lowest maximum temperature of 29.2 ^{o}C and 28.5 ^{o}C in experiment I and II, respectively. The lowest minimum temperatures in experiment I and II, respectively ranged from 13.5 ^{o}C to 13.8 ^{o}C in early planted crops, and 11.0 ^{o}C to 11.9 ^{o}C in late planted crop. The mean temperatures were highest in late planted crop, being 22.6 ^{o}C in experiment I and 22.1 ^{o}C in experiment II. In contrast, lowest mean temperatures were 21.4 ^{o}C and 21.2 ^{o}C for experiments I and II respectively, recorded in early planted crop.

Furthermore, there were variations between day and night temperatures in both experiment I and II (Fig 7.1 a & b). Season II had greater temperature differences between day and night (by 5.8%, 6.0% and 6.0%), respectively in early, normal and late planting in experiment I, whilst, in experiment II season II had greater temperature difference (by 2%, 4.6% and 4.6%), respectively in early, normal and late planting in experiment II.

Table 7.1. Average temperatures recorded during flowering and podding stages

	T_{max} (°C)		T_{min} (°C)		T_{mean} (°C)	
Experiment	One	Two	One	Two	One	Two
Flowering Stage						
Season 1						
Early Planting date	28.7	27.9	11.7	12.5	20.2	20.2
Normal Planting date	30.1	30.6	11.1	11.0	20.6	20.8
Late Planting date	33.3	33.5	10.0	8.7	21.8	21.9
Season 2						
Early Planting date	29.9	30.0	13.3	12.7	21.4	21.6
Normal Planting date	32.0	31.2	10.8	11.4	21.7	21.3
Late Planting date	33.0	33.1	10.0	9.7	22.5	22.4
Podding Stage						
Season 1						
Early Planting date	29.2	28.5	13.5	13.8	21.4	21.2
Normal Planting date	31.4	31.2	12.6	12.3	21.9	21.8
Late Planting date	33.2	33.1	11.9	11	22.6	22.1
Season 2						
Early Planting date	30.1	31.8	14.1	13.9	22.1	22.9
Normal Planting date	31.8	30.9	13.4	12.6	22.6	21.8
Late Planting date	33.7	33.4	12.5	11.7	23.1	22.6

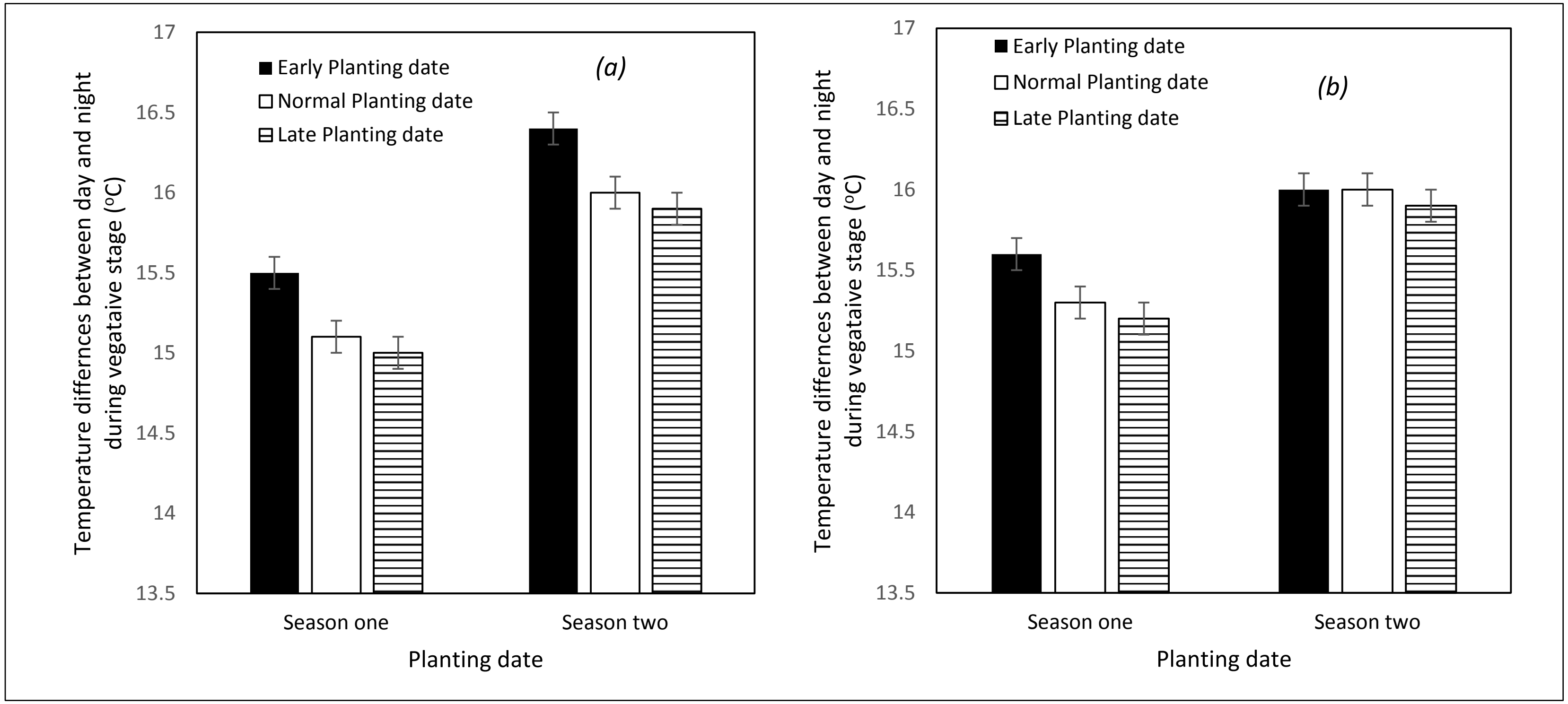


Fig 7.1 Temperature differences between day and night during vegetative stage. Graph a. experiment I, b. experiment II.

7.3.2 Plant height at physiological maturity stage.

Plant height varied significantly with planting date, but was not affected by the main effects of genotype and season as well as the interaction between treatments in experiment I (Table 7.2). Early planting recorded 16.1% and 33.3% greater plant height, respectively compared to normal and late planting in experiment I. In contrast, plant height was affected by the interaction between planting date and genotype in experiment II (Fig 7.2). Range 4 cultivar recorded 17% and 29% greater plant height, respectively in early planting compared with normal and late planting (Fig 7.2). Similarly, plant height was 29% and 37% greater, respectively in early planting compared with normal and late planting in Range 5 cultivar. In contrast, Range 1 recorded similar plant height in early and late planting which was however 19% greater compared with normal planting. Plant height was greater in normal compared with early and late planting in ICCV9901 (15% and 46%, respectively), and in Range 3 (29% and 37%, respectively).

On average, experiment I had 58.3% greater plant height compared to experiment II.

7.3.3 Number of primary branches at physiological maturity stage.

Planting date, genotype and season did not affect number of primary branches in experiment I (Table 7.2). In contrast, the number of primary branches was affected by the interaction between planting date and genotype, genotype and planting season in experiment II (Fig 7.3 a & b). Range 5 cultivar had 33% and 100% greater number of primary branches, respectively in early planting compared with normal and late planting (Fig 7.3 a). Similarly, number of primary branches was greater in early planting compared with normal and late planting in Range 4 (63% and 160%, respectively), and Range 3 (33% and 33%, respectively). However, in early maturing genotype (Range 1), the number of primary branches was 80% and 50% greater, respectively in normal planting compared with early and late planting. Primary branches in ICCV9901 did not vary with planting. Furthermore, the genotypes, Range 1, ICCV9901, Range 3 and Range 4 and Range 5, respectively had significantly 75%, 11%, 80%, 100% and 60% greater number of primary branches in season 1 compared with season 2 (Fig 7.3 b). Experiment II had 29.4% greater number of primary branches compared with experiment I.

Table 7.2 Effect of planting date and genotype on plant height, and number of primary and secondary branches (per plant).

Experiment	Treatment										P (F-ratio)						
2014	**EPD**	**NPD**	**LPD**	**R1**	**R3**	**R4**	**R5**	**ICCV9901**	**S1**	**S2**	**PD**	**G**	**S**	**PD X G**	**PD x S**	**G x S**	**PD x G x S**
Plant height (cm)																	
Exp I	46^{a}	41^{b}	27^{c}	43	40	43	44	38	39	37	***	ns	ns	ns	ns	ns	ns
Exp II	28^{a}	30^{a}	20^{b}	23	23	25	25	24	25	23	***	ns	ns	**	ns	ns	ns
Number of primary branches																	
Exp I	5	6	6	6	6	5	6	5	5	6	ns	ns	ns	ns	ns	ns	ns
Exp II	6	8	8	6	9	7	8	7	8	7	ns	ns	ns	**	ns	**	ns
Number of secondary branches																	
Exp I	10	9	9	9	8	9	10	8	10	9	ns	ns	ns	ns	ns	ns	ns
Exp II	5	7	7	1^{d}	5^{c}	9^{a}	7^{b}	10^{a}	7	6	ns	**	ns	***	ns	**	ns

S. D. E

(experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
Plant Height	20.8	3.3	4.3	2.7	7.5	4.7	6.1	10.6
Primary Branches	20.1	1.0	1.3	0.8	2.3	1.4	1.8	3.2
Secondary Branches								

(experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
Plant Height	27.5	2.5	3.3	2.07	5.7	3.4	4.6	8.0
Primary Branches	6.3	1.1	1.4	0.9	2.5	1.6	2.1	3.6
Secondary	10.0	1.8	1.3	1.5	4.0	2.5	3.3	5.7

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties. Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. ***,** **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively.

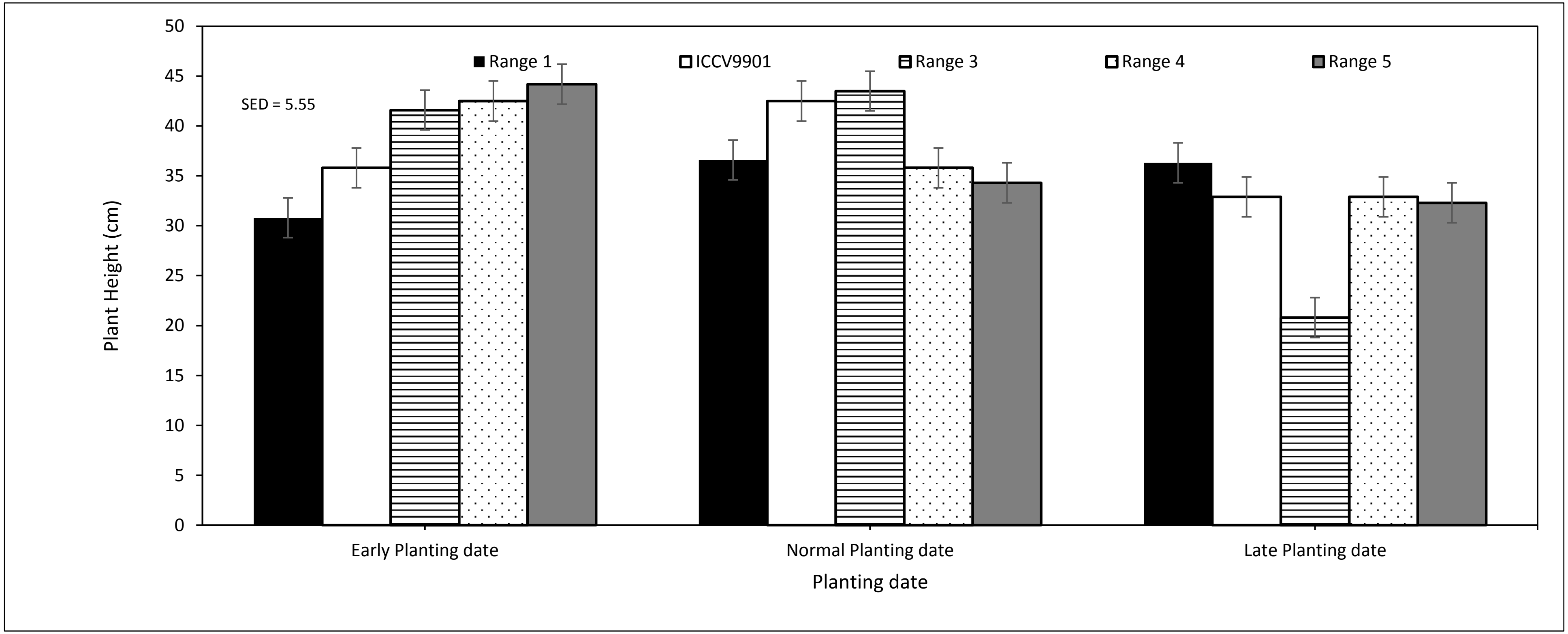


Fig 7.2 Interactive effect of planting date and genotype on plant height in experiment II.

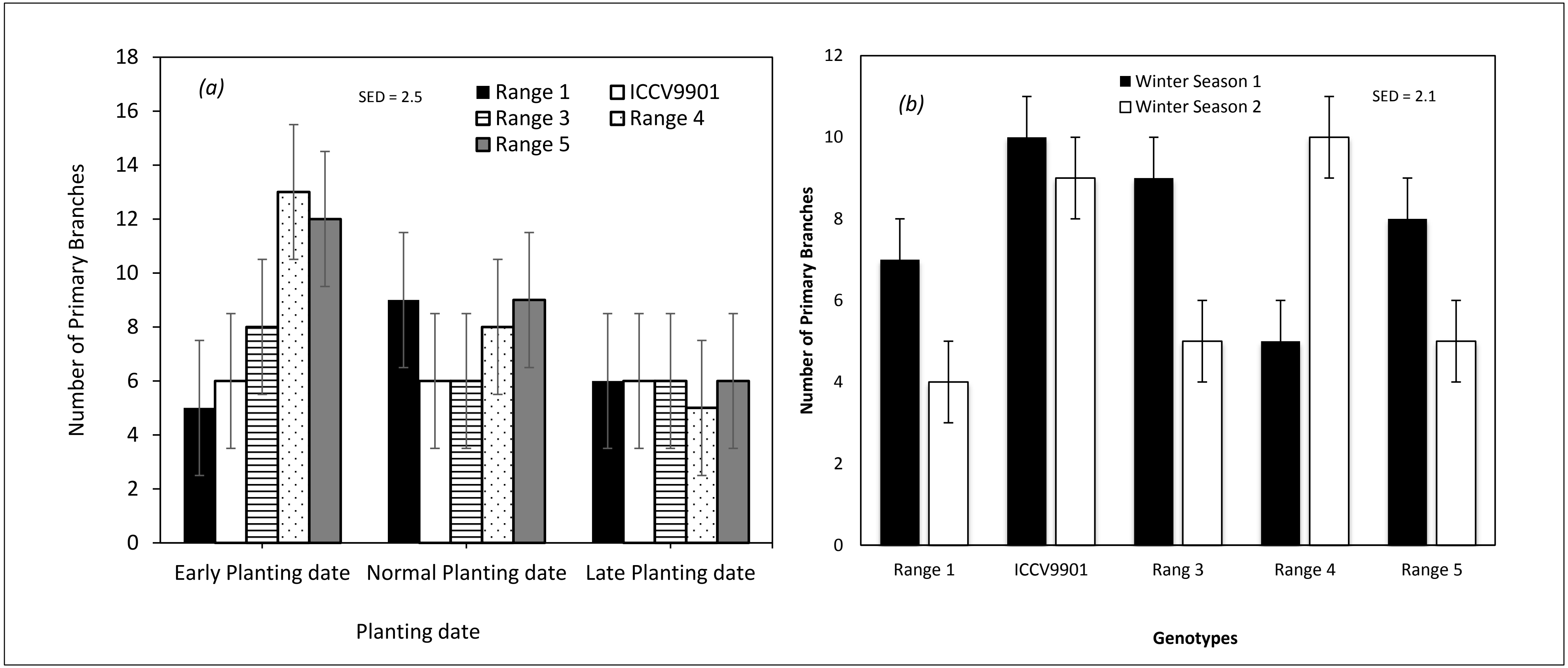


Fig 7.3 Interactive effect of; (a) planting date x genotype, (b) genotype x season on number of primary branches per plant.

7.3.4 Number of secondary branches at physiological maturity stage.

Genotype, planting date and season did not affect the number of primary branches in experiment I (Table 7.2). In contrast, the effect of genotype, planting date x genotype and genotype x season was significant in experiment II (Table 7.2). ICCV 9901 cultivar had 63% and 117% greater number of secondary branches, respectively in early planting compared with normal and late planting in experiment II (Fig 7.4 a). Similarly, number of secondary branches was greater in early planting compared with normal and late planting in Range 3 (11% and 67%, respectively), Range 4 (70% and 143%, respectively), Range 5 (71% and 143%, respectively). In contrast, the number of secondary branches were greater in normal planting compared with early and late planting in Range 1 (50% and 200%, respectively) (Fig 7.4 a). The early maturing cultivar (Range 1), together with medium to late maturing cultivars Range 3 and ICCV9901 had similar number of primary branches per plant, respectively in both seasons, whilst the late maturing cultivars (Range 4 and 5) had 160% and 71% greater number of primary branches in season 1 compared with season 2 (Fig 7.4 b). In addition, experiment II had greater number of primary branches compared with experiment I.

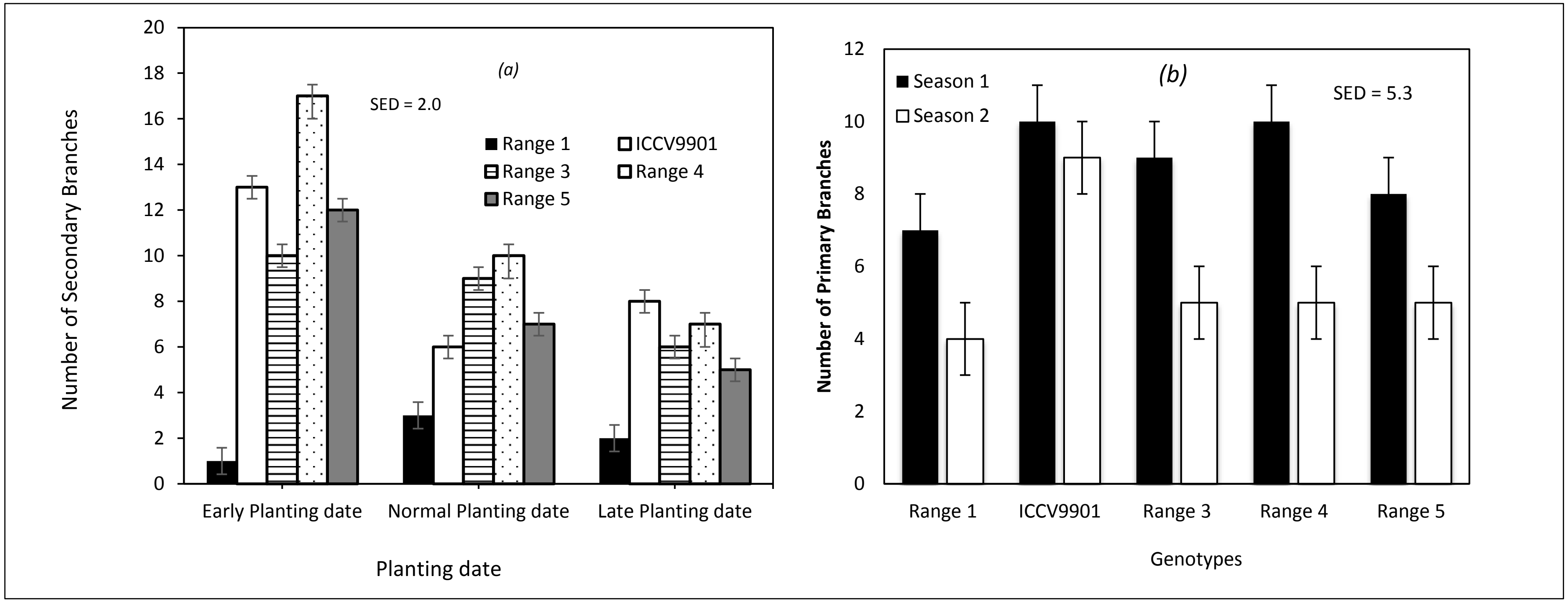


Fig 7.4 The interactive effect of planting date and genotype on number of secondary branches per plant (a), and genotype and season on number of primary branches per plant in experiment II

7.3.5 Accumulated growing degree days of chickpea.

AGDD was affected by the main effects of planting date, genotype and planting season in experiment I. The interaction between treatments was not significant (Table 7.3). AGDD was 14% and 27% greater, respectively in early (2194 ^{o}C days) compared with normal (1917 ^{o}C days) and late sowing (1757 ^{o}C days). Range 4 and 5 cultivars had the highest AGDD (2003 ^{o}C days), which was however 5%, 4% and 3% greater, respectively compared to Range 1 (1916 ^{o}C days), Range 3 (1920 ^{o}C days) and ICCV9901 (1935 ^{o}C days). Season 1 (1988 ^{o}C days) had 3% greater AGDD compared to season 2(1922 ^{o}C days).

In experiment II, in contrast, planting date ($P< 0.001$), genotype ($P< 0.001$), season ($P< 0.001$) as well as planting x genotype ($P< 0.001$), planting date x season ($P< 0.001$) and genotype x season ($P< 0.001$) affected AGDD (Table 7.3). AGDD was greater with early compared with normal and late planting in Range 1 (8% and 27%, respectively), ICCV 9901 (6% and 24%, respectively), Range 3 (7% and 27%, respectively), Range 4 (9% and 33%, respectively) and Range 5 (10% and 33%, respectively. AGDD varied with all genotypes in early and normal planting but was similar in late planting date (Fig 7.5 a). Moreover, AGDD was 5% and 23% greater in early compared to normal and late planting, respectively in season 1 (Fig 7.5 b). In contrast, AGDD was 23% and 29% greater in early planting compared with normal and late planting, respectively in season 2. Also, Range 3, Range 4 and Range 5 had greater AGDD (by 7%, 7%, 10%, and 8%) in season 1 compared with season 2, whilst Range 1 had greater AGDD by 7% in season 2 compared with season 1 (Fig 7.3 c). Experiment 1 had 18.6% greater AGDD compared with experiment II.

7.3.6 Heat use efficiency of grain yield

The effect of planting date ($P< 0.001$) and genotype ($P< 0.001$) on HUE_g was significant in both experiments I & II. HUE_g was greater (by 11.2% and 17.9%), respectively in normal sowing (0.99 Kg ha^{-1} MJ m^{-2}) compared with early (0.89 Kg ha^{-1} MJ m^{-2}) and late sowing (0.84 Kg ha^{-1} MJ m^{-2}) in experiment I (Table 7.3). Similarly, normal sowing produced greater HUE_g (1.06 Kg ha^{-1} MJ m^{-2}) compared with early 0.96 Kg ha^{-1} MJ m^{-2}) and late 0.90 Kg ha^{-1} MJ m^{-2}) sowing in experiment II (Table 7.3). Range 4 had the highest HUE_g 1.30 Kg ha^{-1} MJ m^{-2}), which was greater (by 75.7%, 85.7%, 56.7% and 54.8%), respectively compared to Range 1 (0.74 Kg ha^{-1} MJ m^{-2}), Range 3 (0.70 Kg ha^{-1} MJ m^{-2}), Range 5 (0.83 Kg ha^{-1} MJ m^{-2}) and ICCV9901 (0.84, Kg ha^{-1} MJ m^{-2}) in experiment I. In contrast, All genotypes (Range 1, 3, 4 and 5) had similar HUE_g, (0.88 Kg ha^{-1} MJ m^{-2}) which was 15.8% greater than cultivar ICCV9901 (0.76 Kg ha^{-1} MJ m^{-2}) in experiment II. The interaction between treatments did not affect HUE_g in both experiments. Season 2 had greater HUE_g, (0.97 Kg ha^{-1} MJ m^{-2}) compared with season 1 (0.84 Kg ha^{-1} MJ m^{-2}) in experiment I, whilst season 1 had greater HUE_g, (0.99 Kg ha^{-1} MJ m^{-2}) compared to season 2 (0.96 Kg ha^{-1} MJ m^{-2}) in experiment II.

Table 7.3. Effect of planting date and genotype on AGDD (oC days) and HUE (Kg ha^{-1} ^{o}C $days^{-1}$).

Experiment	Treatment										P (F-ratio)						
2014	**EPD**	**NPD**	**LPD**	**R1**	**R3**	**R4**	**R5**	**ICCV9901**	**S1**	**S2**	**PD**	**G**	**S**	**PD X G**	**PD x S**	**G x S**	**PD x G x S**
AGDD (^{o}C days)																	
Exp I	2194^{a}	1917^{b}	1757^{c}	1916^{c}	1920^{c}	2004^{a}	2002^{a}	1935^{b}	1988^{a}	1922^{b}	***	***	***	ns	ns	ns	ns
Exp II	1853^{a}	1622^{b}	1469^{c}	1636^{c}	1648^{b}	1663^{a}	1665^{a}	1637^{c}	1587^{b}	1709^{a}	***	***	***	***	***	***	ns
HUE_g (Kg ha^{-1} ^{o}C $days^{-1}$)																	
Exp I	0.89^{b}	0.99^{a}	0.84^{c}	0.74^{c}	0.70^{c}	1.30^{a}	0.83^{b}	0.84^{b}	0.84^{b}	0.97^{a}	***	***	ns	ns	ns	ns	ns
Exp II	0.96^{b}	1.06^{a}	0.90^{c}	0.89^{a}	0.88^{a}	0.85^{ab}	0.88^{a}	0.86^{a}	0.99^{a}	0.96^{b}	**	***	ns	ns	ns	ns	ns

		S. D. E						
(experiment I)	**CV%**	**PD**	**G**	**S**	**PD x G**	**PD x S**	**G x S**	**PD x G x S**
AGDD	1.3	6.3	8.2	5.2	14.1	8.9	11.5	20.0
HUE_g	11.1	0.015	0.043	0.073	0.041	0.80	0.90	0.60
(experiment II)								
AGDD	18.7	3.4	4.4	2.8	7.7	4.8	6.2	10.8
HUE_g	12.9	0.04	0.03	0.02	0. 5	0.6	0.8	0.9

EPD, NPD and LPD refer to Early planting date, Normal planting date and Late planting date respectively; PD and G refer to Planting date and Genotype, respectively; R1, R3, R4, R5 are Range 1, Range 3, Range 4, and Range 5 desi varieties
Means in the same row followed by the same letter are not significantly different. Means in the same row followed by the same letter are not significantly different. *, **, and *** were used to show statistical significance at 0.05, 0.01, and 0.001 levels, respectively

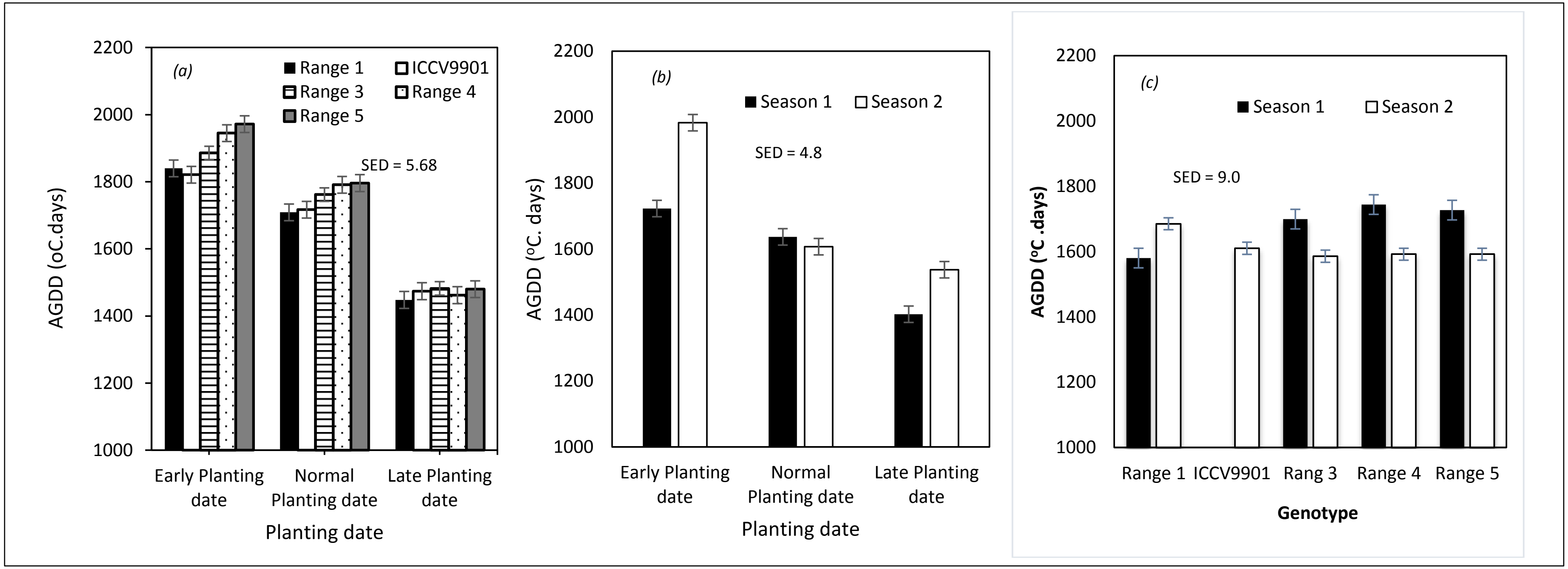


Fig 7.5 Interactive effect of planting date and genotype (a), planting date and season (b), and genotype and season (c) on accumulated growing degree days in Thohoyandou.

7.3.7 Correlation and regression relationships between grain yield and plant height, number of branches per plant, AGDD and heat use efficiency of grain yield.

Heat use efficiency and AGDD showed a strong positive correlation with grain yield in experiments I & II (Fig 7.6), whilst plant height and the total number of branches per plant had a fair correlation with grain yield (Fig 7.7). The strength of the correlation and regression slopes as measured by r and R^2, respectively in experiment I was (0.8160 & 0.7865) for heat use efficiency of grain yield, (0.7951 & 0.7400) for AGDD, (0.6441 & 0.6926) for plant height, and (0.6601 & 0.6376) for total number of branches per plant. Likewise, r and R^2 values, respectively in experiment II was (0.8160 & 0.7865) for heat use efficiency of grain yield, (0.6832 & 0.6511) for AGDD, (0.5372 & 0.5622) for plant height, and (0.6528 & 0.6209) for total number of branches per plant. Furthermore, the associated increase in Plant height, total number of branches, AGDD and heat use efficiency of grain yield resulted in an increase in grain yield in both experiments.

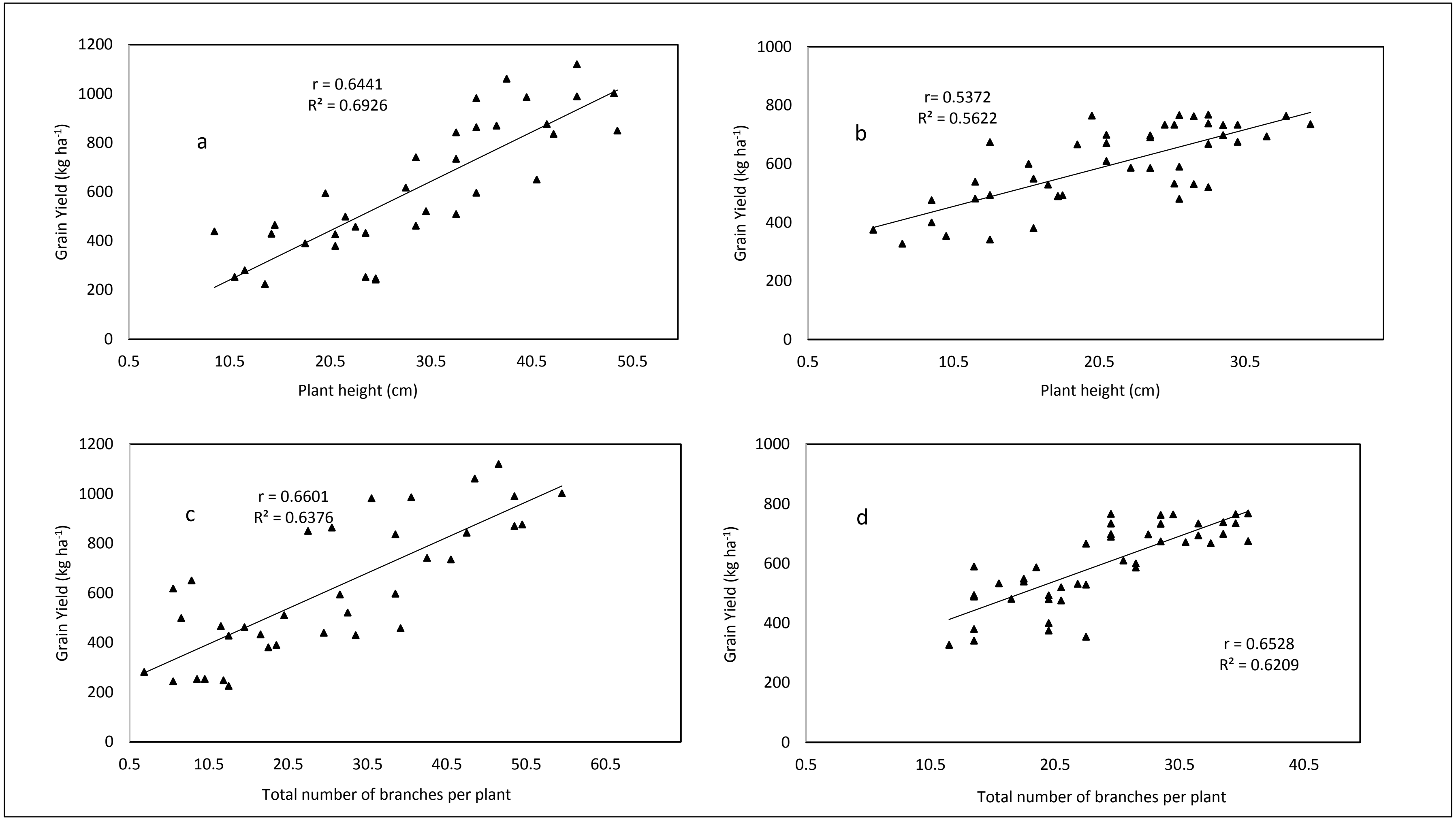


Fig 7.6 Correlation and regression relationships between grain yield and plant height (a) experiment I, (b) experiment II, number of branches per plant (c) experiment I, (b) experiment II.

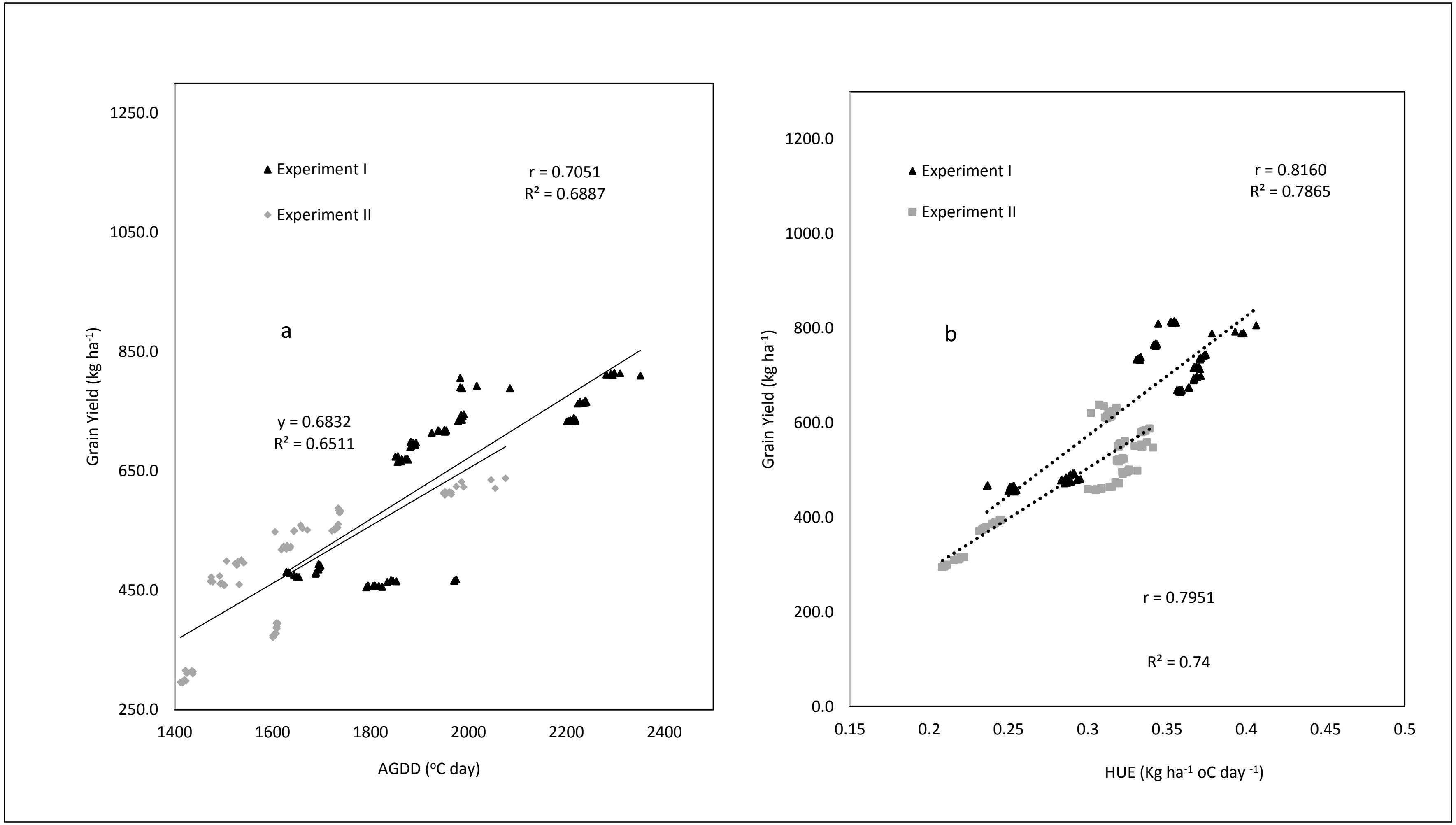


Fig 7.7 Correlation and regression relationships between grain yield and AGDD (a), (b) Heat use efficiency.

7.4 Discussion

7.4.1 plant height.

The variation in plant height with planting date was partly caused by temperature fluctuations between day and night, which also varied with planting dates. The greater temperature difference between day and night observed in early planting compared to late planting may have resulted in highest plant height in early planting compared to the rest, with late planting recording the lowest height (Berghage, 1998). In addition, the lower plant height in early maturing genotypes (Range 1) could partly have been due to the cultivars' shorter days to maturity. In support of this, much earlier, Yadav et al. (1999) reported reduced plant height in late planting and suggested shorter days to physiological maturity as the probable cause of poor height. Similar findings were also reported by Devasirvatham et al, (2012b).

In the limited irrigation experiment, the interaction between planting date and genotype also affected plant height. The nature of the interaction was in such a way that all genotypes except ICCV9901 had greater plant height in early planting compared to normal and late planting, whilst ICCV9901 had greater plant height in normal planting date. This interaction was probably due to a combination of day and night temperature variations between planting dates and variation in genetic factors amongst the genotypes. For instance, the greater plant height in normal planting compared to other planting dates recorded in ICCV9901 could be due to genetic factors (e.g. plant hormones) responsible for plant height in plants. Plant height is genetically influenced by genotypes but may also depend on environmental factors such as temperature (Berghage, 1998), moisture and growing season length (Singh et al., 1997).

Moreover, the variation in plant height between experiment I and experiment II was possibly due to variation in moisture availability in the two experiments. Experiment I had 86% greater water use compared to experiment II because of added irrigation water (430 mm in season 1 and 435 in season 2). Thus, the limited water application in experiment II may have caused low growth in plants, leading to low plant height. In support of this, Sharma and Piri (2006) reported that irrigation application improved plant height compared with non-irrigated crops.

7.4.2 Number of primary and secondary branches.

The greater number of primary branches observed in early compared to normal (control) and late sowing in experiment II was partly caused by differences in temperature experienced by in different planting dates. For example, the early and late planting dates experienced a temperature variation of between 2-3 ^{o}C during the vegetative stage, which could have substantially affected branch initiation and development (Auld et al, 2011). Indeed, temperature is an important factor in the formation and development of branches in plants (Kunshal et al, 2011; Kiran and Chimmad, 2015).

The late maturing genotypes (Range 4 and Range 5) recorded greater number of primary branches compared to the early (Range 1) and medium maturity (Range 3) desi genotypes as well as the medium maturity Kabuli (CCV9901) genotype. This variation in primary branches was probably due to variation in bud dormancy, a condition that is partly promoted by water stress and hence greater concentration of ethylene hormones. Although we did not measure concentration levels of hormones in the plants, the greater temperature coupled with water stress justified accumulation of ethlyne hormones and dormancy of buds. The role of temperature in bud dormancy and branch development in plants has been reported in literature (Kiran and Chimmad, 2015). In addition, variation in number of branches per plant in chickpea grown under different planting dates has been reported in literature, and genetic variation and differences in temperature amongst planting dates have been suggested as some of the causes of the variation (Brar et al., 2004; Kiran and Chimmad (2015; Krishnamurthi et al., 2010).

It was quite intresting to note that cultivars which produced greater number of primary branches had lower number of secondary branches and vice versa. This condition was probably as results of problems in partitioning of photo assimilates between primary and secondary branches (Berghage, 1998). For example, plants with greater primary branches failed to sustain greater number of secondary branches whilst plants with lower number primary branches were able to sustain greater number of secondary branches.

The greater number of secondary branches in experiment I compared with experiment II and vice versa for the number of primary branches was possibly due to variation in moisture availability in the two experiments. The results are consistent with earlier results in other crops (mustard), where application of irrigation was shown to reduce primary branches and increase the number of secondary branches per plant (Sharma and Piri, 2006).

7.4.3 Accumulated growing degree days (AGDD)

The significant variation in AGDD amongst planting date treatments in experiment I may suggests that different planting date treatments received different temperature conditions during their growth and development phases. It was evident from temperature results that each planting date treatment experienced at least 1.5°C to 2°C different temperatures during vegetative and reproductive stages of growth. Thus, higher temperatures experienced by late planted crop during reproductive stage compared to early and late planting may have hastened crop growth, and consequently resulted in the crop reaching physiological maturity too early without having accumulated enough heat units to sustain greater grain yield.

Krishnamurthy et al., (2011) and Devendra et al., (2012a) reported hastened flowering and maturity in late planting as a result of variation in temperature which was directly associated with differences in planting dates. The current study results support earlier views by Kiran and Chimmad, (2015) who suggested that planting date may affect AGDD. In addition, the 14% and 27% greater AGDD, respectively observed in early planting compared with normal and late planting date in the study is comparable to observations by Rao et al (2006), who reported greater AGDD in early compared to late planting, and suggested variation in growing season length as the possible cause of AGDD variations. In previous studies, Chand et al (2010) and Karan and Chimmad (2015), it was reported that AGDD had a significant effect on grain yield and yield components. Thus the current results are in agreement with previous studies and this confirms the reliability of these findings.

Furthermore, the variation in AGDD amongst genotypes, may have been the consequence of differences in days to physiological maturity amongst genotypes. The genotypes used in the study had different days to physiological maturity. Range 1 was early maturing variety, Range 3 and ICCV9901 were medium maturing cultivars and Range 4 and 5 were late maturing varieties, thus their differences in days to physiological maturity meant that they would accumulate different heat units in their life cycles. Moreover, the planted genotypes could have been with different themotolerence characteristics, hence responding differently to temperature stress (Krishnamurthy et al., 2011). For instance, Range 1 attempted to escape high temperature stress by hastening reproduction stage and reach physiological maturity stage early. This ability of chickpea to shorten its life cycle under conditions of temperature stress has been identified as an escape mechanism (Wang et al., 2006; Devasirvatham et al., 2012a; Krishnamurthy et al., 2011; Upadhyaya et al., 2011), but is done at the expense of HUE_g which was evidently low in the study.

Moreover, the variation in AGDD between the seasons was perhaps caused by variation in temperature observed between the seasons. For instance, during the study, season 2 experienced maximum temperatures that were ≥33 ^oC, whilst season 1 had ≥30 ^oC. Thus, the variation of 3^oC may have caused variation in AGDD with seasons. Seasonal temperature variations and their effect on crop heat units have been reported in literature (Kalra et al., 2008).

The interaction between planting date and genotype may possibly have been caused by a combination of differences in growing season length by planting date treatments and variation in days to physiological maturity amongst genotypes. For example, AGDD was greater with early compared with normal and late planting in all genotypes because of a longer growing season length in early planting which allowed all genotypes to reach their genetic potential life span and hence accumulated greater heat units. The similar AGDD recorded in late planting was possibly due to a short season length which forced all genotypes regardless of their days to maturity to reach physiological maturity at the same time, hence accumulating similar heat units.

Furthermore, the marked variation in water application between experiment I and II may have caused variation in days to maturity between the two experiments and consequently resulted in differences in AGDD. The well-watered experiment I had greater days to physiological maturity, implying that they would have greater window to accumulate more heat units compared with experiment II. Piri and Sharma (2006) observed that variation in water application reduced days to physiological maturity by between 15 and 19 days in water stressed crop, whilst Sigh et al (2005) reported of a strong correlation between days to physiological yield and AGDD. Thus by varying days to maturity, application of irrigation water improved AGDD in experiment I.

Moreover, the close positive correlation between AGDD and grain yield may suggests that any management strategy that improve heat units may also improve grain yield in chickpea. The similarity of correlation between AGDD and yield across planting dates in the study confirms the robustness of HUE_g, thus, we therefore recommend use of HUE_g in crop growth models to estimate yield.

7.4.4 Heat use efficiency (HUE_g)

HUE_g was affected by planting date in both experiments probably because of the variation in AGDD and grain yield with planting date. AGDD and grain yield are the two main factors that principally affect HUE_g (Chand et al., 2010). Girijesh et al (2011) reported an inverse relationship between HUE_g and AGDD, and linear relationship between HUE_g with grain yield. Thus the lowest grain yield that was observed in late planting (results presented in chapter four) may have resulted in lowest HUE_g compared to all other planting dates. Although early planting had greater yield compared with normal planting, it accumulated greater heat units which consequently lowered its HUE_g. The late planting had the lowest AGDD, but this was complemented by lowest grain yield, hence resulting in lowest HUE_g. The greater HUE_g in normal planting in both experiments clearly suggests that the accumulated heat energy was efficiently utilised for grain yield production. HUE_g in normal planting in this study are comparable with observations made by (Chand et al (2010), who reported HUE_g of 1.06 (kg ha ^{o}C.day) and attributed the result to variation in planting date. Similar response of HUE_g to the effect of planting date was reported in maize (Girjesh et al 2011), where early planting had greater HUE_g whilst late planting had lowest HUE_g.

Furthermore, HUE_g was affected by genotype in experiment I & II, perhaps because of variation amongst the genotypes in grain yield and AGDD. The greater HUE_g in Range 4 compared to the rest of the genotypes was probably caused by its greater grain yield in experiment I. Although it accumulated greater heat units, its grain ensured the highest HUE_g. The lowest HUE_g recorded on ICCV9901 in experiment II was partly due to its lower grain yield since its AGDD was fairly low.

The variation in HUE_g with season in both experiments was possibly caused by variation in AGDD, which showed similar variation with the seasons. For instance, the lower HUE_g in season 1, in experiment I was caused by greater AGDD, whilst the greater HUE_g in season 1, in experiment II was caused by lower AGDD. Similarly, the greater HUE_g in season 2, in experiment I was caused by lower AGDD, whilst the lower HUE_g in season 2, in experiment II was caused by greater AGDD.

The variation in HUE_g between experiment I and II was possibly caused by differences in grain yield and AGDD between the two experiments. The variation in grain yield and AGDD was caused by variation in moisture as expected. Experiment I was well watered (430 mm in season 1, and 435mm in season 2). In contrast, Experiment II was only irrigated three times (at planting, flowering and podding) giving a total of 175 mm in season 1, and 235mm in season 2.

In general, the results are in agreement with earlier findings that the efficiency of converting heat energy to grain yield is a function of growing degree days, genetic factors, crop type and planting date (Rao et al*.,* 1999; Rao et al., 2006). The results from the current study shows that manipulation of planting date and genotype may be used to improve HUE_g of chickpea crop, however, its effect on crop may depend on the availability of moisture. Normal planting date was the most suitable sowing date in this environment to improve chickpea HUE_g.

7.5 Conclusion

Planting date, genotype and season affected heat use efficiency of grain yield (HUE_g) in both experiments over the two seasons. Highest HUE_g was observed in normal planted crops, whilst the late planted crops had the lowest HUE_g in both experiments. Similarly, AGDD, number of primary and secondary branches and plant height were affected by planting date x genotype, planting date x season and genotype x season interactions, suggesting that the differences between planting dates were not consistent amongst genotypes and seasons. Clearly, normal planting date may be the most suitable sowing date for chickpea in this environment but this may vary with availability of moisture.

References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome*, *300*(9), pp.105-109.

Auld, D.L., Bettis, B.L., Crock, J.E. and Kephart, K.D., 1988. Planting date and temperature effects on germination, emergence, and seed yield of chickpea. *Agronomy Journal*, *80*(6), pp.909-914.

Berghage, R., 1998. Controlling height with temperature. *HortTechnology*, *8*(4), pp.535-539.

Bhattacharya, B.K., Mallick, K., Nigam, R., Dakore, K. and Shekh, A.M., 2011. Efficiency based wheat yield prediction in a semi-arid climate using surface energy budgeting with satellite observations. *Agricultural and forest meteorology*, *151*(10), pp.1394-1408.

Brar, K.S., Sandhu, J.S. and Singh, I., 2004. Association analysis of seed yield and its components in chickpea (Cicer arietinum L.) under late sown conditions in South-western Punjab. *Journal of Research*, *41*(1), pp.8-10.

Chand, M., Singh, D., Roy, N., Kumar, V. and Singh, R.B., 2010. Effect of growing degree days on chickpea production in Bundelkhand region of Uttar Pradesh. *Journal of Food Legumes*, *23*(1), pp.41-43.

Chaturvedi, S.K. and Dua, R.P., 2003, January. Breeding chickpea for late sown conditions in northern India. In *International Chick pea Conference, January* (pp. 20-22).

Chijioke, O.B., Ifeanyi, U.M. and Blessing, A.C., 2010. Comparative study on growth and development of some accessions of local Germplasm of Bambara groundnut (Vigna subterrenea L. Verdc.) of Nigeria in two cropping seasons. *Journal of Crop Science and Biotechnology*, *13*(1), pp.21-27.

Clarke, H.J. and K.H.M. Siddique. (2004). Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops. Res., 90, 323-334 (2004).

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Tokachichu, R.N., Trethowan, R.M. and Tan, D.K., 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology*, *39*(12), pp.1009-1018.

Devasirvatham, V., Tan, D.K.Y., Gaur, P.M., Raju, T.N. and Trethowan, R.M., 2012, October. Effects of high temperature at different developmental stages on the yield of chickpea. In *Capturing opportunities and overcoming obstacles in Australian agronomy. Proceedings of the 16th ASA conference, Armidale, Australia* (pp. 14-18).

Girijesh, G.K., Kumaraswamy, A.S., Sridhara, S., Dinesh Kumar, M., Vageesh, T.S. and Nataraju, S.P., 2011. Heat use efficiency and helio-thermal units for maize genotypes as influenced by dates of sowing under southern transitional zone of Karnataka state. *International Journal of Science*, *2*, pp.529-533.

Gudadhe, N.N., Kumar, N., Pisal, R.R., Mote, B.M. and Dhonde, M.B., 2013. Evaluation of Agrometeorological Indices in Relation to Crop Phenology of Cotton (Gossipium spp.) and Chickpea (Cicer aritinum L.) at Rahuri Region of Maharashtra. *Trends in Biosciences*, *6*(3), pp.246-250.

Heady, H.F., 1957. The measurement and value of plant height in the study of herbaceous vegetation. *Ecology*, *38*(2), pp.313-320.

Iannucci, A., Terribile, M.R. and Martiniello, P., 2008. Effects of temperature and photoperiod on flowering time of forage legumes in a Mediterranean environment. *Field Crops Research*, *106*(2), pp.156-162.

IPCC., 2014. Climate change: impacts, adaptation, and vulnerability. Part B: regional aspects. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.J., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA pp. 688 pp.

Kalra, N., Chakraborty, D., Sharma, A., Rai, H.K., Jolly, M., Chander, S., Kumar, P.R., Bhadraray, S., Barman, D., Mittal, R.B. and Lal, M., 2008. Effect of increasing temperature on yield of some winter crops in northwest India. *Current science*, pp.82-88.

Keatinge, J.D.H., Qi, A., Wheeler, T.R., Ellis, R.H. and Summerfield, R.J., 1998. Effects of temperature and photoperiod on phenology as a guide to the selection of annual legume cover and green manure crops for hillside farming systems. *Field Crops Research*, *57*(2), pp.139-152.

Khanna-Chopra, R. and Sinha, S.K., 1987. Chickpea: physiological aspects of growth and yield. *The chickpea*, *409*.

Kiran, B.A. and Chimmad, V.P., 2015. Effect of temperature regimes on phonological parameters, yield and yield components of chickpea. *Karnataka Journal of Agricultural Sciences*, *28*(2), pp.168-171.

Koocheki, A., Nassiri, M., Soltani, A., Sharifi, H. and Ghorbani, R., 2006. Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran. *Climate Research*, *30*(3), pp.247-253.

Krishnamurthy, L., Gaur, P.M., Basu, P.S., Chaturvedi, S.K., Tripathi, S., Vadez, V., Rathore, A., Varshney, R.K. and Gowda, C.L.L., 2011. Large genetic variation for heat tolerance in the reference collection of chickpea (Cicer arietinum L.) germplasm. *Plant Genetic Resources*, *9*(1), pp.59-69.

Krishnamurthy, L., Kashiwagi, J., Gaur, P.M., Upadhyaya, H.D. and Vadez, V., 2010. Sources of tolerance to terminal drought in the chickpea (Cicer arietinum L.) minicore germplasm. *Field Crops Research*, *119*(2-3), pp.322-330.

Mathews, C., Ogola, J.B.O., Gaur, P.M., Lengwati, M.D. and Gwata, E.T., 2009. Yield response of six chickpea genotypes to varying planting dates in Mpumalanga, South Africa. Combined Congress 2009. Book of Abstracts. pp 223

Ottman, M.J., Husman, S.H., Gibson, R.D. and Rogers, M.T., 1997. Planting Date and Sorghum Flowering at Mariopa. *Forage and Grain Agriculture Report, Publication AZ1059*.

Papastylianou, P.T. and Bilalis, D., 2011. Flowering in Sulla ('Hedysarum coronarium'L. cv. Carmen) and Persian clover ('Trifolium resupinatum'L. cv. Laser) as affected by sowing date in a mediterranean environment. *Australian Journal of Crop Science*, *5*(10), p.1298.

Parthasarathi, T., Velu, G. and Jeyakumar, P., 2013. Impact of crop heat units on growth and developmental physiology of future crop production: A review. *Res. Rev. J. Crop Sci. Technol*, *2*, pp.1-11.

Piri, I.S.S.A. and Sharma, S.N., 2006. Physiological analysis of growth and yield of Indian mustard as affected by irrigation and sulphur. *Indian Journal of Plant Physiology*, *11*(3), p.253.

Rao, V.U.M., Singh, D. and Singh, R., 1999. Heat use efficiency of winter crops in Haryana. *J. Agrometeorol*, *1*(2), pp.143-8.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Singh, P., Nedumaran, S., Boote, K.J., Gaur, P.M., Srinivas, K. and Bantilan, M.C.S., 2014. Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European journal of agronomy*, *52*, pp.123-137.

Singh, T.P., Deshmukh, P.S., Mishra, S.K. and Kushwaha, S.R., 2005. Effect of temperature regimes on physiological parameters in chickpea (Cicer arietinum L.). *NEW BOTANIST*, *32*(1/4), p.225.

Singh, K.B., Malhotra, R.S., Saxena, M.C. and Bejiga, G., 1997. Superiority of winter sowing over traditional spring sowing of chickpea in the Mediterranean region. *Agronomy Journal*, *89*(1), pp.112-118.

Soltani, A., Robertson, M.J., Rahemi-Karizaki, A., Poorreza, J. and Zarei, H., 2006. Modelling biomass accumulation and partitioning in chickpea (Cicer arietinum L.). *Journal of agronomy and crop science*, *192*(5), pp.379-389.

Summerfield, R.J., Virmani, S.M., Roberts, E.H., Ellis, R.H., Walby, B.J. and Hall, S.D., 1990. Adaptation of chickpea to agroclimatic constraints. *Chickpea in the Nineties. ICRISAT, Patancheru, India*, pp.61-72.

Summerfield, R.J., Hadley, P., Roberts, E.H., Minchin, F.R. and Rawsthorne, S., 1984. Sensitivity of Chickpeas (Cicer arietinum) to Hot Temperatures during the Reporductive Period. *Experimental Agriculture*, *20*(1), pp.77-93.

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

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Upadhyaya, H.D., Dwivedi, S.L., Baum, M., Varshney, R.K., Udupa, S.M., Gowda, C.L., Hoisington, D. and Singh, S., 2008. Genetic structure, diversity, and allelic richness in composite collection and reference set in chickpea (Cicer arietinum L.). *BMC Plant Biology*, *8*(1), p.106.

Verghis, T.I., McKenzie, B.A. and Hill, G.D., 1999. Phenological development of chickpeas (Cicer arietinum) in Canterbury, New Zealand. *New Zealand journal of crop and horticultural science*, *27*(3), pp.249-256.

Wahid, A., Gelani, S., Ashraf, M. and Foolad, M.R., 2007. Heat tolerance in plants: an overview. *Environmental and experimental botany*, *61*(3), pp.199-223.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Yadav, V.S., Singh, D., Yadav, S.S., Panwar, J.D.S. and Singh, D., 1999. Morpho-physiological basis of yield variation in chickpea under late planting conditions. *Annals Agric Res*, *20*(2), pp.227-230.

Chapter 8

AquaCrop model calibration and validation in chickpea *(Cicer arietnum)* in Southern Africa.

Abstract

The study parameterised and validated performance of AquaCrop model, to simulate attainable yields in chickpea crop in response to effects of planting date in the North Eastern Region of South Africa. Model calibration data were obtained from two field experiments of contrasting water regime, planted in 2014 winter season at University of Venda, South Africa, whilst data for model validation was obtained from 2015 planting season from same station. The model performance was satisfactory, with a good match between the simulated and observed canopy cover (CC), Soil water content (SWC), biomass (B) and grain yield (Y). All the statistical indicators (R^2, RMSE, and MAPE) used to compare field observed and model predicted parameters, showed good model performance. For example, the regression plot of simulated and observed yield showed a good relationship with R^2 values of 0.949, 0.928 and 0.990 for early, normal and late planting dates, respectively, whilst RMSE was 0.135, 0.143 and 0.031 for early, normal and late planting dates. Similarly, SWC had strong regression relationship (R^2 = 0.982, 0.949, 0.954, respectively and a RMSE of 0.226, 0.696 and 0.310, respectively in early, normal and late planting date). The results indicate that the model could be used for evaluating the effects of different planting dates on chickpea yield.

8.1 Introduction

Chickpea *(Cicer arietnum)* is a fairly drought tolerant legume crop that is widely cultivated in tropical and subtropical regions of the world (FAO, 2013). Production of chickpea is growing in many countries because of its multiple uses as a source of food, livestock feed, fuel, and fertilizer (Gaur et al., 2010). The crop is currently being introduced in the dry and hot environments of north eastern region of South Africa to ameliorate problems of climate change and food insecurity. Despite chickpea's ability to tolerate moisture stress, possible negative effects of climate change on future productivity of the crop has been documented (Koocheki et al., 2006, Singh et al., 2013). Climate change in the form of increase in intensity and severity of drought, frost and heat waves may seriously alter the current planting dates in the region and consequently affect future yield of chickpea. Climate change is expected to cause a decrease in the length of the growing season in the Lowveld regions and the converse in the Highveld regions of Southern Africa (Tadross, et al., 2009).

Amid challenges of climate change, use of planting date has been reported as an important management strategy to improve yield under climate change conditions (Mhizha et al., 2014). Likewise, over the years manipulation of planting date has been reported to improve biomass and grain yield of chickpea (Bahal et al., 1984, Dixit et al., 1993, Hussain et al., 1997, Kabir 2009). For example, in Bangladesh, Kabir et al. (2009) observed that planting date had a significant effect on chickpea growth parameters, yield and yield components. Similar reports have been given across the world and in different crops (Tsimba et al., 2013; Fiwa, 2015) and in Southern Africa (Mathews et al., 2011).

Whilst several authors seem to have a consensus on the importance of planting date, guidelines and procedures on when to plant chickpea in the region have not been developed. Hardly any study has reported planting dates for chickpea particularly in Southern Africa region. AquaCrop model is a crop simulating software that may be used to develop chickpea planting date guidelines for farmers and extension staff using climate data (Steduto et al., 2009). AquaCrop model as a decision-support tool, may be used to assess the effect of different planting dates on evapotranspiration (ET), crop canopy cover (CCC), biomass and grain yield of chickpea. Other than AquaCrop, several crop simulation models such as CERES (Jones and Kiniry, 1986), CropSyst (Stockle et al., 2003), Cropwat (FAO, 1992), DSSAT cropping system (Jones et al., 2003), APSIM (Keating et al., 2003) and ELCROS (de Wit, et al., 1970) have been developed over the years.

Although these models may be used for determining planting dates for farmers, the models are complex and thus rarely used by farmers, extension personnel, and planners. Furthermore, the use of these models requires a large number of variables and input parameters which are not easily available for the diverse range of crops and sites around the world. Therefore there is need for a crop simulation model that is sensitive enough to predict the response of biomass and grain yield to different planting dates under climate change scenario, but yet is simple to run and requires limited number of input parameters.

The Food and Agriculture Organisation (FAO) developed AquaCrop model in an attempt to address the weaknesses of the earlier developed models. AquaCrop has the advantages of sufficiency, transparency, simplicity, accuracy and robustness (Steduto et al., 2006, 2009, and 2012). The model simulation process is water-driven and requires a relatively low number of parameters and input data to simulate the yield response of crops to water (Steduto et al., 2009). For AquaCrop model to be used for a specific crop, it needs to be calibrated and validated using field crop data and weather records. AquaCrop model has been calibrated and validated for maize (Hsiao et al., 2009, Garcia-Vila and Fereres, 2012), soybeans (Steduto et al., 2009), sorghum, sunflower (Stricevic et al., 2011), teff (Araya et al., 2010), tomatoes (Rinaldi et al., 2011, Katerji, et al., 2013), wheat (Xiangxiang et al., 2013, Jin et al., 2014), sugar beet (Stricevic et al., 2011), potatoes (Casa et al., 2013), rice (Shrestha et al., 2013), cotton (Farahani et al., 2009) and barley (Araya et al., 2010). However, no published information is readily available on the calibration and validation of AquaCrop for chickpea. Therefore the objective of this study was to calibrate and validate the performance of AquaCrop model in simulating attainable yields in chickpea in response to varying planting dates at a representative site of the dry environments of North Eastern South Africa.

8.2 Description of the AquaCrop model

AquaCrop is a water driven crop yield simulation model (Raes et al., 2009; Steduto et al., 2009). The model has been used in multiple herbaceous crops for simulating biomass and yield under varying field conditions in different locations across the world. The model can be used to develop optimum planting period for different crops to increase and stabilize crop yields. The model simulate aboveground biomass for each day during crop cycle as a function of temperature stress coefficient, water productivity and the summation of the ratio of crop transpiration to the reference evapotranspiration (equation 8.1).

$$B = K_{sb}.W^{P^*}\sum\frac{T_r}{ETo} \qquad 8.1$$

Where K_{sb} is the temperature stress coefficient. WP* is water productivity and is normalised for place and climate. T_r is crop transpiration and is normalised for climate by reference evapotranspiration for each day of transpiration.

Grain yield (Y): AquaCrop simulate grain yield as a product of above ground biomass and the harvest index as shown by equation 8.2.

$$Y = f_{HI}.HI_o.B \qquad 8.2$$

Where f_{HI} is a multiplier factor which considers various stresses that may affect harvest index (HI) from its reference value. HI is the ratio of grain yield to total dry matter of the crop and is affected by water and temperature stress before the beginning of yield formation, at flowering and during yield formation. Thus HI is constantly adjusted during yield formation (Raes et al., 2011) and is affected by water stress during various stages of crop development.

Transipiration (Tr): AquaCrop calculate transpiration as a product of crop coefficient (K_{cb}) and the evaporative power of the atmosphere (ETo). This calculation is done by considering water stress factor (Ks) as shown in equation 8. 3. In circumstances where water shortage provokes closure of stomatal openings, a stress coefficient (Ks_{sto}) is considered.

$$Tr = K_s.(K_{cbx}.\ CC^*).ETo \qquad 8.3$$

Where CC* is crop canopy cover adjusted for interrow micro-advection.

The operation of AquaCrop, its interface between organs and climate factors and how it determines several parameters for crop growth is shown in Fig 8.1 below.

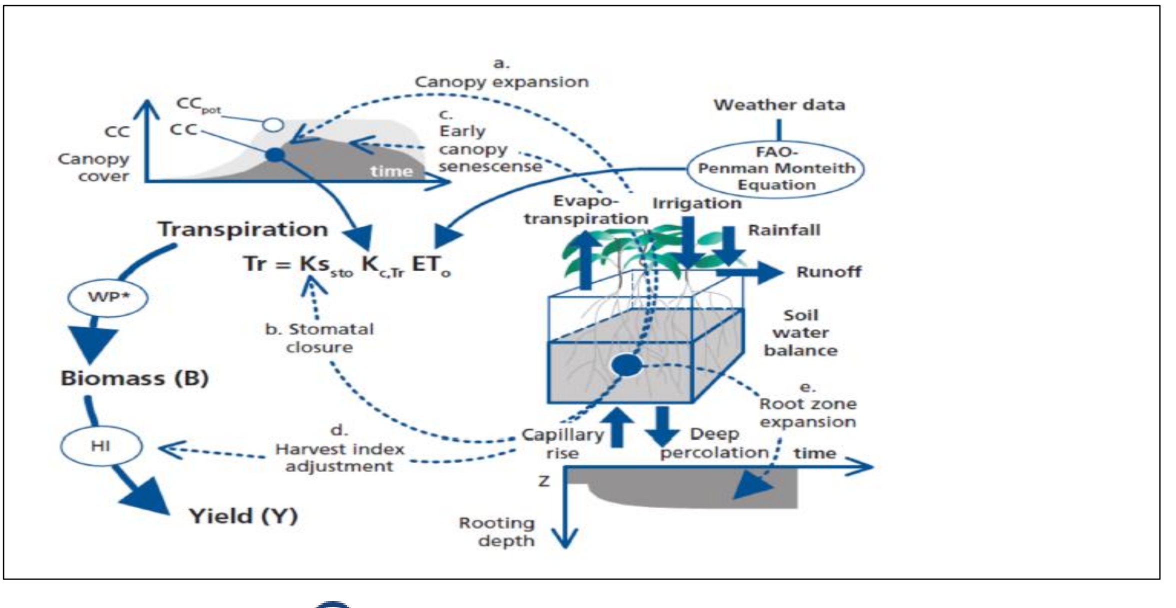


Figure 8-1 AquaCrop flow chart. The dotted arrows indicate the processes (a - e) affected by water stress. CC is simulated canopy cover, CCpot the potential canopy cover, Kssto the water stress for stomatal closure, Kc,tr the crop transpiration coefficient, ETo the reference evapotranspiration, WP* the normalized water productivity for ETo and air CO2 concentration and HI the harvest index (Raes et al., 2009; Steduto et al., 2012).

8.3 Materials and methods

8.3.1 Background

AquaCrop model has not been calibrated for chickpea. Thus the model does not have files for chickpea. So this study entalled a full calibration process. However, we adopted soybean files from the model as a starting point and changed the files with newly developed chickpea files. Soybean files were chosen because it was the only crop closer to chickpea amongst calibrated crops in AquaCrop model. All parameters that specify the crop (conservative, cultivar specific and variables) were calibrated for chickpea. Chickpea values for the parameters were either determined from field experiments, previous studies in region or by iteration. Soybean files were only kept when we had no bases to improve their calibration.

8.3.2 Field experimental design

The study site, experimental design, treatments and planting details are described in Chapter 3. In summary, two separate experiments were laid out in a split-plot design, with main plots comprising of planting date (1st of May being the early planting, 14th of May as the control / normal planting, and 28th of May being the late planting date). These planting dates were selected based on previous studies (Mathews et al., 2009). Chickpea genotypes were used as sub-plot factor; four desi genotypes (Range 1, Range 3, Range 4 and Range 5) were sown in 2014, and 4 desi types and one Kabuli genotype (ICCV99010) were sown in 2015 season. Range 1 is early maturing and has a bushy canopy structure, Range 3 and ICCV 9901 are medium maturing and have an erect canopy, and Range 4 and Range 5 are late maturing and display a prostate and an erect canopy structure, respectively. Experiment one was well watered throughout the season, and experiment two was watered three times (at planting, flowering and pod formation). The total amount of water applied (including rainfall) in 2014 was 430 mm in experiment one and 175 mm in experiment two, whilst 435 mm and 235 mm was applied in 2015 in Experiment one and two, respectively. Variation in the total amount of water applied in 2014 and 2015 was caused by differences in initial soil moisture.

8.3.3 Data collection

8.3.2.1 Climate data

Climate data for the period May to October for each winter season (2014 and 2015) was recorded from an automatic weather station that was already established at the experimental site (approximately 100 m from the experiments). The recorded data needed by AquaCrop model included rainfall (mm), maximum and minimum air temperatures (°C), and reference evapotranspiration (mm) (calculated according to the FAO Penman-Monteith equation using ETo calculator version 3.2 software (FAO, 2012)). This data set was for each day during the trial period. Carbon dioxide data for the experimental period was adopted from the model default file of Mauna Loa atmospheric CO_2 concentration (USA) from 1902-2109.

8.3.2.2 Soil data

Soil characteristics data was adopted from previous studies conducted in the study area (Mzezewa and Rensburg, 2012; Soil Classification Working Group 1991; Fey, 2010). The soil parameters needed by AquaCrop model included soil textural classes, water content (Volumetric) at permanent wilting point (PWP), saturation point (SAT) and at field capacity (FC), total available water (TAW) (mm), soil physical and hydraulic properties (K_{sat}). A summary of soil data that was uploaded into the model is shown in Table 8.1. Analysis of soil water content across the profile showed a maximum rooting depth of 2 m.

8.3.2.4 *Crop data*

Field measurements were conducted on parameters that included above ground biomass (measured at 14-days interval), number of plants per hectare, time from planting to 90% recovery (days), maximum canopy cover, (CCX) (%), time from emergence to start of senescence (days), time from planting to harvest maturity (days), time from planting to flowering (days), length of flowering stage (days), maximum effective rooting depth (m), time from sowing to maximum rooting depth (days), harvest index and grain yield.

Above ground biomass was measured at 14-days interval starting from 28 days after crop emergence (DAE) until harvest maturity (HM) using destructive sampling method. All the plants from a quadrant of 0.36 m^2 were cut at ground level, chopped, and oven dried at 80°C for 48 hours before recording sample dry weight (kg m^{-2}). For grain yield determination, 20 plant samples at harvest maturity stage, from a quadrant of 0.6 m^2 were collected from the two innermost rows of each experimental unit and the pods were manually removed, threshed by hand, cleaned, air-dried, and weighed to determine grain yield (kg ha^{-1}). Harvest index was determined as the ratio of grain yield to total above ground biomass.
Canopy cover was determined from the measured photosynthetically active radiation (PAR) using equation 8.4 (Farahani et al., 2009):

$$CC = (1 - \left(\frac{PAR_{below\ canopy}}{PAR_{above\ canopy}}\right)) * 100 \quad (8.4)$$

The proportion of intercepted radiation by the crop canopy was measured at 7-days intervals between 28 and 105 DAE in both experiments using an AccuPAR, model LP-80 ceptometer (Decagon Devices Ltd., Pullman, USA). The measurements were taken between 1100 and 1300 h on clear, cloudless days. The ceptometer was placed horizontally above the canopy when measuring PAR above the canopy. When measuring PAR below the canopy, the ceptometer was positioned between the rows in such a manner that it ran perpendicular to the rows.

Soil moisture content was measured at 7-day interval using a neutron probe. Measurements were taken between 14 and 105 DAE. On each occasion, the probe was lowered into access tubes that had been inserted in each experimental plot at sowing and 16 seconds counts readings (N_{soil}) were taken at 30, 60, 90 and 120 cm depth. Standard counts (N_{std}) were taken before taking any soil moisture readings; these readings were used to calculate count ratios, X ($X=N_{soil}/N_{std}$). Volumetric water content (QV) at each depth was calculated using the calibration equations that have already been developed for the site (Thangwena and Ogola, 2016).

Crop Transpiration: transpiration (Tr) was determined from equation:

$$T_r = ET - E \quad (8.5)$$

where E is evaporation from bare soil surface and ET is evapotranspiration from the crop. ET was determined using the standard water balance equation:

$$ET = \Delta S + P + I + U - D - R \quad (8.6)$$

Where ΔS is the change in storage (difference in volumetric water content of the entire profile between the first and last neutron probe readings), P is precipitation (mm), I is irrigation (mm), U is upward capillary, D is drainage and R is the surface runoff (Allen et al., 1998; Anwar et al*.*, 1999). Considering the flatness of the field (less than 2% slope) and following earlier studies (Ogola & Thangwana*,* 2013; Ogola, et al*.*, 2013; Thangwana and Ogola*,* 2016), rate of infiltration, drainage, capillary rise and surface runoff were assumed to be negligible. Therefore, ET was estimated as a function of change in storage, irrigation and precipitation. The total irrigation amount of water applied in 2014 was 430 mm in experiment I and 230 mm in experiment II, whilst 435 mm and 235 mm were applied in 2015, in Experiment 1 and II, respectively.

Evaporation was mostly from the wetted soil surface unshaded by the canopy and was measured at a depth of 5 and 15 cm on daily basis using a hygrotech probe soil moisture sensor (Decagon Devices Ltd., Pullman, USA). Water productivity (WP*) was determined as a ratio of biomass to cumulative normalised transpiration (equation 8.7). Transpiration was normalised using ETo calculated by Penman-Monteth equation (Allen et al., 1998) from the weather station.

$$WP^* = \left[\frac{B}{\Sigma\left(\frac{Tr}{ET_O}\right)}\right] \qquad (8.7)$$

8.3.4 Creating model input files

AquaCrop model requires soil, crop, climate and field management data for a specific area and time in order for it to simulate biomass and yield of crops. This data is uploaded into the model as files. Thus, soil, crop, climate and field management files were developed to calibrate/parameterise the model. Because AquaCrop model has not been parameterised for chickpea, the study used default parameter values of soybean crop on few parameters that were difficult/impossible to measure using the available materials. This soyabean crop file is from AquaCrop model software, which contains crop parameters that were calibrated and validated by FAO.

The soil data file was developed by specifying local soil type, texture, soil depth and number of soil horizons, slope, soil water content at field capacity and at permanent wilting point, total available water, saturated hydraulic conductivity, bulk density and the type of land use (Table 8.1). From this input specification, the model was able to generate a set of complete soil parameters, which are adjustable to the site specification. Developing a climate data file involved creating small sub-files of rainfall, temperature, reference evapotranspiration (ET_o), and carbon dioxide for the study area during the experimental period. Creating the sub-files involved uploading daily whether data into the model (including specifying the time and range of data). A collection of these sub-files was used to form a climate file for the study area. Carbon dioxide data was adopted from the model default file of Mauna Loa atmospheric CO_2 concentration (USA) from 1902-2109. This adopted CO_2 file is a global average represented by measurements at a station in Hawaii (Mauna Loa) and already uploaded as a default file within AquaCrop. CO_2 concentration is rarely measured weather station at study site and so the data could not otherwise be found for local conditions.

Table 8.1 Soil physical properties of the soil at the University of Venda experiment station.

Soil property	Soil Depth (mm)				
	0-300	300-600	600-900	900-1200	1200-1500
Type of soil	Clay	Clay	Clay	Clay	Clay
Field capacity	49.5 %	48.2 %	47.7 %	47.6 %	47.7 %
Permanent wilting point	29.3 %	28.6 %	28.2 %	28.2 %	28.2 %
Total available water	123 mm	120 mm	121 mm	122 mm	125 mm
K_{sat} (mmday^{-1})	24.2	24.2	24.2	24.2	24.2
Bulk density (g cm^{-3})	1.11	1.14	1.12	1.13	1.20

(Mzezewa and Rensburg, 2012; Soil Classification Working Group 1991; Fey, 2010), The reference evapotranspiration, ETo was collected from experimental weather station, and had already been calculated according to the Penman-Monteith equation using ETo calculator version 3.1 software (Allen et al., 1998). Similarly, rainfall, maximum and minimum temperatures were recorded from experimental weather station. The crop inputs to the model were made up of three types of parameters (conservative, management and cultivar specific). The conservative parameters do not change with geographic location, time or management practices (Steduto et al., 2009). However, because there were no predetermined parameters for chickpea crop in AquaCrop model, adopted conservative parameters for soybeans were fine-tuned to match values for chickpea crop. The soybean conservative parameters that were fine-tuned included: base temperature, upper temperature, crop coefficient when canopy is complete but prior to senescence, water productivity normalized for ET_o and CO_2 (gram m^{-2}), possible increase (%) of harvest index (HI) due to water stress before flowering stage and during yield formation, coefficient describing negative impact of stomatal closure during yield formation on harvest index, allowable maximum increase (%) of specified HI, soil water depletion factor for canopy expansion – upper threshold, soil water depletion factor for canopy expansion – lower threshold, soil water depletion fraction for stomatal control – upper threshold, soil water depletion factor for canopy senescence – upper threshold and minimum growing degrees required for full biomass production (°C.day), heat stress temperature for pollination and cold stress temperature for pollination.

The cultivar specific parameters are less conservative and may vary with soil characteristics, field management or climatic conditions (Steduto et al., 2009). Therefore, these cultivar specific parameters were uploaded into the model for it to assume the characteristics of the study area. During the development of the crop data file, the following subcomponent files were created: phenology, green canopy cover, rooting depth, crop transpiration, soil evaporation, above ground biomass production and harvestable yield.

The field management file was created; it specified the description of the soil conditions during planting stage of the crop (a wet soil with an average volumetric water content of 30%, a sub-soil of 25% as measured from the field was used, whilst a ground water of varying depth and salinity was assumed from model default files because of its difficulty to measure). The management file also specified the field condition at planting, which was free from mulching and was with soil bunds of less than or equal to 0.3 metres in height as measured from the field. An irrigation data file was created by specifying the irrigation method and irrigation events (irrigation time, water quality and net application amount) for each experiment (I and II) (Table 8.2). The study used sprinkler irrigation method.

Table 8.2 Irrigation events recorded for 2014 and 2015 planting seasons

Date	Amount of irrigation application (mm)			
	2014 season		2015 season	
	Experiment I	Experiment II	Experiment I	Experiment II
1 May	25	65	30	80
14 May	30		30	
28 May	30		30	
03 June	40		30	
10 June	40	55	40	80
17 June	40		40	
24 June	30		30	
01 July	40		40	
08 July	40	55	40	75
22 July	40		40	
29 July	30		30	
12 August	30		30	
19 August	15		15	
Total (mm)	430	175	435	235

8.3.5 Model parameterization

Parameterisation refers to high level adjustment of specific model parameters (Farahani et al., 2009) and is more than just calibration. There were no predetermined parameters for chickpea crop in AquaCrop model 5.0. However, we adopted soybean files from the model as a starting point and changed the files with chickpea files during parameterization. Soybean crop was chosen because it was the only crop closer to chickpea amongst all calibrated crops in AquaCrop model, however the challenge was that soybean is a summer crop whilst chickpea was being parameterized for winter cropping. Thus, the following conservative parameters were parameterised to suit chickpea crop: base temperature, upper temperature, crop coefficient when canopy is complete but prior to senescence, water productivity normalized for ETo and CO_2 (gram m^{-2}), possible increase (%) of harvest index (HI) due to water stress before flowering, and during yield formation, coefficient describing negative impact of stomatal closure during yield formation on harvest index, allowable maximum increase (%) of specified HI, soil water depletion factor for canopy expansion – upper threshold, soil water depletion factor for canopy expansion – lower threshold, soil water depletion fraction for stomatal control – upper threshold, soil water depletion factor for canopy senescence – upper threshold and minimum growing degrees required for full biomass production (°C.day). Field data from 2014 was used for parameterisation of the model.

The decision criteria in the parameterisation process was an objective method of measuring the parameter in the field and comparing it with model default values for soybean before replacing them. However, in very few parameters that were difficult or impossible to measure in the field, a trial and error method was also used to parameterize them. These parameters include soil water depletion fraction for stomatal control – upper threshold and coefficient describing negative impact of stomatal closure during yield formation on HI. The trial and error method was by iteration method of changing the model threshold values repeatedly until a value corresponding to when the model grain yield matched the measured grain yield in the field. A base temperature of 8^{o}C instead of a default value of 10^{o}C was used. This base temperature was adopted from previous studies for chickpea in the study area (Thangwana and Ogola, 2012). Upper temperature threshold for chickpea was changed from a default value of 35 ^{o}C to 32^{o}C. This change was following upper temperature threshold for chickpea reported by Devarsirvathum et al. (2012).

8.3.6 Model validation

The parameterised AquaCrop model was tested using field data recorded during 2015 winter season. This involved uploading the necessary climate data for the 2015 growing season without changing any other files and comparing the model simulations with field observations.

8.3.7 Model quality assessment

The model evaluation criteria involved comparing experimental data that was measured from the field with the model simulated results. Performance of AquaCrop model was assessed using linear regression analysis (R^2), the Root Mean Square Error (RMSE), and the Mean Square Regression Error (MAPE). The choice of this assessment criterion was adopted following earlier studies (Geerts et al*.,* 2009; Katerji et al*.,* 2013; Xiangxiang et al*.,* 2013; Antonio et al., 2013; Mhizha, et al., 2014). All the statistical tests were conducted using XLSTAT version 2016. 04.32310 Addinsoft USA. The model was considered to be excellent when the RMSE was less than 10, good when the RMSE was between 10 and 20, fairly acceptable when the RMSE was between 20 and 30, and poor when the value of RMSE was greater than 30 (Jamieson et al*.,* 1991; Katerji et al*.,* 2013).

8.4 Results and discussion

8.4.1 Weather conditions during the experimental period

In 2014, monthly maximum temperatures varied from 33.0 ^{o}C in October to 31.4 ^{o}C in September (Table 8.3). Monthly minimum temperatures ranged between 9.0 ^{o}C in June and 15.3 ^{o}C in October. Lowest mean monthly temperature, recorded in July, was 16.8 ^{o}C. Total cold units (CU) were calculated from hourly data and were highest (22 ^{o}C day^{-1}) in July. Average heat units (HU) per month was 268 ^{o}C day^{-1}. Highest HU was recorded in October (363.4 ^{o}C day^{-1}), whilst the lowest units were observed in July (190.7 ^{o}C day^{-1}). In 2015, the monthly maximum temperature range was between 33.8 ^{o}C, recorded in September, and 33.6 ^{o}C, recorded in October. The lowest minimum monthly temperature was 8.4 ^{o}C, recorded in June, whilst the highest minimum monthly temperature was 15.7 ^{o}C, recorded in October. Highest mean monthly temperature was 22.2 ^{o}C, recorded in September and October. Average heat units per month was 284.9 ^{o}C.days. Highest HU were recorded in October, whilst the lowest HU were recorded in June.

Table 8.3 Summary of meteorological conditions recorded during the trial period (May –October 2014 and 2015).

2014 Month	**T_{max} (ºC)**	**T_{min} (ºC)**	**T_{mean} (ºC)**	**CU (ºC day^{-1})**	**HU (ºC day^{-1})**	**Rn (mm)**	**VPD (KPa)**
May	27.0	11.6	19.3	0	287.7	0.02	2.23
June	26.2	9.0	17.6	14	223.3	0.00	2.24
July	24.7	9.1	16.8	22	195.7	0.03	1.91
August	28.0	10.0	17.7	2	293.5	0.02	2.31
September	31.4	13.6	21.5	0	365.4	0.37	2.54
October	33.0	15.3	22.5	0	383.8	0.83	2.25
Mean	**28.0**	**11.4**	**19.2**	**6.3**	**291.6**	**0.211**	**2.24**
2015 Month	**T_{max} (ºC)**	**T_{min} (ºC)**	**T_{mean} (ºC)**	**CU (ºC day^{-1})**	**HU (ºC day^{-1})**	**Rn (mm)**	**VPD (KPa)**
May	29.4	12.8	21.1	0	324.7	0.00	2.14
June	25.1	9.4	17.3	13	249.6	0.03	1.98
July	26.1	10.6	18.4	15	228.0	0.02	1.99
August	30.0	11.6	19.8	2	293.2	0.05	2.26
September	33.8	13.5	21.7	0	368.7	0.75	2.27
October	33.6	15.7	22.2	0	395.1	0.90	2.38
Mean	**29.7**	**12.3**	**20.1**	**5**	**309.9**	**0.29**	**2.17**

*T_{max} – daily maximum temperature, T_{min} is the daily minimum temperature, T_{mean} is the mean temperature, CU is the cold units, HU is the growing degree days, Rn if the rainfall and RH is the relative humidity. The total amount of water applied in 2014 was 430 mm in experiment I and 230 mm in experiment II, whilst 435 mm and 235 mm were applied in 2015, in Experiment 1 and II, respectively.*Temperature was presented as the mean temperature for the month; rainfall was presented as cumulative totals.

8.4.2 Parameterization of AquaCrop for chickpea

Canopy cover: During parameterization of canopy cover, the first stage was to determine the crop response to the environmental conditions and water balance in the root zone for AquaCrop model. This was performed through determining four water stress indices. Amongst the indices, three of them affected canopy cover and crop transpiration, whilst the other one had an impact on harvest index (HI). Data for field capacity (FC), available soil water content (SW) and total water content in the root zone (TAW) were extrapolated using graphs to represent daily data. Thus parameterisation of soil water depletion factor (P) was conducted on daily basis, following equation 8.8 below.

$$P = \frac{FC - SW}{TAW} \qquad (8.8)$$

P (which included P_{upper} and P_{lower}) is defined as, the ratio of actual to total available soil water (Raes et al., 2009). P_{upper} represents the upper threshold limit where no stress may affect the crop as long as water extraction does not exceed this threshold. Conversely, P_{lower} represents lower threshold, where depletion of soil water may increase water stress, though it will depend on crop characteristics such as sensitivity of the crop to water stress. Therefore, the calculated P thresholds were used as stress indices to parameterise the model. This enabled the model to simulate canopy cover. Canopy cover (CC) that expresses growth potential for chickpea crop was determined following equations 8.9 and 8.10, whilst canopy decline phase was determined following equation 8.11.

$$CC = CC_o \, . \, e^{CGC \, x \, t} \qquad (8.9)$$

$$CC = CC_x - [CC_x - CC_o] \, x \, e^{-CGCxt} \qquad (8.10)$$

$$CC = CC_o \, [1 - 0.05] \left[e^{\frac{CDC \, x \, t}{CCx}} - 1 \right] \qquad (8.11)$$

Where CC is canopy cover at time t, CC_o is the initial canopy cover at time t = 0, CGC is the canopy growth rate per day and CDC is canopy decline coefficient.

By adopting a trial and error approach, chickpea canopy development was better simulated when a value of 8.5% increase per day for CGC and a value of 6.5% for daily decline was used. Furthermore, calculations for leaf expansion in P_{upper}, P_{lower} and f_{shape}, respectively using equation 8.8 were 0.3, 0.65, 4.0. The soil depletion threshold for canopy senescence (upper threshold) was 0.87, 0.85 and 0.82, respectively for early, normal and late planting date. The f_{shape} had a value of 0.30, 0.70 and 0.4, was also calculated using equation 8.8.

After parameterisation of CC, evaluation of graph plots of the simulated CC were able to fit in well to plots of the field observed measurements of CC in all planting dates Fig 8.2(a-f). However, the model overestimated CC between the days from 42 DAE and 70 DAE and under estimated CC from 77 DAE until physiological maturity in early and normal planting dates. Similarly, the model overestimated CC between the days from 35 DAE and 63 DAE and under estimated CC from 70 DAE until physiological maturity in late sowing. Although the overestimation and under estimation of CC was observed in all planting dates at different periods of growth, these variations were not significant as shown by error bars. Moreover comparison of liner regression analysis (R^2) (0.948, 0.887, 0.942), Root mean square error (RMSE) (6.689, 7.619, 4.937), and MAPE (15.166, 12.449, 18.620) (Table 8.5) in early, normal and late planting, respectively showed excellent model performance in simulating CC.

Table 8.4 Statistical evaluation for model parameterisation

				Statistics		
Planting date	**Parameter**	**n**	**R^2**	**RMSE**	**MAPE**	**Pr > F**
Early Planting	CC	36	0.948	6.689	15.17	<0.0001
	Biomass	36	0.985	0.256	37.88	<0.0001
	ET_a	36	0.959	2.543	11.20	<0.0001
	SWC	36	0.946	0.350	0.505	<0.0001
	Yield	36	0.976	0.076	10.100	<0.0001
Normal Planting	CC	36	0.887	7.619	12.449	<0.0001
	Biomass	36	0.998	0.093	40.170	<0.0001
	ET_a	36	0.937	2.841	15.42	<0.0001
	SWC	36	0.893	0.401	0.63	<0.0001
	Yield	36	0.969	0.121	11.82	<0.0001
Late Planting	CC	36	0.942	4.937	18.62	<0.0001
	Biomass	36	0.965	0.235	15.41	<0.0001
	ET_a	36	0.952	2.73	13.95	<0.0001
	SWC	36	0.950	0.329	0.56	<0.0001
	Yield	36	0.992	0.052	7.642	<0.0001

Where n is the sample size, R^2 is the linear regression model, RMSE if the root mean square error, MAPE is the mean absolute percentage error, Pr > F is a probability of F statistic, CC is the canopy cover, ET is the evapotranspiration, and SWC is the soil moisture content.

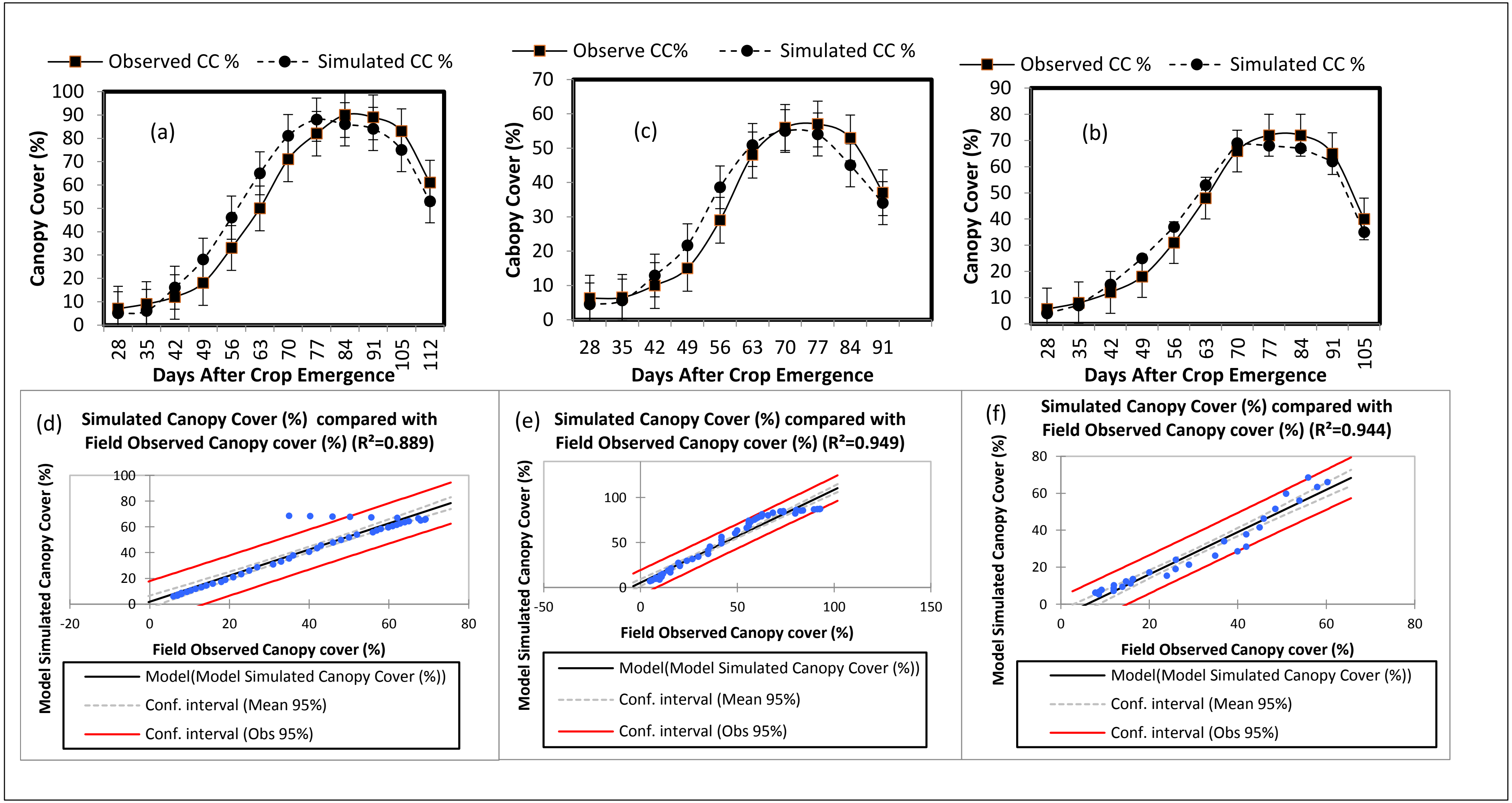


Figure 8.2 Comparison of model simulated and field observed canopy cover. a, b and c are graph plots of early, normal and late planting dates respectively, whilst d, e and f are regression of model simulated canopy cover verses field observed canopy cover for early, normal and late planting date respectively.

8.4.3 Soil water content

Water balance algorithim in AquaCrop is based on water storage capacity of the soil layers (Raes et al., 2011). These soil layers were described by Raes et al (1982), and (1986) in the BUDGET model and by Smith et al (1990) in CROPWAT model. Parameterisation of soil profile consisted of defining the total number of soil layers as 5 layers. The layers had an approximate soil thickness of 0.3m, PWP was 21.0%, FC was 33.3%, SAT was 50.0%, TAW was 121 mm/m, the shear soil properties (Tau) was 0.26 and a soil restrictive layer of 3 m was used for the study (Table 8.1). All these soil profile characteristics presented above were adopted from field calculations in the study area by Mzezewa and Rensburg, (2012). Qualitative reliability of this data was confirmed by comparing the data with reports from Soil Classification Working Group (1991) and Fey (2010).

Soil capillary was not measured in the study and therefore default values: a = -0.5686 and b = -1.831942 corresponding to red clay soil was adopted from the model. In addition all stress thresholds in AquaCrop that have been parameterised above have a direct function on soil water.

After parameterisation, evaluation of graph plots of the simulated SWC were able to match with the graph plots of the field observed measurements of SWC in all planting dates Fig 8.3(a-c), However, the model overestimated SWC between the days from 42 DAE and 70 DAE but estimated SWC well from 77 DAE until physiological maturity in early and normal planting dates. Similarly, the model overestimated SWC during the days from 35 DAE to 63 DAE and under estimated SWC from 70 DAE until physiological maturity in late planting date. Although there was overestimation and under estimation of SWC as shown in Fig 8.3(a-c) at different periods of growth, these variations were not significant as shown by error bars. Moreover comparison of regression analysis (R^2) (0.948, 0.887, 0.942), Root mean square error (RMSE) (6.689, 7.619, 4.937), and mean absolute percentage error (MAPE) (15.166, 12.449, 18.620) (Table 8.4) in early, normal and late planting, respectively showed excellent model performance in simulating SWC.

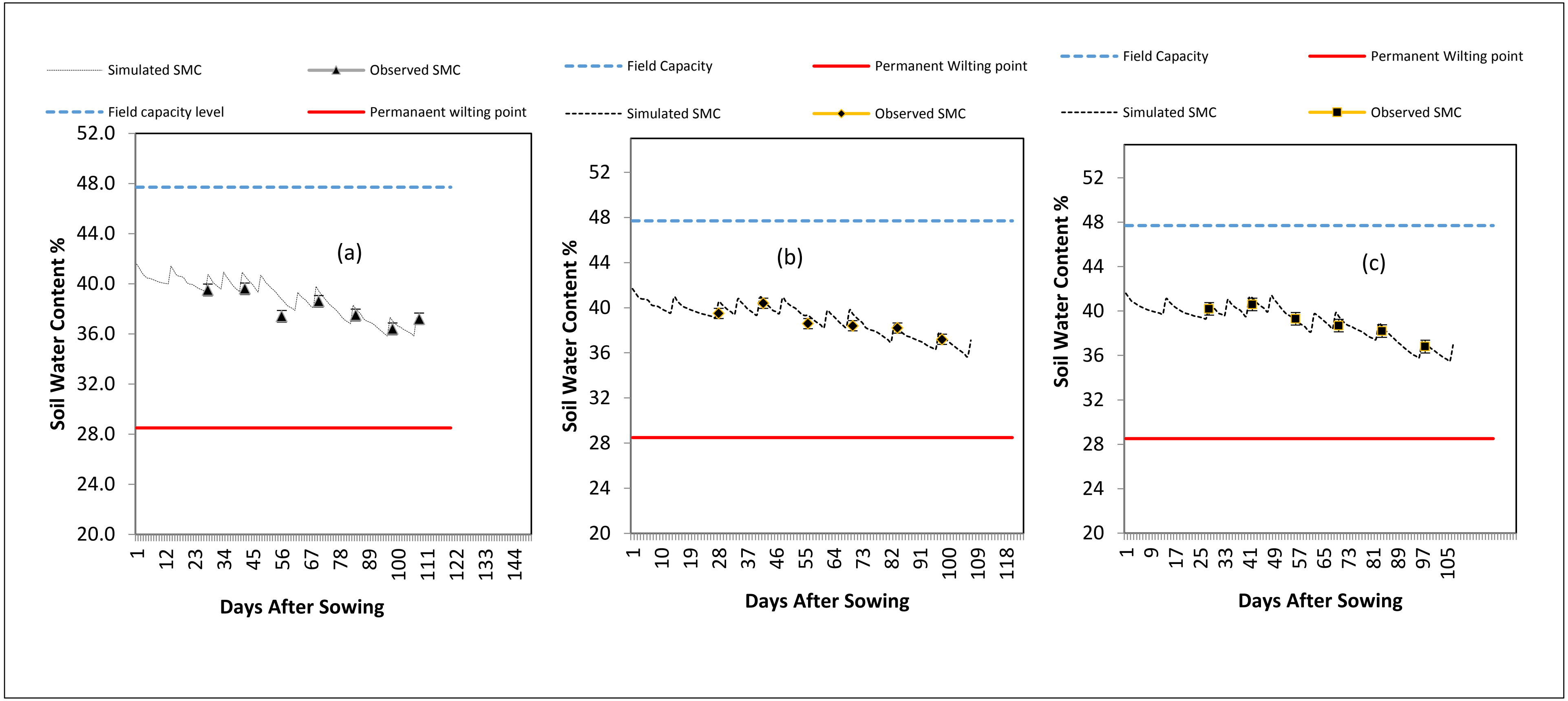


Figure 8.3 Comparison of model simulated and field observed Soil Moisture Content. a, b and c are graph plots of early, normal and late planting dates, respectively.

8.4.4 Evapotranspiration, water productivity and biomass

AquaCrop model is water driven (Steduto et al., 2009). Thus, accurate prediction of water that is lost by evapotranspiration is important for model biomass prediction. AquaCrop simulate biomass directly using the parameterised water productivity function (WP*) that is normalised for climate and place by ETo and carbon dioxide (Steduto et al., 2009). Equation 8.7 was used to determine WP*. Moreover, since chickpea is rich in proteins, WP* was multiplied by an adjustment factor of 0.2 and a WP* value of 7 kg ha^{-1} mm^{-1} was obtained for the study. Furthermore, parameterisation for ET_a and biomass depended on the determination of threshold P_{upper} and P_{lower} for stomatal closure. Because of unavailability of equipment to measure stomatal closure, a trial and error (Iteration method) was conducted until a suitable P_{upper} for stomatal closure of 0.55 and an f_{shape} of 0.4 was determined for ET_a prediction.

After parameterisation, evaluation of graph plots of the model simulated WP and B were able to match with the graph plots of the field observed measurements of WP and B in all planting dates Fig 8.4(a-c). However, the model overestimated B between the days from 42 DAE and 70 DAE and under estimated B from 77 DAE until physiological maturity in early and normal planting dates. Similarly, the model overestimated B between the days from 35 DAE to 63 DAE and under estimated B from 70 DAE until physiological maturity in late planting date. Although the overestimation and under estimation of B was observed at different periods of growth, these variations were not significant as shown by error bars. Moreover comparison of regression analysis (R^2) (0.948, 0.887, 0.942), Root mean square error (RMSE) (6.689, 7.619, 4.937), and MAPE (15.166, 12.449, 18.620) (Table 8.5) in early, normal and late planting, respectively showed excellent model performance in simulating B. Furthermore, the simulated ET_a, compared well with the measured ET_a in both experiments although the model ET_a was slightly higher than the field measurements. The greater model ET_a could possibly have been due the estimation of P_{upper} for stomatal closure. ET_a is strongly affected by P_{upper} for stomatal closure. Thus accurate calculation of of P_{upper} for stomatal closure will improve ET_a simulation.

Table 8.5 Comparison of model simulated versus measured ET

Experiment	Measured ET_a	Simulated ET_a	Measured WP	Simulated WP.
I	682	686	9.4	7.0
II	475	484	8.6	6.7

ET_a is Evapotranspiration, WP* is normalised water productivity function.

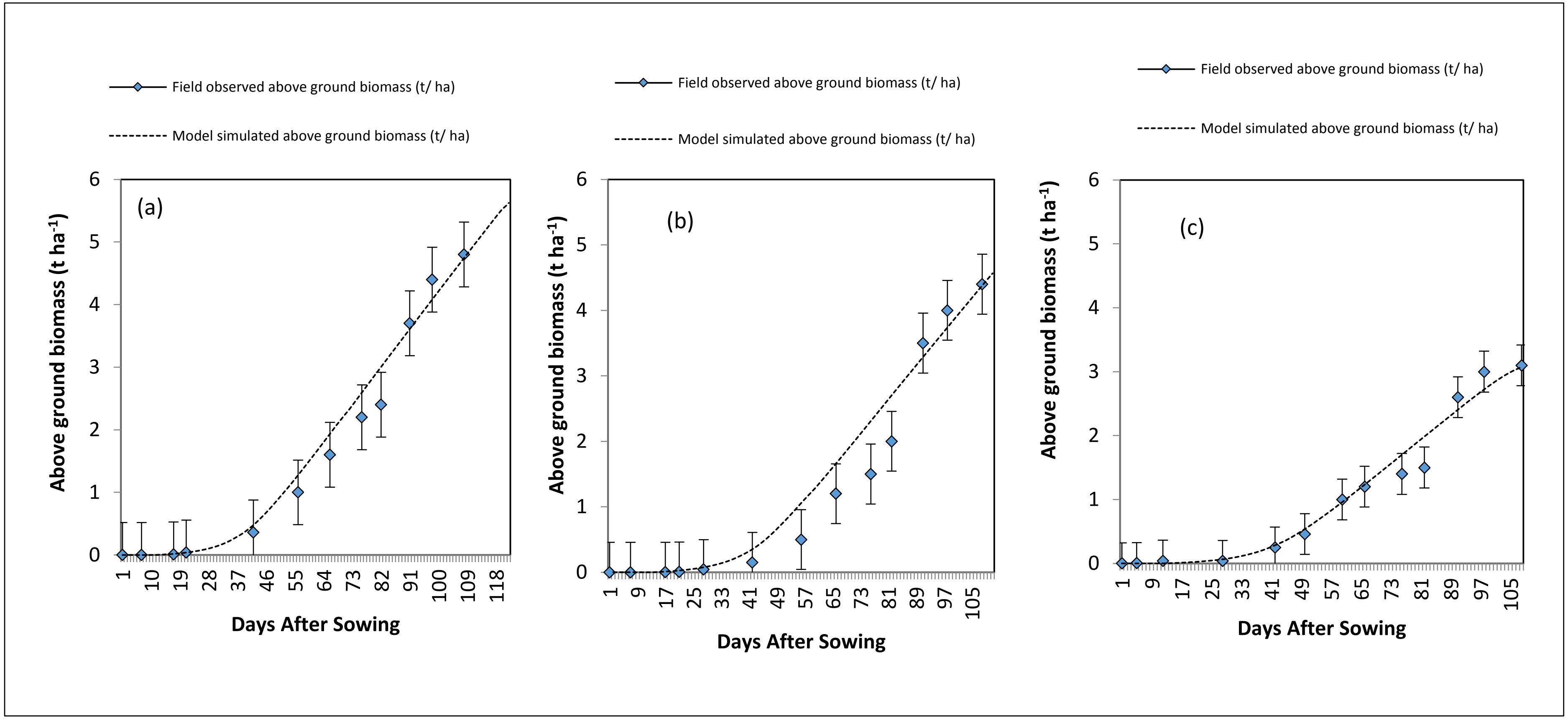


Figure 8.4 Comparison of model simulated and field observed above ground biomass. a, b and c are graph plots for early, normal and late planting date, respectively.

8.4.5 Grain yield

AquaCrop simulate grain yield as a function of biomass and the harvest index. Biomass, simulated according to equation 8.1 is partitioned into grain yield (Y) with the help of harvest index (HI). HI is constantly adjusted during yield formation (Raes et al., 2011) and is affected by water stress during various stages of crop development. Thus accurate prediction of yield in AquaCrop is based on good parameterisation of the effect of water stress on HI at different stages of growth such as before flowering, during flowering and physiological maturity. The effects of water stress on HI before flowering was calculated as a percentage decrease / increase in HI as a function of total biomass measured at peak vegetative stage. Similarly, the effect of water stress on HI during flowering was estimated as a percentage decrease/increase in HI as a function of total flowers aborted between well-watered and water stressed crop. However because of difficulty in measuring Ks for stomatal closure, a default class of moderately tolerant to water stress corresponding to soil water depletion fraction (P) for failure of pollination of 0.88 and a range of 0.87-0.90 was used for the study. Likewise, a positive stress effect on HI was 2 and in the range of 1.5 - 2.9, whilst a negative stress effect on HI was 5 and in the range of between 4.1 and 7.0. The excess of potential fruits suffered due to water stress was calculated as the differences in pod abortion percentages between well-watered and water stressed crop. A class corresponding to this pod abortion variation between the two water regimes was selected from the model default values. Thus, excess of potential fruits was small (above 50).

After combining various effects of water stress on HI, HI was further adjusted by iterative method so that it matches field calculated HI at physiological maturity. This involved adjusting the maximum possible increase of HI. The extent of reduction in HI caused by extreme temperature or severe water stress during pollination time was calculated as the differences in flower abortion between well-watered and moisture stressed experiment. A class corresponding to this flower abortion variation between the two water regimes, selected from the model default values was small and in excess of 50. In general, the model was able to predict crop yield for all planting dates. The regression plot of simulated and observed yield showed a good relationship with R^2 values of 0.949, 0.928 and 0.990 for early, normal and late planting dates, whilst the RMSE was 0.135, 0.143 and 0.031 for early, normal and late planting dates (Fig 8.5 and Table 8.5). This low RMSE clearly show that the model error in predicting yield was low and gives confidence of a reliable simulation results.

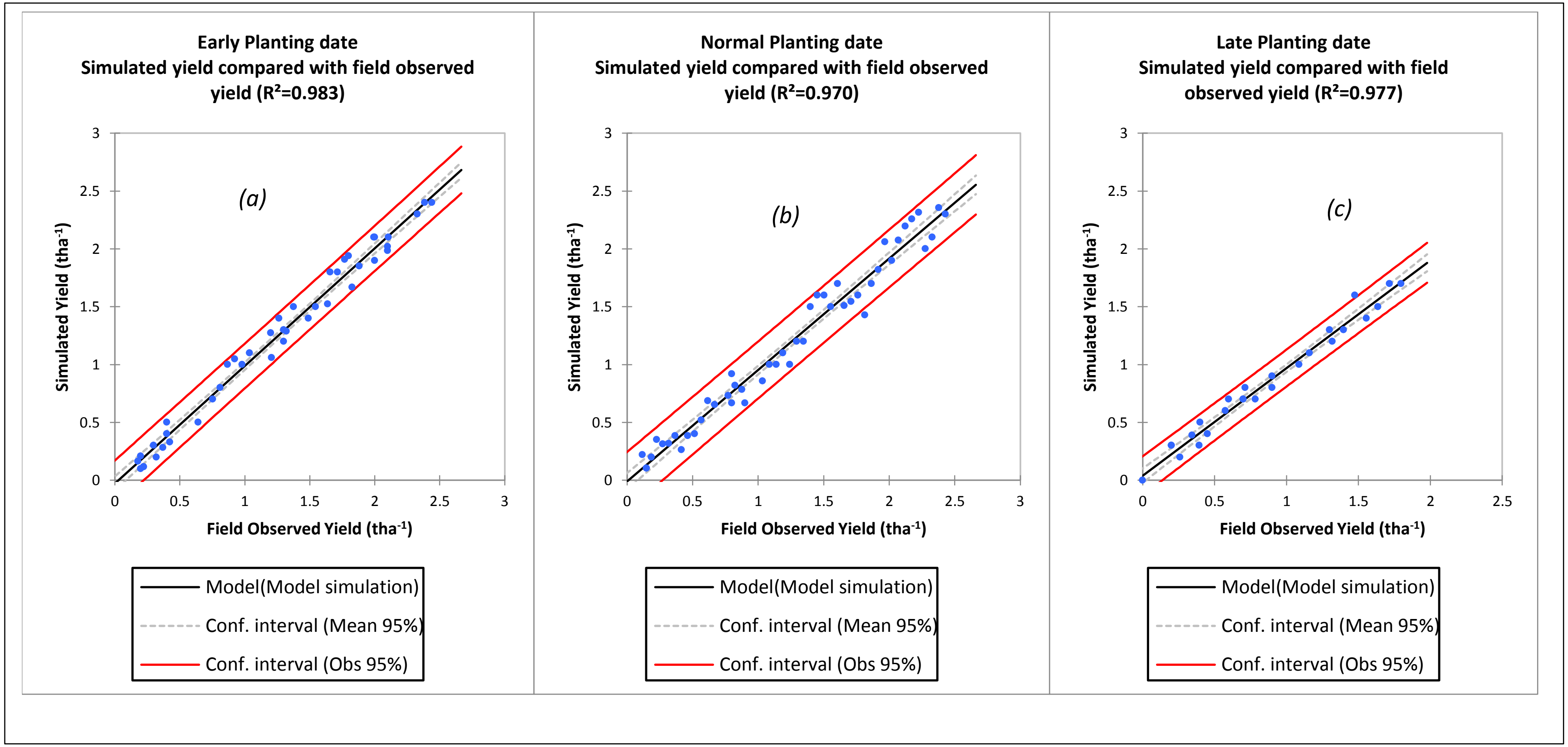


Figure 8.5 Comparison of model simulated and field observed yield. a, b and c are regression model of simulated yield verses field observed yield for early, normal and late planting date, respectively.

8.4.6 A summary comparing default model conservative parameters values and the new parameterised values

A summary comparing default model conservative parameters values and the new parameterised values is shown in Table 8.6. Since there were no old parameters for chickpea, the study adopted default values for soybeans. The choice of soybeans is mainly because it comes from the same family group with chickpea. These crops have similar physiology and yield development system though they vary in their telerence to water stress. However the biggest challenge is that chickpea was calibrated for winter planting whilst soybean is a summer crop. Using default values of soybean which varies from chickpea on water stress may compromise the results but soybean was chosen because it was the only crop that is parameterised in AquaCrop model which is closer to chickpea in terms of growth and development characteristics. Data that was used for parameterisation was not used for testing the model.

Table 8.6 Conservative and non-conservative parameters for chickpea in University of Venda.

	University of Venda Planting Date EP	NP	LP	Model Default values (soybeans)
A. Conservative crop parameters				
Base temperature	8	8	8	10
Upper temperature	32	32	32	40
Crop coefficient when canopy is complete but prior to senescence	2.8	2.8	2.8	3.0
Water productivity normalized for ETo and CO2 (gram m^{-2})	16	16	16	17
Possible increase (%) of HI due to water stress before flowering Growth during yield formation on HI	0	0	0	0
Coefficient describing negative impact of stomatal closure during Yield formation on HI	0.42	0.42	0.42	0.42
Allowable maximum increase (%) of specified HI	12	12	12	10
Soil water depletion factor for canopy expansion – Upper threshold	0.3	0.3	0.3	0.25
Soil water depletion factor for canopy expansion – Lower threshold	0.65	0.65	0.65	0.60
Soil water depletion fraction for stomatal control – Upper threshold	0.5	0.5	0.5	0.5
Soil water depletion factor for canopy senescence – Upper threshold	0.85	0.85	0.85	0.85
Minimum growing degrees required for full biomass production (°C-day)	1354	1354	1354	1295
Heat stress temperature for pollination (°C)	32	32	32	40
Cold stress temperature for pollination (°C)	8	8	8	10
B. Non-conservative parameters				
Plant density (no. of plants per hectare)	333333	333333	333333	-
Emergence (days after sowing)	12	13	13	-
Senescence (days after sowing)	116	112	105	-
Maturity (days after sowing)	133	125	114	-
Maximum canopy cover (%)	93	70	64	-
Flowering (days after sowing)	56	50	42	-
Maximum effective rooting depth (m)	2	1.5	1.5	-
Reference harvest index (%)	55	47	36	-

*EP is early planting date, NP is normal planting date and LP is late planting date.

8.4.7 Validation of the model

Validation of the model was done using field independent data observed during 2015 winter season. Graphical plotting of the simulated and observed parameters showed that AquaCrop model was able to predict CC, Biomass and SWC and yield and showed a strong correlation between observed and simulated parameters in all planting dates (Fig 8.4, 8.5, 8.6 and Table 8.6).

The model was able to predict crop yield for all planting dates. The regression plot of simulated and observed yield showed a good relationship with R^2 values of 0.949, 0.928 and 0.990 for early, normal and late planting dates, whilst the RMSE was 0.135, 0.143 and 0.031 for early, normal and late planting dates (Table 8.6). This low RMSE clearly show that the model error in predicting yield was low and gives confidence of reliable simulation results.

The simulated ET_a, compared well with the measured ET_a in both experiments (Table 8.7 and 8.8), although the model ET_a was slightly higher than the field measurements. Despite the slight over-estimation, the results are consistent with earlier reports by Katerj et al. (2013) who reported that AquaCrop is less accurate in predicting Eta under water stressed crop.

Furthermore, SWC was simulated well in all planting dates. A good match between the observed and simulated SWC was observed during the first 42 DAE and from 70 DAE until physiological maturity stage in early and normal planting date. The late planting date had a good match between the simulated and observed SWC during the first 35 DAE and from 63 DAE until physiological maturity. The model struggled to simulate SWC during 42-70 DAE in early and normal planting and 35-63 DAE in late planting date. This period coincided with peak reproduction stages in all planting dates and may have resulted in peak water demand which was not well simulated by the model. During that same period SWC was observed to fall and almost approached PWP, suggesting that the model may have problems in simulating SWC under water limiting conditions. The over-estimation of SWC observed in all planting dates during the peak reproduction stage may have been responsible for the overestimation of CC. AquaCrop model is water driven (Steduto et al., 2009), thus an overestimation in SWC may result in overestimation in CC and all other crop physiological parameters that are water driven. In addition, the model also overestimated biomass during the same period, indicating that the problems experienced by the model in simulating SWC may also have affected simulating of biomass during the same period. Indeed, biomass is calculated as a function of water productivity and transpiration in AquaCrop (Steduto et al., 2009; Raes et al., 2009). Therefore overestimation in SWC may have resulted in overestimation of CC and biomass during the peak reproduction stage. However, a comparison of liner regression analysis (R^2) (0.982, 0.949, 0.954), Root mean square error (RMSE) (0.226, 0.696, 0.310), and MAPE (0.466, 1.364, 0.665) (Table 8.6) in early, normal and late planting, respectively showed a good model performance in simulating SWC in all planting dates. The match between observed and simulated SWC may indicate good model performance in simulating soil water fluxes in the root zone and also evaporation and transpiration of the crop.

In general, AquaCrop simulated above ground biomass well. The simulated above ground biomass development followed the normal growth curve and a graphical plotting of simulated and observed biomass fitted well (fig 8.5). However, the model was less accurate in predicting above ground biomass during the period from 37 DAE until 91 DAE in early planting and from 21 DAE to 71 DAE in late planting, whilst normal planting date had the best model prediction. Significant variations between the model simulated and field observed above ground biomass was observed during the period from 56-63 DAE in early planting and from 49 -60 DAE in late planting date, whilst no significant differences between simulated and observed was observed in normal planting. Field visual inspection of the late planted crop during first 30 DAE showed that the crop was less tolerant to low temperatures and experienced poor early growth during the coldest month of June. Whilst temperature is well taken care of in AquaCrop (Steduto, et al., 2009), this problem may have caused variations between the observed and simulated biomass during early growth stages in late planting date. Above ground biomass in all planting dates was similar during the first 21 DAE, possibly because of the way AquaCrop calculate initial CC during early stages of growth. Initial CC calculated as a function of plant density and mean canopy size per seedling (Steduto, et al., 2009). However, the slight variation in CC though not significant observed amongst planting date during the early stages of growth may have been possibly due to differences in rate of mobilisation of seed reserves and partially heterogeneity of germination (Steduto et al., 2009). Despite the significant variations between simulated and observed above ground biomass in early and late planting, a comparison of liner regression analysis (R^2) (0.893, 0.995, 0.982), Root mean square error (RMSE) (0.736, 0.130, 0.236), and MAPE (38.604, 26.675, 38.311) (Table 8.6) in early, normal and late planting, respectively showed a good model performance in simulating above ground biomass in all planting dates. The results of this study, regardless of different crops used, are comparable to earlier studies in Quinoa (Geerts et al, 2009), winter wheat (Xiangxiang et al., 2013), in corn (Katerji et al., (2013). The good quality of the model simulation results in canopy cover implies that AquaCrop model was able to pick out any significant differences for canopy cover that were caused by variation in planting date. Therefore the model may also simulate canopy cover variations fairly well if the model is used to investigate scenario assessment of the effect of climate change on planting dates of chickpea in the same area of study.

Table 8.7 Comparison of model simulated versus measured ET

Experiment	Measured ET_a	Simulated ET_a	Measured WP*	Simulated WP*.
I	694	705	9.5	7.2
II	468	498	10.4	8.3

ET_a is Evapotranspiration, WP* is normalised water productivity function

Table 8.8 Statistical evaluation for model validation

			Statistics			
Planting date	**Parameter**	**n**	**Adjusted R^2**	**RMSE**	**MAPE**	**P (F-ratio)**
Early Planting	CC	36	0.979	3.948	8.59	< 0.0001
	Biomass	36	0.893	0.736	38.60	< 0.0001
	ET_a	36	0.951	3.670	17.84	<0.0001
	SWC	36	0.982	0.226	0.47	< 0.0001
	Yield	36	0.949	0.135	16.62	< 0.0001
Normal Planting	CC	36	0.986	2.514	7.49	< 0.0001
	Biomass	36	0.995	0.130	26.68	< 0.0001
	ET_a	36	0.968	4.920	15.47	< 0.0001
	SWC	36	0.949	0.696	1.36	< 0.0001
	Yield	36	0.928	0.143	21.12	< 0.0001
Late Planting	CC	36	0.978	2.948	9.03	< 0.0001
	Biomass	36	0.982	0.236	38.31	< 0.0001
	ET_a	36	0.943	5.230	20.33	< 0.0001
	SWC	36	0.954	0.310	0.67	< 0.0001
	Yield	36	0.990	0.031	6.01	< 0.0001

Where n is the sample size, R^2 is the linear regression model, RMSE if the root mean square error, MAPE is the mean absolute percentage error, Pr > F is a probability of F statistic, CC is the canopy cover, ET is the evapotranspiration, and SWC is the soil moisture content.

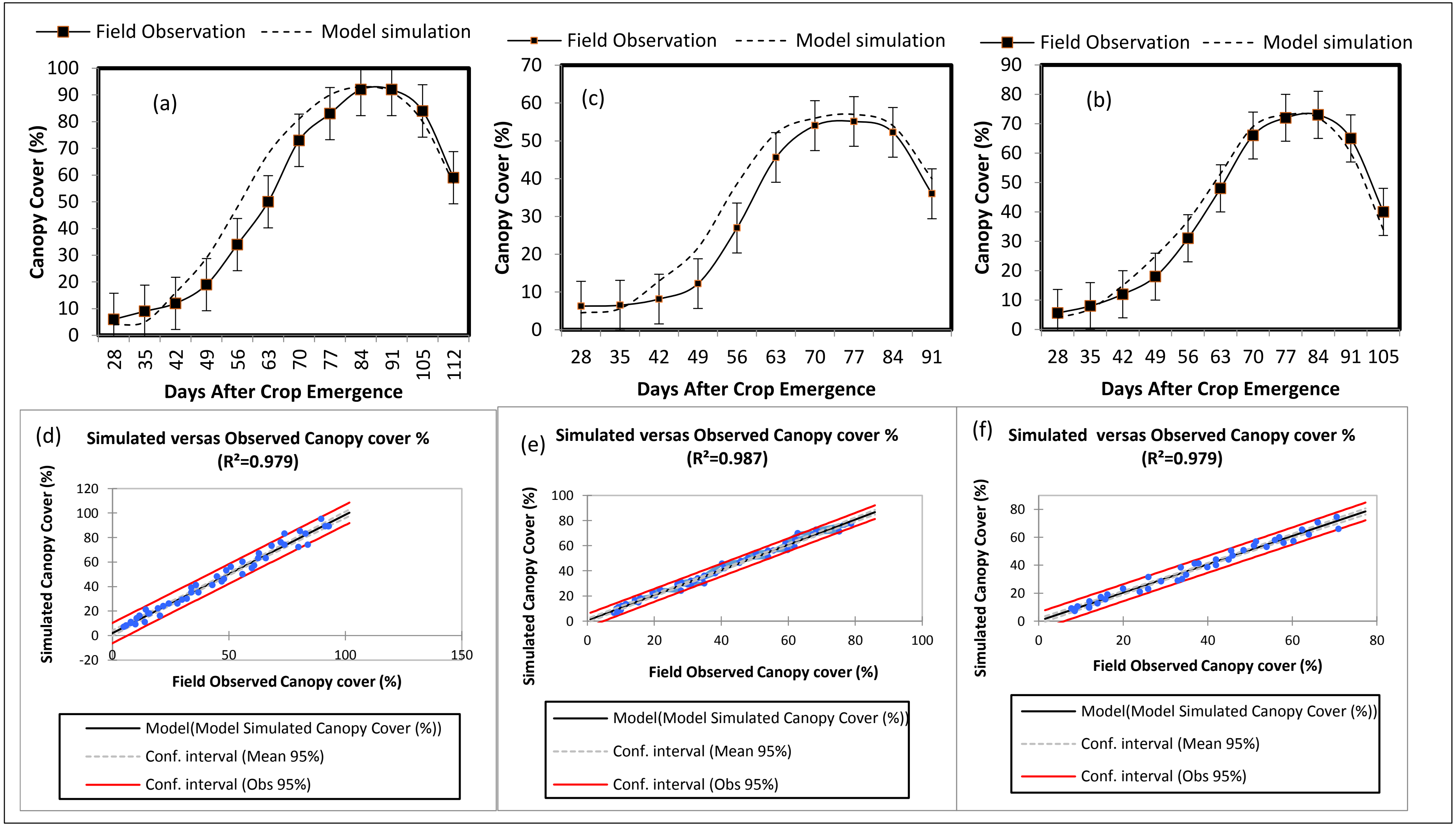


Figure 8.6 Comparison of model simulated and field observed canopy cover. a, b and c are graph plots of early, normal and late planting dates respectively, whilst d, e and f are regression model for canopy cover in early, normal and late planting date, respectively.

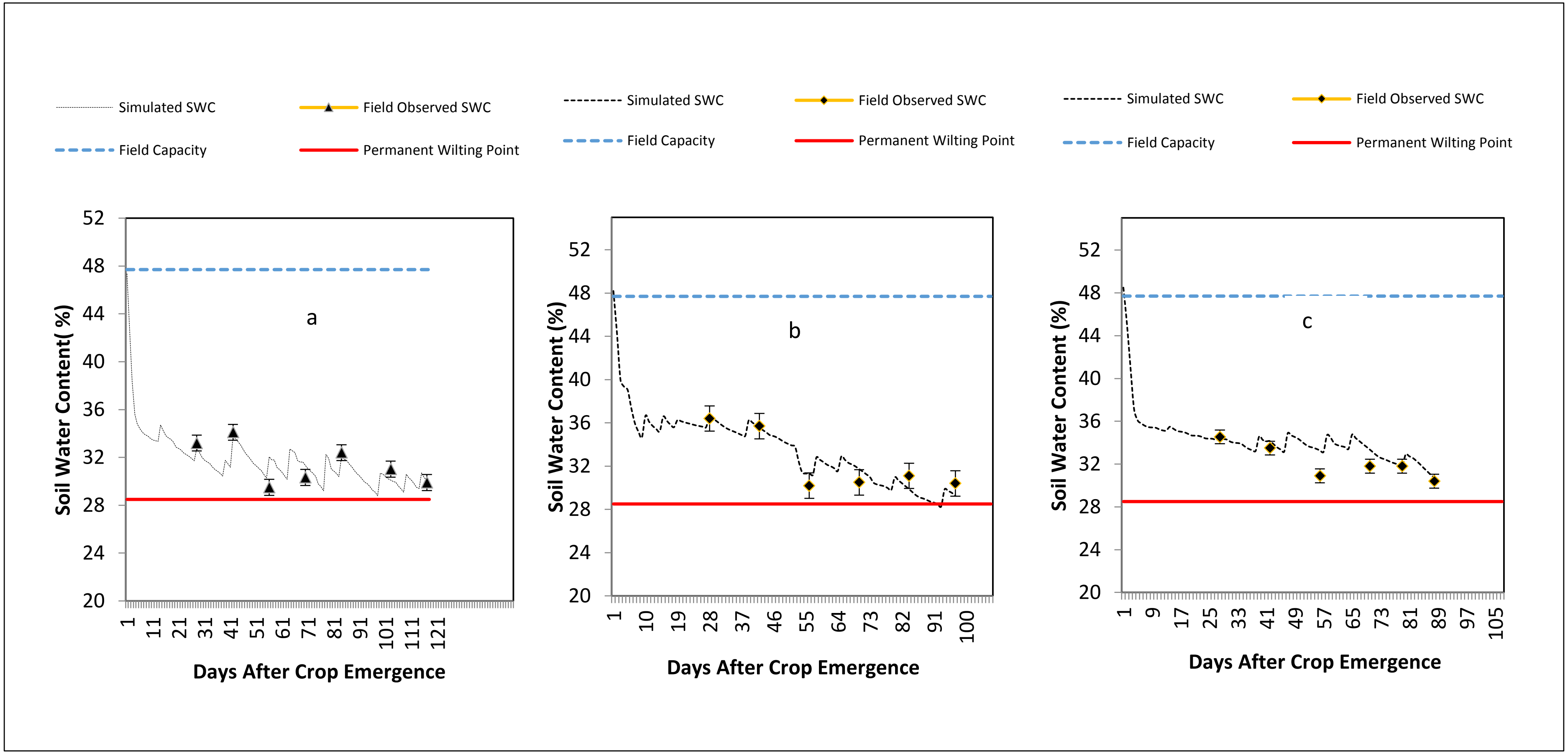


Figure 8.7 Comparison of model simulated and field observed Soil Water Content. a, b and c are graph plots of early, normal and late planting dates respectively.

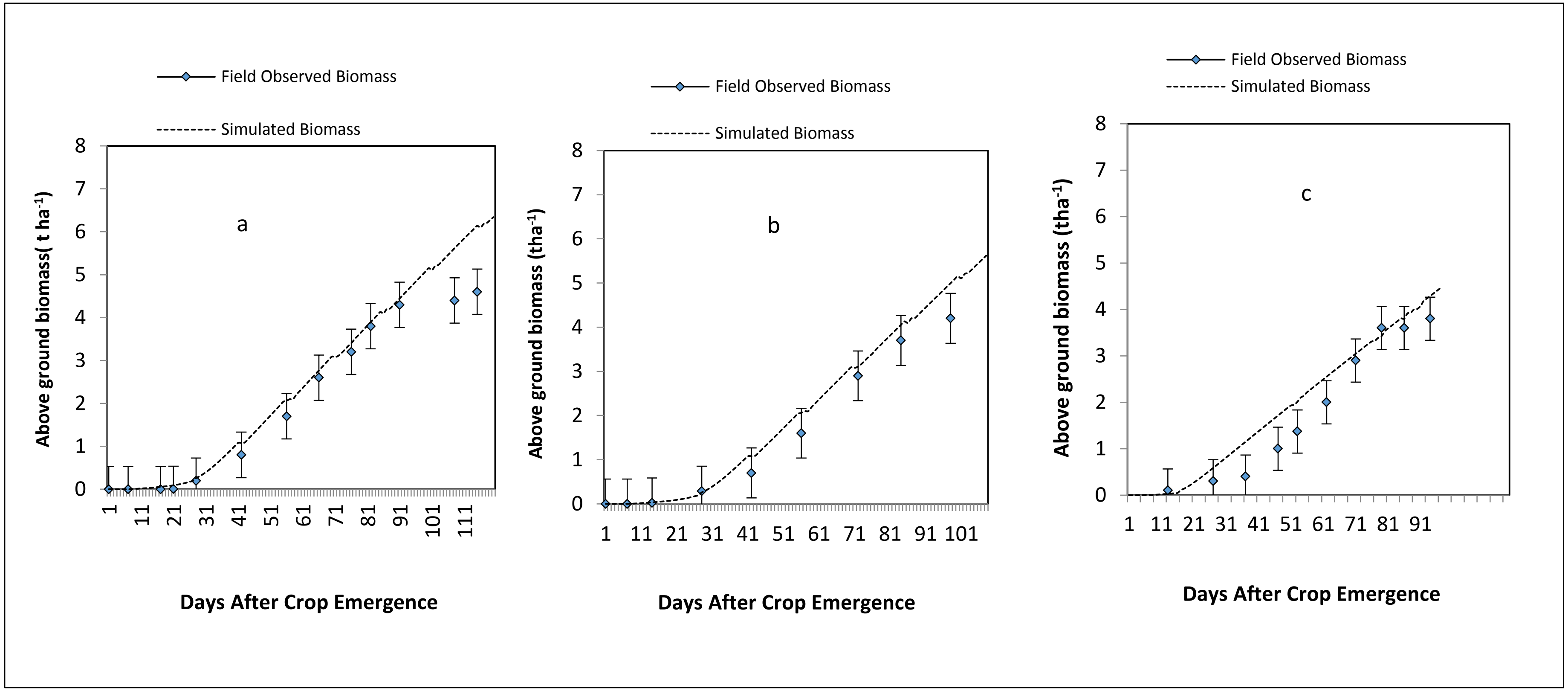


Figure 8.8 Comparison of model simulated and field observed aboveground biomass: a, b and c are graph plots of early, normal and late planting dates respectively.

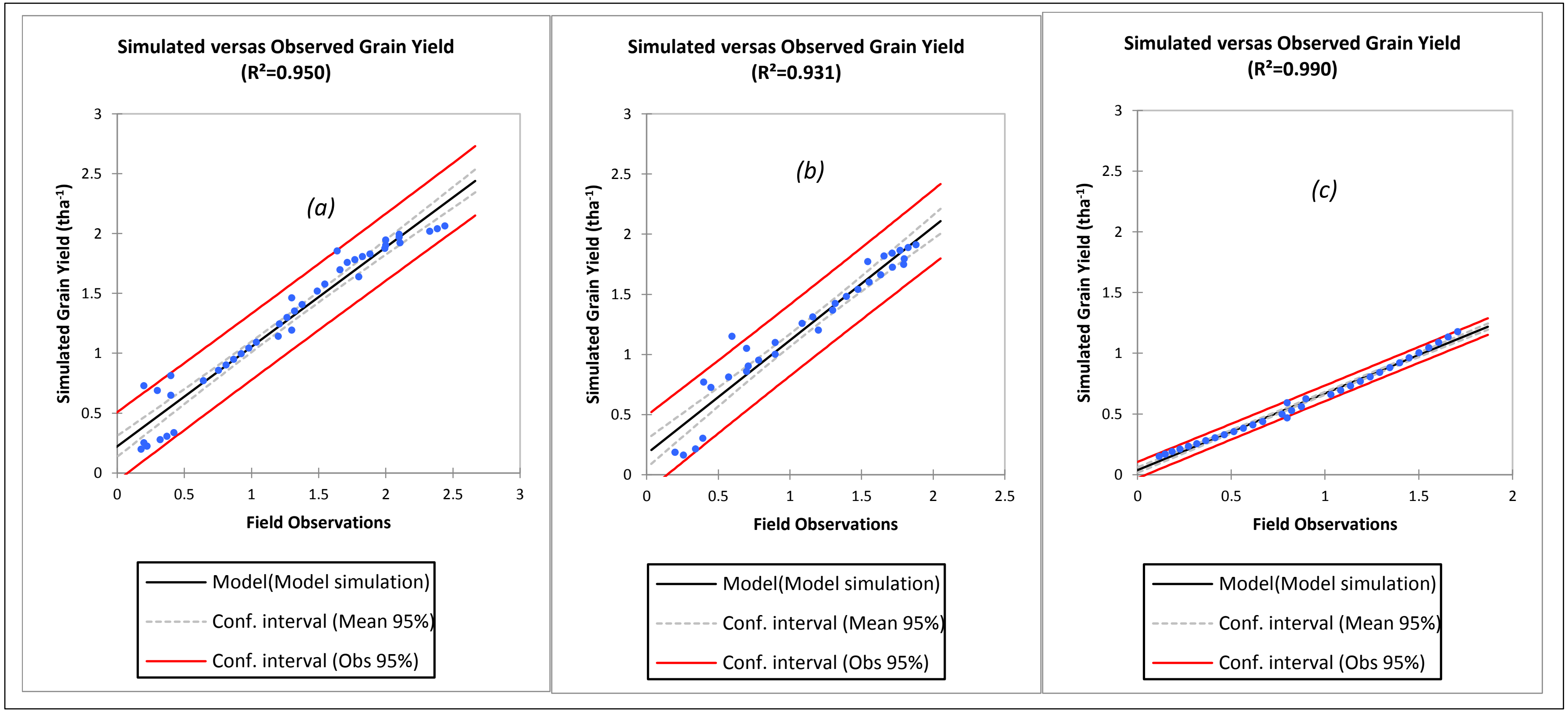


Figure 8.9 Comparison of model simulated and field observed yield. Graphs a, b and c are for early, normal and late planting date, respectively**.**

8.5 Conclusion

AquaCrop was well calibrated and validated for simulating attainable yields in chickpea crop grown under different planting dates, in a representative site of the dry environments of North Eastern South Africa. All the statistical indicators used to compare field observed and model predicted parameters showed good model performance. The model predicted CC, SWC, and B and yield fairly well and picked out differences attributed to planting date in North Eastern South Africa. The validated model can be used for evaluating the effects of different planting dates on yield.

References

Allen, R.G., Periera, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirement. FAO Irrigation and Drainage Paper No. 56. FAO, Rome

Antonino, S., Deidda, R., Marrocu, M., Paniconi, C., Ludwig, R., Sodde, M., Mascaro, G., Perra, E. 2013. Climate variability and Durum Wheat adaptation using the AquaCrop Model in Southern Sardinia. Precedia Environmental Sciences. 19: 830-835.

Araya, A., Habtu, S., Hadgu, K.M., Kebede, A. and Dejene, T., 2010. Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (Hordeum vulgare). *Agricultural Water Management*, *97*(11), pp.1838-1846.

Bahl, P.N., Singh, K.P. and Singh, D., 1984. Evaluation of tall chickpea genotypes for normal and late sowings. *Indian Journal of Agricultural Sciences*.

de la Casa, A., Ovando, G., Bressanini, L. and Martínez, J., 2013. Aquacrop model calibration in potato and its use to estimate yield variability under field conditions. *Atmospheric and Climate Sciences*, *3*(03), p.397.

Devasirvatham, V., Tan, D.K.Y., Gaur, P.M., Raju, T.N. and Trethowan, R.M., 2012, October. Effects of high temperature at different developmental stages on the yield of chickpea. In *Capturing opportunities and overcoming obstacles in Australian agronomy. Proceedings of the 16th ASA conference, Armidale, Australia* (pp. 14-18).

de Wit, C.D., Brouwer, R. and De Vries, F.P., 1970. The simulation of photosynthetic systems. In *Proceedings of the IBP/PP technical meeting, Trebon, 14-21 September 1969*(pp. 47-70).

Dixit, J.P., Pillai, P.V.A. and Namdeo, K.N., 1993. Response of chickpea (Cicer arietinum) to planting date and irrigation schedule. *Indian Journal of Agronomy*, *38*, pp.121-121.

FAO Statistics. 2013. Food and Agriculture Organization of the United Nations. Rome, Italy, January 2013

FAO. 1992. CROPWAT: A Computer Program for Irrigation Planning and Management. FAO, Rome.

Farahani, H.J., Izzi, G. and Oweis, T.Y., 2009. Parameterization and Evaluation of the AquaCrop Model for Full and Deficit Irrigated Cotton All rights reserved. No part of this periodical may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. *Agronomy journal*, *101*(3), pp.469-476.

Ferreira, T.C., 1996. *Factors affecting the responses of potatoes to irrigation in the hot, dry climate of NE Portugal*(Doctoral dissertation, Ph. D. thesis, Cranfield University).

Fey, M., 2010. *Soils of South Africa*. Cambridge University Press.

Fiwa, L., 2015. Improving rainfed cereal production and water productivity in Malawi: Modelling field management options in response to current and future climatic conditions.

García-Vila, M. and Fereres, E., 2012. Combining the simulation crop model AquaCrop with an economic model for the optimization of irrigation management at farm level. *European Journal of Agronomy*, *36*(1), pp.21-31.

Gaur, P.M., Tripathi, S., Gowda, C.L., Ranga Rao, G.V., Sharma, H.C., Pande, S. and Sharma, M., 2010. Chickpea seed production manual.

Geerts, S., Raes, D., Garcia, M., Miranda, R., Cusicanqui, J.A., Taboada, C., Mendoza, J., Huanca, R., Mamani, A., Condori, O. and Mamani, J., 2009. Simulating yield response of quinoa to water availability with AquaCrop. *Agronomy Journal*, *101*(3), pp.499-508.

Hsiao, T.C., Heng, L., Steduto, P., Rojas-Lara, B., Raes, D. and Fereres, E., 2009. AquaCrop—the FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. *Agronomy Journal*, *101*(3), pp.448-459.

Hussain, A., Nawaz, M. and Chaudhry, F.M., 1998. Radiation interception and utilization by chickpea (Cicer arietinum L.) at different sowing dates and plant populations. *Journal of Agricultural and Marine Sciences [JAMS]*, *3*(2), pp.21-25.

Jamieson, P.D., Porter, J.R. and Wilson, D.R., 1991. A test of the computer simulation model ARCWHEAT1 on wheat crops grown in New Zealand. *Field crops research*, *27*(4), pp.337-350.

Jin, X.L., Feng, H.K., Zhu, X.K., Li, Z.H., Song, S.N., Song, X.Y., Yang, G.J., Xu, X.G. and Guo, W.S., 2014. Assessment of the AquaCrop model for use in simulation of irrigated winter wheat canopy cover, biomass, and grain yield in the North China Plain. *PloS one*, *9*(1), p.e86938.

Jones, C.A., Kiniry, J.R. and Dyke, P.T., 1986. *CERES-Maize: A simulation model of maize growth and development*. Texas A& M University Press.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T., 2003. The DSSAT cropping system model. *European journal of agronomy*, *18*(3-4), pp.235-265.

Kabir, A.F., Bari, M.N., Karim, M.A., Khaliq, Q.A. and Ahmed, J.U., 2009. Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed condition. *Bangladesh Journal of Agricultural Research*, *34*(2), pp.335-342.

Katerji, N., Campi, P. and Mastrorilli, M., 2013. Productivity, evapotranspiration, and water use efficiency of corn and tomato crops simulated by AquaCrop under contrasting water stress conditions in the Mediterranean region. *Agricultural Water Management*, *130*, pp.14-26.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N., Meinke, H., Hochman, Z. and McLean, G., 2003. An overview of APSIM, a model designed for farming systems simulation. *European journal of agronomy*, *18*(3-4), pp.267-288.

Koocheki, A., Nassiri, M., Soltani, A., Sharifi, H. and Ghorbani, R., 2006. Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran. *Climate Research*, *30*(3), pp.247-253.

Mathews, C, Ogola, JBO, Vilane, M & Gaur, PM 2011. Optimum planting date for chickpea in one dry region of South Africa', 'Book of Abstracts of the 10th African Crop Science Society Conference, African Crop Science Society, Maputo, Mozambique, pp. 67

Mhizha, T., Geerts, S., Vanuytrecht, E., Raes, D. and Makarau, A., 2014. Use of the FAO AquaCrop model in developing sowing guidelines for rainfed maize in Zimbabwe. *Water SA*, *40*(2), pp.233-244.

Ogola, J.B., Madzivhandila, T. and Odhiambo, J.J., 2013. Water use of chickpea (Cicer arietinum L.): Response to genotype and phosphorus fertilizer rates in winter and summer sowings. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.1341-1347.

Ogola, J.B.O. and Thangwana, N., 2013. Water use efficiency of summer sown chickpea in a tropical environment: Response to genotype and planting density. *Journal of Food, Agriculture & Environment*, *11*(3&4), pp.2689-2695.

Raes, D., Steduto, P., Hsiao, T.C. and Fereres, E., 2009. AquaCrop–The FAO crop model to simulate yield response to water. *FAO Land and Water Division, FAO, Rome*.

Raes, D., 1982. A summary simulation model of the water budget of a cropped soil (budget). *Dissertationes de Agricultura (Belgium). no. 122.*

Raes, D., Geerts, S., Kipkorir, E., Wellens, J. and Sahli, A., 2006. Simulation of yield decline as a result of water stress with a robust soil water balance model. *Agricultural water management*, *81*(3), pp.335-357.

Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E. 2011. FAO crop water productivity model to simulate yield response to water: Reference manual Chapter 1 version 3.1 plus.

Rinaldi, M., Garofalo, P., Rubino, P. and Steduto, P., 2011. Processing tomatoes under different irrigation regimes in Southern Italy: agronomic and economic assessments in a simulation case study. *J Agrometeorol*, *3*(3), pp.39-56.

Shrestha, N., Raes, D. and Sah, S.K., 2013. Strategies to improve cereal production in the Terai region (Nepal) during dry season: simulations with aquacrop. *Procedia Environmental Sciences*, *19*, pp.767-775.

Smith, M. 1990. CROPWAT—A computer program for irrigation planning and management. FAO Irrigation and Drainage Paper No. 46. FAO, Rome.

Singh, P., Nedumaran, S., Boote, K.J., Gaur, P.M., Srinivas, K. and Bantilan, M.C.S., 2014. Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European journal of agronomy*, *52*, pp.123-137.

Soil Classification Working Group. 1991. Soil Classification. A Taxonomic System for South Africa. Department of Agricultural Development, Pretoria.

Steduto, P., Fereres, E., Hsiao, T.C. and Raes, D., 2006, January. 'Yield Response to Water': The FAO revision framework and the crop-water productivity model AquaCrop. In *Proceedings*.

Steduto, P., Hsiao, T. C., Fereres, E., Raes, D., 2012. Crop yield response to water- FAO Irrigation and Drainage paper 66, Rome (Italy). 500.

Steduto, P., Hsiao, T. C., Raes, D., Fereres, E. 2009. AquaCrop: The FAO crop model to simulate yield response to water: 1. Concepts and underlying principles. Agronomy Journal. 101: 426-435.

Stöckle, C.O., Donatelli, M. and Nelson, R., 2003. CropSyst, a cropping systems simulation model. *European journal of agronomy*, *18*(3-4), pp.289-307.

Stricevic, R., Cosic, M., Djurovic, N., Pejic, B. and Maksimovic, L., 2011. Assessment of the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower. *Agricultural Water Management*, *98*(10), pp.1615-1621.

Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, D. and Muchinda, M., 2009. Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize. *Climate Research*, *40*(2/3), pp.147-161.

Thangwana, M. N.and Ogola J. B. O. Calibration of a neutron Probe in clay soil in Thohoyandou. Combined Congress, Bloemfontein. 18-21 January 2016.

Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Xiangxiang, W., Quanjiu, W., Jun, F. and Qiuping, F., 2013. Evaluation of the AquaCrop model for simulating the impact of water deficits and different irrigation regimes on the biomass and yield of winter wheat grown on China's Loess Plateau. Agricultural water management, 129, pp.95-104.

Chapter 9

Effect of climate change on chickpea *(Cicer arietinum)* winter planting date in North Eastern part of South Africa.

9.0 Abstract

Climate change, in the form of a significant increase in carbon dioxide and temperature, and a decrease in rainfall, may alter the current planting date for chickpea crop (*Cicer arietinum)* in Southern Africa. This study aimed at determining the likely effect of climate change on winter planting date for chickpea crop. Daily temperature and rainfall data for chickpea winter growing season (May –October) were simulated using 15 Global circulation models (GCMs) from the coupled Model Intercomparison Project phase 5 (CMIP 5). The simulated dataset had baseline data ranging from 1950 to 2015 and projections of future climate ranging from 1950 to 2100. Dataset was generated in accordance with CMIP 5 agreement of medium mitigation representative pathway scenario (RCP 4.5) and high representative pathway emissions scenario (RCP 8.5). Possible optimal planting dates based on temperature for each year (1950 to 2100) were generated using a calibrated and validated AquaCrop model 5.0 for chickpea in the Region. Assessment of climate change using temperature, rainfall, Evapotranspiration (ETo) and planting date, in the years 1950 to 2100 was performed using a non-parametric Mann-Kendall test. Furthermore, the cumulative sum test was used to test the presence of a change point in the simulated data. The level of variability in simulated temperature, planting date and rainfall was evaluated by the variability test. The simulation results indicated a significant increase in temperature in the study area, under both RCP 4.5 and 8.5 (by 4.2 to 5.5 ^{o}C). This increase in temperature will lead to a concomitant increase in ETo and AGDD for chickpea. Moreover, the results from the GCMs show that optimal planting date for chickpea could have shifted from mid-month of April during 1950 to end of May in 2100. This will reduce chickpea growing season from 140 days to 85 days. Therefore, there is need to determine the effect of a shift in planting date on biomass and yield of chickpea crop under RCP 4.5 and 8.5.

9.1 Introduction

Projections of future climate place the Southern Africa region at the forefront of climate change vulnerability, with negative impacts on revenue from dryland farming (IPPC, 2007). The fifth Assessment Report from the International Panel on Climate change (IPCC) gave projections of surface temperature increase of between 3.7 ºC and 4.8 ºC compared to pre-industrial levels (IPCC, 2014). It is largely expected that under climate change, many areas in Southern Africa will experience a decrease in the length of the growing season (Fiwa, 2015), while in some highland areas, rainfall changes may lead to prolonged growing season (Tadross, *et al.,* 2009). Amid such negative projections, agricultural activities, particularly chickpea production, will be affected by changes in temperature and precipitation conditions in large parts of sub-Saharan Africa (Muller *et al.,* 2011; Waha *et al.,* 2012).

Evaluation of a collective insight of climate change impacts in Southern Africa by Zinyengerere and Crespo (2013) suggested the need to develop adaptation strategies, into the future, that consider carbon dioxide fertilization. Moreover, it is viewed that impacts of climate change on chickpea crop may substantially be reduced with improvement of field management strategies. Therefore the farmers' choice of planting date, amongst other field management strategies, might be an important adaptation strategy to changing climate conditions (Waha *et al.,* 2012). Omotosho *et al.* (2000) and Odekunle (2003) suggested that a reliable understanding of rainfall onset and cessation times will greatly assist in timely preparation of farmlands, mobilization of seed and will reduce the risk involved in planting too early or too late. Waha *et al.* (2012), working with historical data from 1971-2000 and GCM model projections from 2070-2099, reported that planting dates in sub-Saharan Africa were changing with changes in the start of the rainy season.

Planting date as a management strategy, together with a good choice of crop cultivar has been reported to improve yield in chickpea (Siddique and Sedgley, 1986; Siadat and Hemayat, 2009), in other legumes (Confalone *et al*., 2009) and in other crops (Tsimba *et al*., 2013). Mahomed *et al* (2016), recommended planting date as a tool that could be used as an adaptive management strategy to improve yield under climate change conditions. However, it is not clear whether the current planting dates for chickpea crop will remain useful when climate has changed. Hardly any study has projected chickpea planting date response to changes in climate in South Africa. Where studies on climate change have been conducted (Hajarpoor *et al*., 2014; Birthal *et al*., 2014; Ehteramian *et al*., 2012), the studies have not followed CMIP 5 agreement. In some reports (Hajarpoor *et al*., 2014; Birthal *et al*., 2014; Koocheki *et al*, 2006; Waha *et al*., 2012), very few GCMs were used and hence compromising the credibility of the conclusions. Therefore, this study aimed at determining the likely effect of climate change on winter planting date for chickpea crop in North Eastern Region of South Africa.

9.2 Materials and methods

9.2.1 Study sites

This chapter is about modelling climate data and planting dates. The University of Venda was used as a research station from which weather data and site characteristics were used as inputs. The meteorological coodinates from which the datasets was measured and simulated are as follows: Latitude-22.97783, Longitude 30.4415 and Altitude 712, comp # 30720 and the weather station is the Universty of Venda.

9.2.2 Experimental design

The study design incorporated a combination of modelling and manipulation of historical meteorological data for the years (1984-2015). Daily temperature and rainfall data for chickpea winter growing season (May –October) was simulated using 15 Global circulation models (GCMs) from the coupled Model Inter-comparison Project phase 5 (CMIP 5) (Taylor *et al*., 2011).The output from GCMs was downscaled to local level of Thohoyandou using self-organised maps (SOM) approach (Hewitson and crane, 2006). The simulated dataset had baseline data ranging from 1984-2015 and projections of future climate ranging from 1950-2100. Dataset was generated in accordance with CMIP 5 agreement of medium mitigation representative pathway scenario (RCP 4.5) and high representative pathway emissions scenario (RCP 8.5). Possible optimal planting dates based on temperature for each year (1950-2100) were generated using a calibrated and validated AquaCrop model 5.0 for chickpea in the Region.

9.2.3 Generation of future climate data

The simulations used 15 different models: BCMZ, GGMR, CNCM3, CSMK3, CSMD, GFCM21, GIAOM, HadCM3, HADGEM, INCM3, IPCM4, MIHR, MPEH5, NCCCS, and NCPCM (see Table 1 for full names). All the selected models are members of phase 5 of the Coupled Model Intercomparison Project (CMIP 5) and have completed all core simulations within the suit of long term experiments and some prioritised tier 1 and 2 experiments that are aimed to determine simulations forced with specified concentrations that are consistent with medium mitigation representative pathway scenario (RCP 4.5) and high representative pathway emissions scenario (RCP 8.5).

9.2.3.1 Determination of future Evapotranspiration (Eto) (1950-2100)

Evapotranspiration (ETo) for all the 15 GCMs was calculated from maximum and minimum temperature datasets using the ETo calculator (Allen *et al*., 1998). The simulated ETo for the years from 1950 – 2100 was used as input in AquaCrop model to develop planting date simulations.

9.2.3.2 Determination of planting dates (1950-2100) using AquaCrop model

To develop future winter planting dates, simulated climate datasets from 15 GCMs were used as input climate data in the AquaCrop model 5.0 that was parameterised and validated for chickpea in the study area. The model simulated planting dates from the years 1950 to 2100 based on optimum temperatures for germination. Selection of optimum planting date for each year was based on maximum yield obtained from iterative process using different planting dates options availed by the model (Mhizha *et al*., 2014).

9.2.3.3 Determination of future growing degree days (1950-2100)

Accumulated growing degree days for chickpea crop based on the developed planting dates in paragraph 9.2.3.2 and a base temperature of 8 °C (Soltani *et al.,* 2006, Biabani *et al.,* 2011, Ogola and Thangwana, 2012). was calculated according to equation 9.1 (Allen *et al*., 1998):

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base} \qquad (9.1)$$

Where, T_{max} is the maximum temperature for the day, and T_{min} is the minimum temperature for the day, T_{base} is the temperature below which no growth can take place. GDD units were calculated for each day from the date of planting until date of physiological maturity (When 80% of leaves had turned yellow) and summed up to give one cumulative heat units value (AGDD).

9.2.4 Data analysis

Autocorrelation tests of temperature, rainfall, AGDD, ETo and planting date datasets was conducted using the Pragmatic Approach to Statistical Testing and Estimation model 3.0 (PASTE) (Leppink, 2018) to detect the existence of serial correlation at 95% confidence interval (Von Storch, 1995). Assessment of the existence of effect of climate change on temperature, rainfall, ETo, AGDD and planting date was done using a non-parametric Mann-Kendall test. Furthermore, the cumulative sum test was used to assess the presence of periods of sudden change amongst planting dates (Tabari, *et al*., 2014). The level of variability amongst temperature, rainfall, ETo, AGDD and planting dates was evaluated by the variability test. The regression relationship between planting date and temperature, rainfall, ETo, AGDD and planting dates was determined by regression plots.

9.2.5.1 Mann- Kendall test (MK test)

Assessment of the existence of effect of climate change on temperature, rainfall, ETo, AGDD and planting date was done using a non-parametric Mann-Kendall test. Statistical correlation in temperature, rainfall, ETo, AGDD and planting dates was evaluated using the Kendall's tau, where, a value > + 0.6 was considered to have a strong positive relation, whilst < - 0.4 was taken to have a weak relation (Hennemuth et al., 2013). MK test was selected for use in the study following recommendations from earlier studies: where Ngongondo *et al*, (2011) reported that the MK test has the advantage of being simple, robust and is less sensitive to outliers and missing data. MK test is less sensitive to abrupt changes in data trends that may be due to non-homogeneity or linearity in dataset (Hennemuth et al., 2013). In addition, the World Meteorological Organisation (WMO) recommends the MK test for assessment of trends in meteorological datasets (WMO, 1998). MK test is computed as as shown in equation 9.2.

$$Z_{MK} = \begin{cases} \frac{s-1}{\sqrt{var\ s}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s+1}{\sqrt{var(s)}} & if\ s < 0 \end{cases} \qquad 9.2$$

Zmk is the normalised MK test statistic, *S* is the MK test statistic and is defined as shown in equation 9.3.

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sign\ (x_j - x_i) \qquad 9.3$$

The variance of S in the x values is given as as shown in equation 9.4.

$$Var\ (S) = \frac{1}{18}[n\ (n-1)(2n+5) - \sum_{i=1}^{m}(t_i - 1)(2t_i + 5)] \qquad 9.4$$

Where *xj* and *xi* are sequential data values (Kendal, 1975; Mann, 1945). m is the number of tied groups (a tied group is a set of sample data having the same value), ti is the number of data points in the ith group and n is the length of data set (Kendal, 1975; Mann, 1945).

Xlstat (2016) software was used to perform the MK test. The null hypothesis was tested at 95% confidence level for all parameters under evaluation.

9.2.5.2 Variability test

The variability test was performed by computing the coefficiency of variance (CV) as follows:

$$CV = \frac{S}{\bar{X}} \quad x\,100\,\% \qquad \text{(Hennemuth et al., 2013)} \qquad 9.5$$

Where S is the standard deviation and $\bar{X}$ is the statistical mean.

9.2.5.3 The cumulative sum test (Cumsum)

Cumsum test was performed to determine the period (years) sudden changes in temperature, ETo, AGDD and planting dates. The test was conducted only in datasets where Mk test showed significant trend. The cumsum test was computed as follows:

$$S_K = \sum_{t=1}^{k}(x_t - \bar{x}\ ),\ k = (1, 2\ldots, n) \qquad \text{(Hennemuth et al., 2013)} \qquad 9.5$$

Where t is time in years, k is dataset.

The possible sudden change in temperature, ETo, AGDD and planting dates was observed when S_k was at maximum (Navares and Aznarte, 2017).

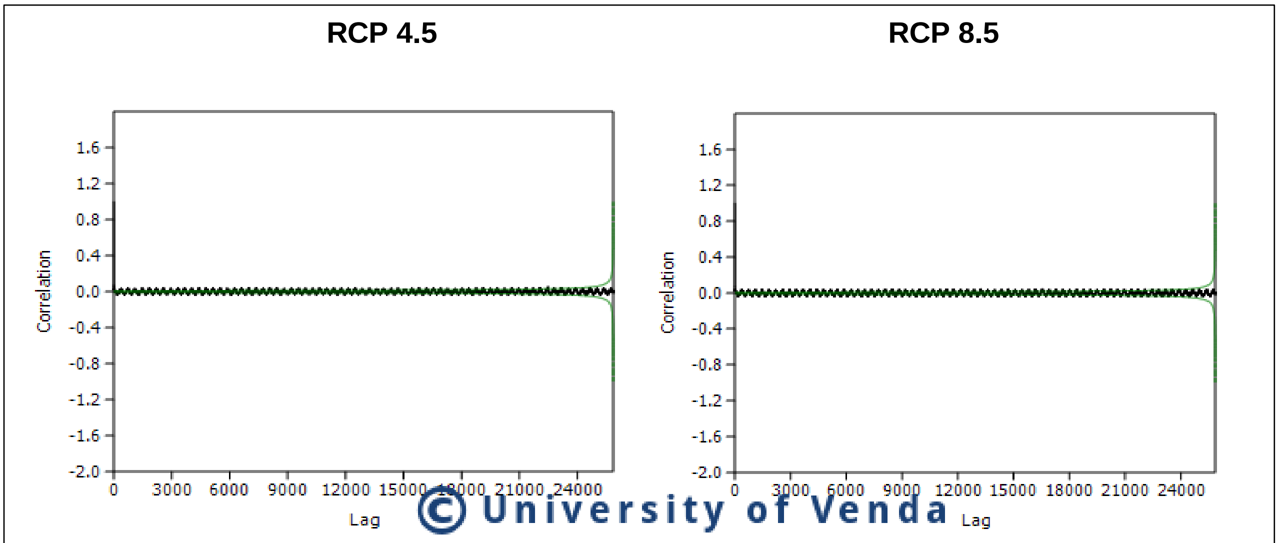
Table 9.1 List of GCMs and their grid resolutions used in the study.

Model acronym used	Research centre	Model full name	Grid resolution	Reference
BCM2	Bjerknes Centre for Climate Research	BCM2.0 L1	1.9 x 1.9°	Déqué *et al*. (1994)
CGMR	Canadian Centre for Climate Modelling and Analysis	CGCM33.1(T47) L, U2	2.8 x 2.8°	McFarlane *et al*. (1992)
CNCM3	Centre National de Recherches Meteorologiques	CNRM-CM3 L, U	1.9 x 1.9°	Déqué *et al*. (1994)
CSMK3	Commonwealth Scientific and Industrial Research	CSIRO-MK3.0 L, U	1.9 x 1.9°	Gordon *et al*. (2002);
CSMD (2005)	FGOALS Institute of Atmospheric Physics	FGOALS-g1.0 L	2.8 x 2.8°	Wang *et al*. (2004)
GFCM21	Geophysical Fluid Dynamics Laboratory	FGFDL-CM2.1 L, U	2.0 x 2.5°	Anderson *et al*. (2004)
GIAOM	Goddard Institute for Space Studies	GISS-AOM L, U	3 x 4°	Russell *et al*. (1995)
HadCM3	UK Meteorological Office	HadCM3 L	2.5 x 3.75°	Gordon *et al*. (2002)
HADGEM	UK Meteorological Office	HadGEM1 L	1.3 x 1.9°	Martin *et al*. 2006;
INCM3	Institute for Numerical Mathematics	INM-CM3.0 L	4 x 5°	Galin *et al*. (2003)
IPCM4	Institute Pierre Simon Laplace	IPSL-CM4 L, U	2.5 x 3.75°	Hourdin *et al*. (2006)
MIHR	National Institute for Environmental Studies	MRI-CGCM2.3.2 L, U	2.8 x 2.8°	Hasumi and Emori (2004)
MPEH5	Max-Planck Institute for Meteorology	ECHAM5-OM L, U	1.9 x 1.9°	Roeckner and Arpe (1996)
NCCCS	National Centre for Atmospheric Research	CCSM3 L	1.4 x 1.4°	Collins *et al*. (2006)
NCPCM	National Centre for Atmospheric Research	PCM L, U	2.8 x 2.8°	Kiehl and Gent (2004).

9.3 Results

9.3.1 Autocorrelation results

Autocorrelation tests of daily rainfall, temperature, and planting dates for Thohoyandou from 15 GCMs did not show serial correlations (Fig 9.1). The regression evaluation of the data sets for Thohoyandou from all 15 GCMs revealed no autocorrelation and was random at 95% confidence interval. Therefore the simulated datasets from all 15 GCMs was taken as independent from the observed data and there was no need for pre-whitening before running the MK test. Results shown in Fig 9.1 are only a sample of rainfall, temperature and planting date but other parameters such as ETo and AGDD were tested for serial correlation and the results did not show autocorrelation.



c

d

e

f

Figure 9.1 Autocorrelation tests of daily temperature (a and b), rainfall (c and d), and planting dates (e and f). The plots are averages from all 15 GCMs.

9.3.2 Time series analysis of temperature, rainfall, ETo, AGDD and planting dates

Table 9.2 depicts MK test results on temperature, rainfall and planting dates datasets that were computed as average from 15 GCMs. Time series analysis of mean temperatures revealed statistically significant (P value <0.0001) increase for the years 1950 to 2100 (Table 9.2). Both representative pathway emission scenarios (RCP) showed a temperature increase, with the high representative pathway scenario (RCP 8.5) showing a greater temperature increase. The average mean temperatures from 15 GCMs under the RCP 4.5

for the study area revealed a 4.4% temperature increase from 20.6 ^{o} C to 21.5 ^{o} C at a period from 1950 to 2010 (Fig 9.2 a), and was expected to increase sharply by 4.7% to 22.5 ^{o}C in 2030. Furthermore, the temperatures are expected to increase by 4.3% to 23.5 ^{o}C in the 2070s before slowing down and finally reach 24.3 ^{o}C in 2100. Similarly, an average of mean temperatures from 15 GCMs under RCP 8.5 revealed a temperature increase of 7.7% from 20.9 ^{o}C to 22.5 ^{o}C between the years 1950 and 2010 (Fig 9.2 b), and is expected to increase by 2.2% to 23 ^{o}C in 2030, and further increase by 5.2% to 24.2 ^{o}C in 2060 and by 9.5% to 26.5 ^{o}C in 2100. In general, for all representative pathway emission scenarios, temperatures are expected to increase by a magnitude of between 4.2 and 5.5 ^{o}C in the study area.

Moreover, the variability test revealed a low co-efficient of variation of 4.9 % in RCP 4.5 and 7.1 % in RCP 8.5, whilst the cumulative sum test depicted abrupt changes in temperature in the years 2029, 2066 and 2094 in RCP 4.5 and 2032, 2060 and 2087 in RCP 8.5 (Table 9.3).

However, average rainfall from all 15 GCMs did not show a significant trend (P value =0.166) for RCP 4.5 (Fig 9.2 c) and (P value = 0.094) for RCP 8.5 (Fig 9.2 d and Table 9.2). Furthermore, rainfall exhibited a greater variability which was indicated by a co-efficiency of variance of 62.2% and 62. 8% in RCP 4.5 and 8.5 respectively (Table 9.3). Although the trend was not significant, rainfall simulations under RCP 4.5 showed a slight decline as was depicted by a negative slope of -0.817, whilst RCP 8.5 had a slope of -0.681.

Just like temperature, time series analysis of potential evapotranspiration (ETo) revealed statistically significant (P value <0.0001) increase in ETo for the years from 1950 to 2100 (Fig 9.2 e – f and Table 9.2). Both representative pathway emission scenarios showed an increase in ETo over time. The average ETo from 15 GCMs under RCP 4.5 for the study area revealed an ETo increase from 1366 mm per year to 1399 mm per year for the period from 1950 to 2010 (Fig 9.2 e), and was expected to increase sharply to 1420 mm per year in 2030. Furthermore, the ETo was expected to increase to 1473 mm per year in the 2070s and finally reach 1480 mm per year in 2100. Similarly, an average ETo from 15 GCMs under high mitigation representative pathway emission scenario (RCP 8.5) revealed ETo increase from 1377 to 1418 mm per year between the years 1950 and 2010 (Fig 2 f), and is expected to increase to 1450 in 2030, 1521 in 2070 and 1608 mm per year in 2100. In general, for all representative pathway emission scenarios (4.5 and 8.5), ETo is expected to increase by a magnitude of between 114 mm and 231 mm respectively, in the study area.

Moreover, the variability test revealed a low co-efficient of variation of 2.9 % in RCP 4.5 and 5.0 % in RCP 8.5, whilst the cumulative sum test depicted abrupt changes in ETo in the years 2029, 2066 and 2094, and in RCP 4.5 and 2032, 2060 and 2087 in RCP 8.5 (Table 9.3).

Table 9.2 MK test results for mean temperature, rainfall, ETo, AGDD and planting dates

Parameter	Kendall's *Tau*	S	Var(s)	P (F-ratio)	alpha	Test Interpretation
Temperature						

(RCP 4.5)	0.883	10951	442373.67	<0.0001	0.05	Accept
(RCP 8.5)	0.912	11307	442373.67	<0.0001	0.05	Accept
Rainfall						
RCP 4.5	-0.076	-861	386308.33	0.166	0.05	Reject
RCP 8.5	-0.092	-1041	386308.33	0.094	0.05	Reject
ETo						
(RCP 4.5)	0.786	8666	371208.67	<0.0001	0.05	Accept
(RCP 8.5)	0.792	8685	371208.67	<0.0001	0.05	Accept
AGDD						
(RCP 4.5)	0.860	9478	371208.67	<0.0001	0.05	Accept
(RCP 8.5)	0.924	9637	371208.67	<0.0001	0.05	Accept
Planting date						
RCP 4.5	0.862	9677	385980.33	<0.0001	0.05	Accept
RCP 8.5	0.834	9241	378401.67	<0.0001	0.05	Accept

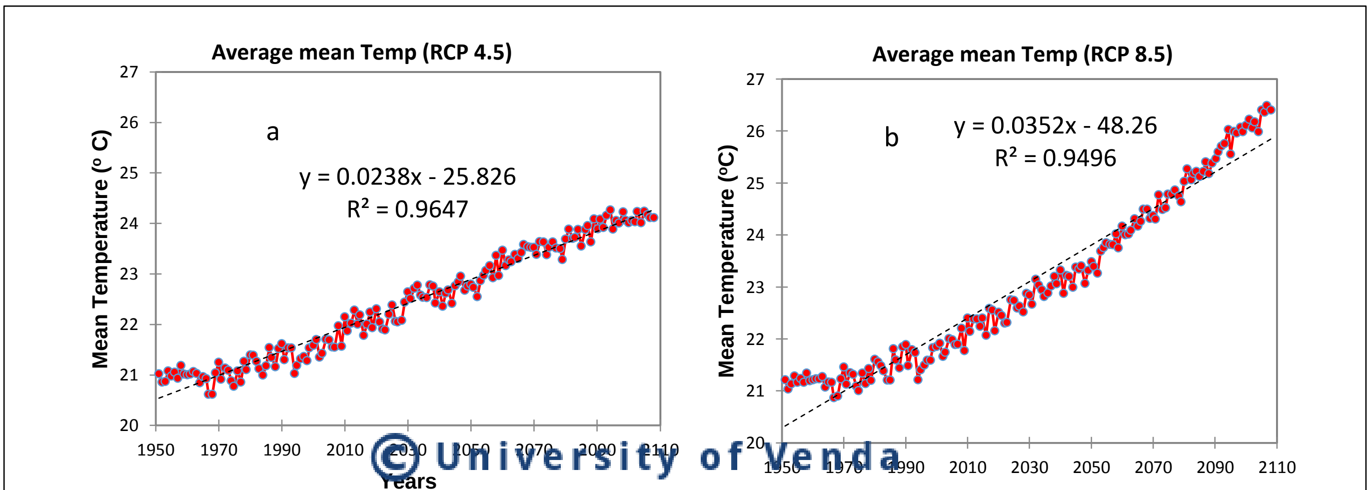
Kendall's Tau is the rank correlation coefficient, S is the slope, variance of S in x values, Var (s) is the variance of dataset, P value is the probability, alpha is the level of significant. The null hypothesis (Ho) was that the parameters (temperature, rainfall, ETo, AGDD and planting date) varied with time.

Table 9.3 Cumsum test and variability test for daily mean temperatures, rainfall and planting dates.

Parameter	CV		Year	Cumsum Year	Year
Temperature	(RCP 4.5)	4.9 %	2029	2066	2094
Temperature	(RCP 8.5)	7.1 %	2032	2060	2087
Rainfall	(RCP 4.5)	62.2 %	------	------	------

Rainfall	(RCP 8.5)	62.8%	------	------	------
ETo	(RCP 4.5)	2.9 %	2029	2066	2094
ETo	(RCP 8.5)	5.0 %	2032	2060	2087
AGDD	(RCP 4.5)	5.1 %	2029	2066	2094
AGDD	(RCP 8.5)	8.1 %	2032	2060	2087
Planting date	(RCP 4.5)	10.8 %	2031	2065	2093
Planting date	(RCP 8.5)	12.4 %	2033	2061	2088

CV is the coefient of variance, ETo is the evapotranspiration, and AGDD is the accumulated growing degree days.



c

f

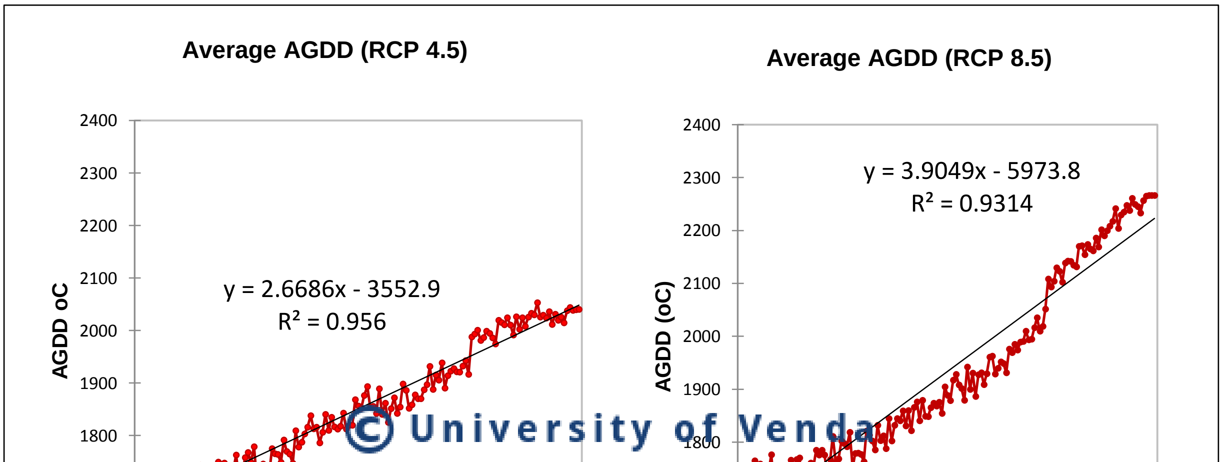
Figure 9.2 Time series graphs for temperature, rainfall and ETo under 4.5 and 8.5 representative pathway emission scenarios.

Time series analysis of accumulated growing degree days per season (May –October) (AGDD) revealed statistically significant (P value <0.0001) increase in AGDD over the years from 1950 to 2100 (Table 9.2). Both representative pathway emission scenarios showed AGDD increase, with the high representative pathway scenario (RCP 8.5) showing a greater increase (Fig 9.3 a and b). The average AGDD from 15 GCMs under the medium mitigation representative pathway emission scenario (RCP 4.5) for the study area revealed an AGDD increase from 1675 °C. days to 1755 °C. days per winter season at a period from 1950 to 2010 (Fig 9.3 a), and is expected to increase sharply to 1796 °C. days per season in 2030. Furthermore, the AGDD is expected to increase to 1861 °C. days per season in the 2070s and finally reach 1913 °C days per year in 2100. Similarly, an average AGDD from 15 GCMs under high mitigation representative pathway emission scenario (RCP 8.5) revealed AGDD increase from 1701 to 1831 between the years 1950 and 2010 (Fig 9.3 b), and is expected to increase to 1902 °C days per season in 2030, 2134 °C days per season in 2070 and 2267 °C days per season in 2100. In general, for all representative pathway emission scenarios (RCP 4.5 and 8.5), AGDD is expected to increase by a magnitude of between 793 and 1422 respectively, in the study area.

Moreover, the variability test revealed a low co-efficient of variation of 5.1 % in RCP 4.5 and 8.1 % in RCP 8.5, whilst the cumulative sum test depicted abrupt changes in AGDD in the years 2029, 2066 and 2094 in RCP 4.5 and 2032, 2060 and 2087 in RCP 8.5 (Table 9.3).

Furthermore, time series analysis of average planting dates from 15 GCMs for the years from 1950 to 2100 revealed statistically significant (P value <0.0001) change of planting dates (Table 9.2). The planting dates shifted from the month of April into the month of May in both representative pathway emission scenarios, RCP 8.5 showing a greater change or shift of the planting dates. The variability test revealed a low co-efficient of variation of 10.8 % under RCP 4.5 scenario and 12.4 % under RCP 8.5 scenario, whilst the cumulative sum test depicted abrupt changes in planting dates in the years 2031, 2065 and 2093 under RCP 4.5 scenario and 2033, 2061 and 2088 under RCP 8.5 scenario (Table 9.3).

Moreover, trend analysis of average planting dates that were computed from all 15 GCMs under the RCP 4.5 emission scenario revealed a shift in planting date from 5th of April to the 13th of May over the period from 1950 to 2010 (Fig 2 e), and the planting date is expected to increase to 17 May in 2030. Furthermore, the planting date is expected to shift to 21 May in the 2070s before slowing down and finally reach to 25 May in 2100. Similarly, the average planting date from 15 GCMs under high mitigation representative pathway emission scenario (RCP 8.5) revealed a shift in planting date from 9th of April to the 15th of May over the period from 1950 to 2010 (Fig 2 f), and the date is expected to shift to 19 May in 2030. Furthermore, the planting date is expected to shift to 23 May in the 2070s before slowing down and finally reach 31 May in 2100.



b

a

Figure 9.1 Time series graphs for accumulated growing degree days (AGDD) and planting date under different representative pathways.

d

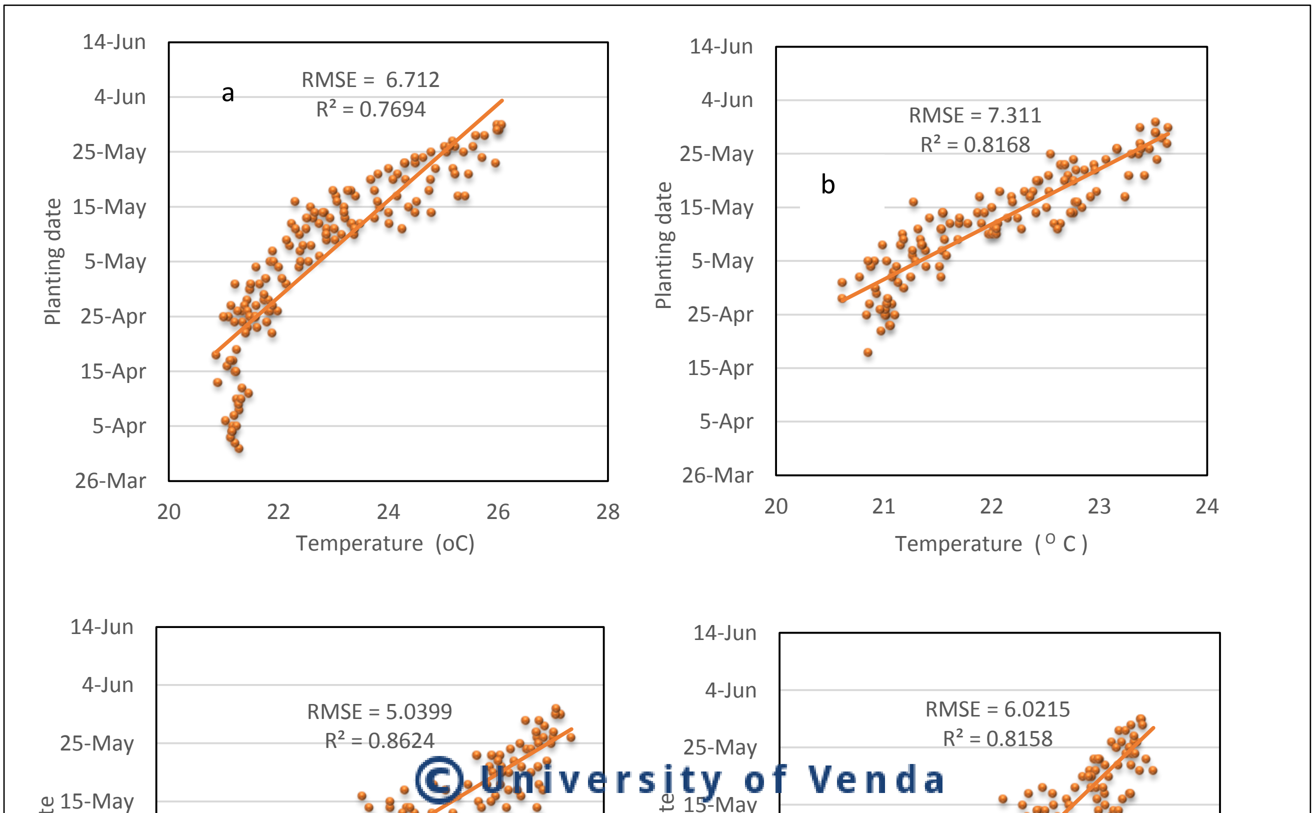
c

Figure 9.3 Time series graphs for accumulated growing degree days (AGDD) and planting date under different representative pathways.

9.3.3 Relationship between planting date and temperature, AGDD and ETo

The linear regression analysis of planting date against temperature, AGDD and ETo showed a strong relationship in all parameters (Fig 9.4 a-f). Planting dates shifted into the growing season with each successive year as temperature, AGDD and ETo was increasing. However, there was a slight variation in strength of the relationships amongst the representative pathways, with RCP 4.5 showing greater regression slope compared to RCP

8.5 in AGDD and ETo and vice versa in temperature. For example, the strength of regression slopes as measured by R^2 in RCP 4.5 and RCP 8.5, respectively was 0.7694 and 0.8168 for temperature (Fig 9.4 a & b), 0.8624 and 0.8158 for AGDD (Fig 9.4 c & d) and 0.8200 and 0.7496 for ETo (Fig 9.4 e & f).



c

d

f

Figure 9.4 Regression analysis between planting date temperature (graphs a and b), ETo (graphs c and d), AGDD (graphs e and f).

9.4 Discussion

Time series analysis using MK test revealed significant changes in temperature, ETo, AGDD and chickpea planting dates. The observed significant changes in these parameters may indicate climate change in the study area. The average temperature from all the 15 GCMs projected a temperature increase of the magnitude between 4.2 and 5.5 ^{o}C in the study area, whilst the IPCC, (2014) projected a temperature increase of between 3.7 and 4.8 ^{o}C in the whole Southern Africa Region. Several studies have confirmed that climate change is taking place in the region, however, the magnitude of change in temperature have been reported varyingly in literature (Battisti and Naylor, 2009; World bank, 2011; IPCC, 2014) and is possibly due to the methods of downscaling used in computing climate datasets (Tadross et., al 2005). Therefore, the small variation between our study results with earlier reports may partly be due to differences in scale of resolution and experimental approaches used. Moreover, the several abrupt changes in temperature observed in the study may indicate that temperature stress events will be more common in future. The results clearly confirms earlier speculation by Dreccer *et al* (2018) that current hottest seasons on record will be similar to normal temperatures of the future. Temperature above 32ºC have been reported to affect chickpea production (Devasirvatham *et al*., 2012). Thus chickpea yield may be affected in future by increase in temperature.

Insignificant changes observed in rainfall amount may indicate that the amount of rainfall received may not change for the period up until 2100. Studies have confirmed that rainfall amount may not vary significantly with time up until 2100 but the pattern of distribution may vary spatially and temporally (World bank, 2011; IPCC, 2007 & 2014). The variability in rainfall observed in the study may be felt inform of drought and extreme precipitation or water stress events (Challinor and Wheeler, 2008; Sage *et al*., 2008) and this may affect chickpea productivity.

The significant changes observed in ETo and AGDD are expected due to the involvement of temperature in calculation of ETo (Allen *et al*., 1998) and AGDD (Allen *et al*., 1998). However, the significant increase in ETo clearly show that the atmosphere will have a higher demand for water vapour, leading to great water use. This may negatively affect chickpea yield (Dreccer *et al*., 2018) unless irrigation water is added to reduce water stress. Moreover, the increase in AGDD may imply a hastened crop development and maturation in future (DaMatta *et al*., 2010). This may result in lower biomass and grain yield owing to less time spent by plants to accumulate heat units.

The results clearly show that planting date for chickpea in the study area shifted markedly from mid-month of April in the 1950s to mid-month of May by the year 2010. Projections are that planting dates will shift even further to end of May by the year 2100. The shift in planting dates may be explained by the expected variation in temperature. The influence of temperature in determining planting date of crops was explained by Raes *et al*., (2004). Moreover, in the current study, field experiments showed that temperature has a significant effect on planting date for chickpea. However it is not clear whether the shift in planting dates will significantly affect chickpea growth, development and yield. From the field experiments that were conducted as part of this study, optimal planting date was found in the early-month of May, whilst end of May was observed to produce suboptimal yields and was considered to be a late planting date in the region.

It is suggested that the extension of planting period to end of May could possibly and partly be due to warming of winter temperatures expected under climate change. Furthermore, the expected extension of planting date to end of May may widen the planting period for chickpea and this positively will provide famers with ample time to grow the crop. In addition, the increase in temperature may have the advantages of improving germination rate from the current 85% observed in the study and reduce seedling emergence period (Mubvuma, 2018). The projected rise in AGDD coupled with an extension of the planting period into the season may suggests a reduced growing season length for chickpea in future. Because of the observed shift in planting dates, growing period cycle for chickpea will fall from 140 days to 85 days. The results confirms earlier suggestions that the expected temperature rise will reduce the current crop growing cycle. In support of this, Fiwa *et al*., (2015) reported a projected shortening of the growing season and growing cycle for maize in Southern Africa due to temperature increase under climate change.

The close association depicted by the regression relationship between temperature, ETo and AGDD with planting date (Fig 4) clearly indicate the importance of temperature in determining planting dates for chickpea. The increase in temperature of the magnitude of between 4.2 to 5.5 ^{o}C, coupled with greater rainfall variability may suggests that the impact of climate change may be felt in form of extreme temperatures and uneven rainfall distribution. This view was shared by Koocheki *et al* (2006) and may affect crop yield in future.

The results also revealed that projections for temperature, ETo, AGDD and planting dates will vary with representative carbon dioxide concentration pathway scenarios. The high representative pathway emission scenario (RCP 8.5) showed more increase in temperature, ETo, and AGDD compared to RCP 4.5. Such increase was reflected in a greater shift in planting dates for chickpea crop under RCP 8.5. The effect of a rise in carbon dioxide concentration under climate change to crops has been reported by several authors and is expected to benefit chickpea biomass and yield because of its inefficiency C_3 photosynthetic pathway system (Jablonski *et al*., 2002).

The variability test revealed a low co-efficient of variation in temperature, ETo, AGDD and planting date, indicating reliability and consistence of study results. However relatively lower co-efficient of variation was observed in RCP 4.5 compared to RCP 8.5, possibly due to the effect of carbon dioxide in absorbing greater longwave radiation in RCP 8.5. Cumulative sum test depicted abrupt changes in temperature, ETo, AGDD and planting dates in the years 2029, 2066 and 2094 in RCP 4.5 and 2032, 2060 and 2087 in RCP 8.5. The effect of such abrupt changes on crops is beyond the scope of this study and has hardly been studied but intuitively may have significant effect on chickpea growth and development and therefore warrant further study on their likely effect on chickpea biomass, and yield.

9.5 Conclusion

Planting dates for chickpea were shown to change significantly by the year 2100. Projections for temperature, ETo, AGDD and planting dates varied with representative carbon dioxide concentration pathway scenarios. The high representative pathway emission scenario (RCP 8.5) showed greater shift in planting dates, increase in temperature, ETo, and AGDD compared to RCP 4.5. The results answers positively to the general question: will there be a future for chicpea in the study area? However, it is not clear whether the shift in planting dates will significantly affect chickpea growth, development and yield. Therefore, there is need to determine the effect of a shift in planting date on biomass and yield of chickpea crop under RCP 4.5 and 8.5 climate change scenarios.

References

Allen, R.G., Periera, L.S., Raes, D., Smith, M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirement. FAO Irrigation and Drainage Paper No. 56. FAO, Rome. 1-281

Anderson, J.L., Balaji, V., Broccoli, A.J., Cooke, W.F., Delworth, T.L., Dixon, K.W., Donner, L.J., Dunne, K.A., Freidenreich, S.M. and Garner, S.T., 2004. The new GFDL global atmosphere and land model AM2–LM2: Evaluation with prescribed SST simulations. *Journal of Climate*, *17*(24), pp.4641-4673.

Battisti, D.S. and Naylor, R.L., 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. *Science*, *323*(5911), pp.240-244.

Hennemuth, B., Bender, S., Bülow, K., Dreier, N., Keup-Thiel, E., Krüger, O., Mudersbach, C., Radermacher, C. and Schoetter, R., 2013. Statistical methods for the analysis of simulated and observed climate data, applied in projects and institutions dealing with climate change impact and adaptation. *CSC report*, *13*, pp.1-135.

Biabani, A. and Katozi, M., 2011. Correlation and relationships between seed yield and other characteristics in chickpea (Cicer arietinum L.) cultivars under deterioration. *African Journal of Agricultural Research*, *6*(6), pp.1359-1362.

Birthal, P.S., Khan, M.T., Negi, D.S. and Agarwal, S., 2014. Impact of climate change on yields of major food crops in India: Implications for food security. *Agricultural Economics Research Review*, *27*(2), pp.145-155.

Challinor, A.J. and Wheeler, T.R., 2008. Crop yield reduction in the tropics under climate change: processes and uncertainties. *Agricultural and Forest Meteorology*, *148*(3), pp.343-356.

Collins, W.D., Bitz, C.M., Blackmon, M.L., Bonan, G.B., Bretherton, C.S., Carton, J.A., Chang, P., Doney, S.C., Hack, J.J., Henderson, T.B. and Kiehl, J.T., 2006. The community climate system model version 3 (CCSM3). *Journal of Climate*, *19*(11), pp.2122-2143.

Confalone, A., Lizaso, J.I., Ruiz-Nogueira, B., López-Cedrón, F.X. and Sau, F., 2010. Growth, PAR use efficiency, and yield components of field-grown Vicia faba L. under different temperature and photoperiod regimes. *Field crops research*, *115*(2), pp.140-148.

DaMatta, F.M., Grandis, A., Arenque, B.C. and Buckeridge, M.S., 2010. Impacts of climate changes on crop physiology and food quality. *Food Research International*, *43*(7), pp.1814-1823.

Déqué, M., Dreveton, C., Braun, A. and Cariolle, D., 1994. The ARPEGE/IFS atmosphere model: a contribution to the French community climate modelling. *Climate Dynamics*, *10*(4-5), pp.249-266.

Devasirvatham, V., Tan, D.K.Y., Gaur, P.M., Raju, T.N. and Trethowan, R.M., 2012, October. Effects of high temperature at different developmental stages on the yield of chickpea. In *Capturing opportunities and overcoming obstacles in Australian agronomy. Proceedings of the 16th ASA conference, Armidale, Australia* (pp. 14-18).

Dreccer, M.F., Fainges, J., Whish, J., Ogbonnaya, F.C. and Sadras, V.O., 2018. Comparison of sensitive stages of wheat, barley, canola, chickpea and field pea to temperature and water stress across Australia. *Agricultural and Forest Meteorology*, *248*, pp.275-294.

Ehteramian, K., NoRMoHAMADI, G., Bannyan, M. and Alizadeh, A., 2012. Impacts of climate change scenarios on wheat yield determined by evapotranspiration calculation. *Zemdirbyste Agriculture*, *99*(3), pp.279-286.

Fiwa, L., 2015. Improving rainfed cereal production and water productivity in Malawi: Modelling field management options in response to current and future climatic conditions.

Galin, V.Y., 2003. Atmospheric general circulation model of INM RAS with ozone dynamics. *Russ. Meteor. Hydrol.*, *5*, pp.13-22.

Gordon, H.B., Rotstayn, L.D., McGregor, J.L., Dix, M.R., Kowalczyk, E.A., O'Farrell, S.P., Waterman, L.J., Hirst, A.C., Wilson, S.G., Collier, M.A. and Watterson, I.G., 2002. The CSIRO Mk3 climate system model.

Hasumi, H., and Emori, S. 2004. " K-1 coupled model (MIROC) description." University of Tokyo, Tokyo.

Hajarpoor, A., Soltani, A., Zeinali, E. and Sayyedi, F., 2014. Simulating climate change impacts on production of chickpea under water-limited conditions. *Agric. sci. dev*, *3*(6), pp.209-217.

Hewitson, B.C. and Crane, R.G., 2006. Consensus between GCM climate change projections with empirical downscaling: precipitation downscaling over South Africa. *International Journal of Climatology*, *26*(10), pp.1315-1337.

Hourdin, F., Musat, I., Bony, S., Braconnot, P., Codron, F., Dufresne, J.L., Fairhead, L., Filiberti, M.A., Friedlingstein, P., Grandpeix, J.Y. and Krinner, G., 2006. The LMDZ4 general circulation model: climate performance and sensitivity to parametrized physics with emphasis on tropical convection. *Climate Dynamics*, *27*(7-8), pp.787-813.

IPCC, 2007. Climate Change 2007. Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

IPCC, 2014. Climate change. 2014. Impacts, adaptation, and vulnerability. Part B: regional aspects. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.J., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 688 pp.

Jablonski, L.M., Wang, X. and Curtis, P.S., 2002. Plant reproduction under elevated CO2 conditions: a meta-analysis of reports on 79 crop and wild species. *New Phytologist*, *156*(1), pp.9-26.

Kendall, M., 1975. Rank correlation methods (4th edn.) charles griffin. *San Francisco, CA*, *8*.

Kiehl, J.T. and Gent, P.R., 2004. The community climate system model, version 2. *Journal of Climate*, *17*(19), pp.3666-3682.

Koocheki, A., Nassiri, M., Soltani, A., Sharifi, H. and Ghorbani, R., 2006. Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran. *Climate Research*, *30*(3), pp.247-253.

Leppink, J., 2018. A Pragmatic Approach to Statistical Testing and Estimation (PASTE). *Health Professions Education*.

Li, R., Wang, S.Y. and Gillies, R.R., 2016. A combined dynamical and statistical downscaling technique to reduce biases in climate projections: an example for winter precipitation and snowpack in the western United States. *Theoretical and applied climatology*, *124*(1-2), pp.281-289.

Mann, H.B., 1945. Nonparametric Tests against Trend. Econometrics, 13, 245-259. *Mantua, NJ, SR Hare, Y. Zhang, JM Wallace, and RC Francis (1997), A Pacific decadal*.

Martin, G.M., Ringer, M.A., Pope, V.D., Jones, A., Dearden, C. and Hinton, T.J., 2006. The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model (HadGEM1). Part I: Model description and global climatology. *Journal of Climate*, *19*(7), pp.1274-1301.

McFarlane, N.A., Boer, G.J., Blanchet, J.P. and Lazare, M., 1992. The Canadian Climate Centre second-generation general circulation model and its equilibrium climate. *Journal of Climate*, *5*(10), pp.1013-1044.

Mhizha, T., Geerts, S., Vanuytrecht, E., Raes, D. and Makarau, A., 2014. Use of the FAO AquaCrop model in developing sowing guidelines for rainfed maize in Zimbabwe. *Water SA*, *40*(2), pp.233-244.

Müller, C., Cramer, W., Hare, W.L. and Lotze-Campen, H., 2011. Climate change risks for African agriculture. *Proceedings of the National Academy of Sciences*, *108*(11), pp.4313-4315.

Navares, R. and Aznarte, J.L., 2017. Predicting the Poaceae pollen season: six month-ahead forecasting and identification of relevant features. *International journal of biometeorology*, *61*(4), pp.647-656.

Ngongondo, C., Xu, C.Y., Gottschalk, L. and Alemaw, B., 2011. Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scarce region. *Theoretical and applied climatology*, *106*(1-2), pp.79-93.

Odekunle, T.O., 2004. Rainfall and the length of the growing season in Nigeria. *International journal of climatology*, *24*(4), pp.467-479.

Omotosho, J.B., Balogun, A.A. and Ogunjobi, K., 2000. Predicting monthly and seasonal rainfall, onset and cessation of the rainy season in West Africa using only surface data. *International Journal of Climatology*, *20*(8), pp.865-880.

Pope, V.D., Gallani, M.L., Rowntree, P.R. and Stratton, R.A., 2000. The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3. *Climate Dynamics*, *16*(2-3), pp.123-146.

Raes, D., Sithole, A., Makarau, A. and Milford, J., 2004. Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. *Agricultural and forest meteorology*, *125*(3-4), pp.177-185.

Ringer, M.A., Martin, G.M., Greeves, C.Z., Hinton, T.J., James, P.M., Pope, V.D., Scaife, A.A., Stratton, R.A., Inness, P.M., Slingo, J.M. and Yang, G.Y., 2006. The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model (HadGEM1). Part II: Aspects of variability and regional climate. *Journal of climate*, *19*(7), pp.1302-1326.

Roeckner, E., Arpe, K., Bengtsson, L., Christoph, M. and Claussen, M., 1996. L. Dü menil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida, The atmospheric general circulation model ECHAM-4: Model description and simulation of present-day climate. *MPI Report*, *218*.

Russell, G.L., Miller, J.R. and Rind, D., 1995. A coupled atmosphere-ocean model for transient climate change studies. *Atmosphere-ocean*, *33*(4), pp.683-730.

Sage, R.F., Way, D.A. and Kubien, D.S., 2008. Rubisco, Rubisco activase, and global climate change. *Journal of experimental botany*, *59*(7), pp.1581-1595.

Siadat, S.A. and Hemayati, S.S., 2009. Effect of sowing date on yield and yield components of three oilseed rape varieties.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Soltani, A., Robertson, M.J., Rahemi-Karizaki, A., Poorreza, J. and Zarei, H., 2006. Modelling biomass accumulation and partitioning in chickpea (Cicer arietinum L.). *Journal of agronomy and crop science*, *192*(5), pp.379-389.

Tabari, H., Talaee, P.H., Nadoushani, S.M., Willems, P. and Marchetto, A., 2014. A survey of temperature and precipitation based aridity indices in Iran. *Quaternary International*, *345*, pp.158-166.

Tadross, M., Jack, C. and Hewitson, B., 2005. On RCM-based projections of change in southern African summer climate. *Geophysical Research Letters*, *32*(23).

Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, D. and Muchinda, M., 2009. Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize. *Climate Research*, *40*(2/3), pp.147-161.

Taylor, K.E., Stouffer, R.J. and Meehl, G.A., 2011. A summary of the CMIP5 experiment design. PCDMI Rep.
Tsimba, R., Edmeades, G.O., Millner, J.P. and Kemp, P.D., 2013. The effect of planting date on maize grain yields and yield components. *Field Crops Research*, *150*, pp.135-144.

Von Storch, H., 1999. Misuses of statistical analysis in climate research. In *Analysis of Climate Variability* (pp. 11-26). Springer, Berlin, Heidelberg.

Waha, K., Müller, C., Bondeau, A., Dietrich, J.P., Kurukulasuriya, P., Heinke, J. and Lotze-Campen, H., 2013. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change*, *23*(1), pp.130-143.

Wang, B., Wan, H., Ji, Z., Zhang, X., Yu, R., Yu, Y. and Liu, H., 2004. Design of a new dynamical core for global atmospheric models based on some efficient numerical methods. *Science in China Series A: Mathematics*, *47*(1), pp.4-21.

World Bank. 2011. The World Bank Annual Report 2011 : Year in Review. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/2378 License: CC BY 3.0 IGO.

WMO. 1988. Analyzing long time series of hydrological data with respect to climate variability. WCAP-3, WMO/TD No. 224, World Meteorological Organisation, Geneva,

Zinyengere, N., Crespo, O. and Hachigonta, S., 2013. Crop response to climate change in southern Africa: A comprehensive review. *Global and Planetary Change*, *111*, pp.118-126.

Chapter 10

The effect of planting date on aboveground biomass and grain yield of chickpea crop *(Cicer arietinum)* grown under future climate scenarios.

Abstract

This study aimed at determining the likely effect of planting date on chickpea biomass and yield under climate change scenario in North Eastern Region of South Africa. FAO AquaCrop model 5.0 that was calibrated and validated in Chapter 8 was used for simulating future heat use efficiency (HUE), water use efficiency (WUE), Carbon dioxide productivity

(CP), and biomass and grain yield of chickpea crop for the years 1950 to 2100 The model used daily climate datasets that were computed as averages from 15 Global circulation models (GCMs) from the Coupled Model Intercomparison Project-phase 5 (CMIP5). Dataset was generated in accordance with CMIP 5 agreement of medium mitigation representative pathway scenario (RCP 4.5) and high representative pathway emissions scenario (RCP 8.5). Aboveground biomass increased from 2.0 & 2.05 t ha^{-1} in 1950 to 4.3 & 4.57 t ha^{-1}, respectively in RCP 4.5 and 8.5, in 2100, when planting dates recommended by AquaCrop model were used, whilst it increased from 1.95 & 1.94 t ha^{-1} in 1950 to 2.16 & 2.31 t ha^{-1}, respectively under RCP 4.5 and 8.5, in 2100, when late planting date was used. Similarly, grain yield increased from 1.07 & 1.08 t ha^{-1} in 1950 to 1.68 & 2.21 t ha^{-1} in 2100, respectively under RCP 4.5 and 8.5, in 2100 when planting dates recommended by AquaCrop model were used, whilst it increased from 0.72 & 0.69 t ha^{-1} in 1950 to 0.74 & 0.81 t ha^{-1}, respectively under RCP 4.5 and 8.5, in 2100 when late planting date was used. The yield improvement was caused by sustained increase in WUE, and HUE. The findings clearly indicate the possibility of using planting date as a management strategy in improving chickpea biomass and grain yield under climate change conditions.

10.1 Introduction

The North Eastern region of South Africa is largely semi-arid and characterised by low crop productivity which is likely to be exacerbated by anticipated climate change ; IPCC, 2014. Predicted changes in climate, in the form of increase or decrease in temperature, carbon dioxide and rainfall conditions may alter the current planting dates and affect chickpea (*Cicer arietinum)* productivity (Koocheki et al, 2006; Kalra et al*,* 2008; Singh et al*.,* 2014). It has been reported that by the end of the 21st century, the global average surface temperatures will warm at a magnitude of between 3.7 and 4.8^{o}C, and global rainfall patterns will change considerably and affect crop yield (Kharin and Zwiers, 2000; Viatcheslav et al*.,* 2007; IPCC, 2014; IPCC, 2007). In India, a decrease in chickpea yield of 53 kg/ha was observed per 1^{o}C rise in seasonal temperature (Kalra et al*,* 2008). Therefore, management strategies such as manipulation of planting date and cultivar selection may be important ways to improve chickpea yield under climate change conditions.

Furthermore, attaining sustainable chickpea yields not only requires a better understanding of the response of the crop to current climate conditions but also a reliable crop yield prediction tool under different projected climate scenarios. Several studies have proposed combining the Global Circulation Models (GCMs) and crop simulation models to determine the possible effects of climate change on crops when grown under different management strategies e.g. choice of planting dates (Jones and Kiniry, 1986; Stockle et al., 2003; FAO, 1992; Jones et al., 2003; Keating et al., 2003; de Wit, et al., 1970). Where studies have explored the possible range of climate change impacts on chickpea crops, contrasting results regarding yield variability have been reported (Koocheki et al., 2006; Kalra et al., 2008; Singh et al., 2014). Some predictions have shown a yield increase (Hajarpoor et al., 2014; Mahomed et al., 2016) possibly due to anticipated increase in carbon dioxide concentration levels (DaMatta et al., 2010), whilst others have shown a yield decrease possibly due to high temperatures off-setting the carbon dioxide advantages (Koocheki et al, 2006).

Planting date as a management strategy together with a good choice of crop cultivar has been reported to improve chickpea yield (Siddique and Sedgley, 1986; Siadat and Hemayat, 2009), and recommended as a possible adaptive management strategy to improve yield under climate change conditions (Lehmaan et al., 2012). However, it is not clear whether the current planting dates for chickpea crop will remain relevant with climate change. Hardly any study has assessed biomass and yield response of chickpea crop to changes in planting date that may be expected under different future climate scenarios in South Africa. Where studies on the effect of climate change have been conducted (Hajarpoor et al., 2014; Birthal et al., 2014; Ehteramian et al., 2012), the studies have been found at times not following CMIP 5 agreement. In some reports (Hajarpoor et al., 2014; Birthal et al., 2014; Koocheki et al, 2006; Waha et al., 2013), very few GCMs have been used in the studies and hence compromising the validity of the conclusions. Therefore, this study used 15 GCMs that are members of the phase 5 of the Coupled Model Intercomparison Project (CMIP 5) and have completed all core simulations within the suit of CMIP 5’s long term experiments and some prioritised tier 1 and 2 experiments aimed to determine simulations of forced with specified concentrations that are consistent with medium mitigation representative pathway scenario (RCP 4.5) and high representative pathway emissions scenario (RCP 8.5).

Differences in environmental factors amongst planting dates may expose crops to different conditions (temperature and moisture) during their vegetative and reproduction stages, which consequently may affect water use efficiency (WUE) (Hajarpoor et al., 2014), heat use efficiency (HUE), radiation use efficiency (RUE) and carbon dioxude productivity (CP), aboveground biomass and grain yield. For example, an early planting date in Southern Africa during winter may expose the crop to extremely low temperatures (less than 8 ^{o} C) (Nayyar, 2005; Viatcheslav et al., 2007) which affects biomass development , flower retention, pod abortion, and grain yield and consequently affects WUE, HUE, RUE CP. In contrast, late planting of chickpea during the winter season may result in flowering stage coinciding with high temperatures during early days of the month of reproduction stage, which may affect fruit set and hence chickpea yield (Wang et al., 2006). The study aimed at determining the effect of planting date on biomass and yield of chickpea crop grown under medium and long term climate projections in North Eastern region of South Africa.

10.2 Materials and methods

10.2.1 Study site

This chapter is about modelling WUE, HUE, CP, aboveground biomass and grain yield of chickpea crop. University of Venda was used as the research station from which weather data and site characteristics were used as inputs. The average monthly rainfall totals and mean monthly temperature for the period from 1984 to 2015 in the study area is depicted in Fig 10.1.

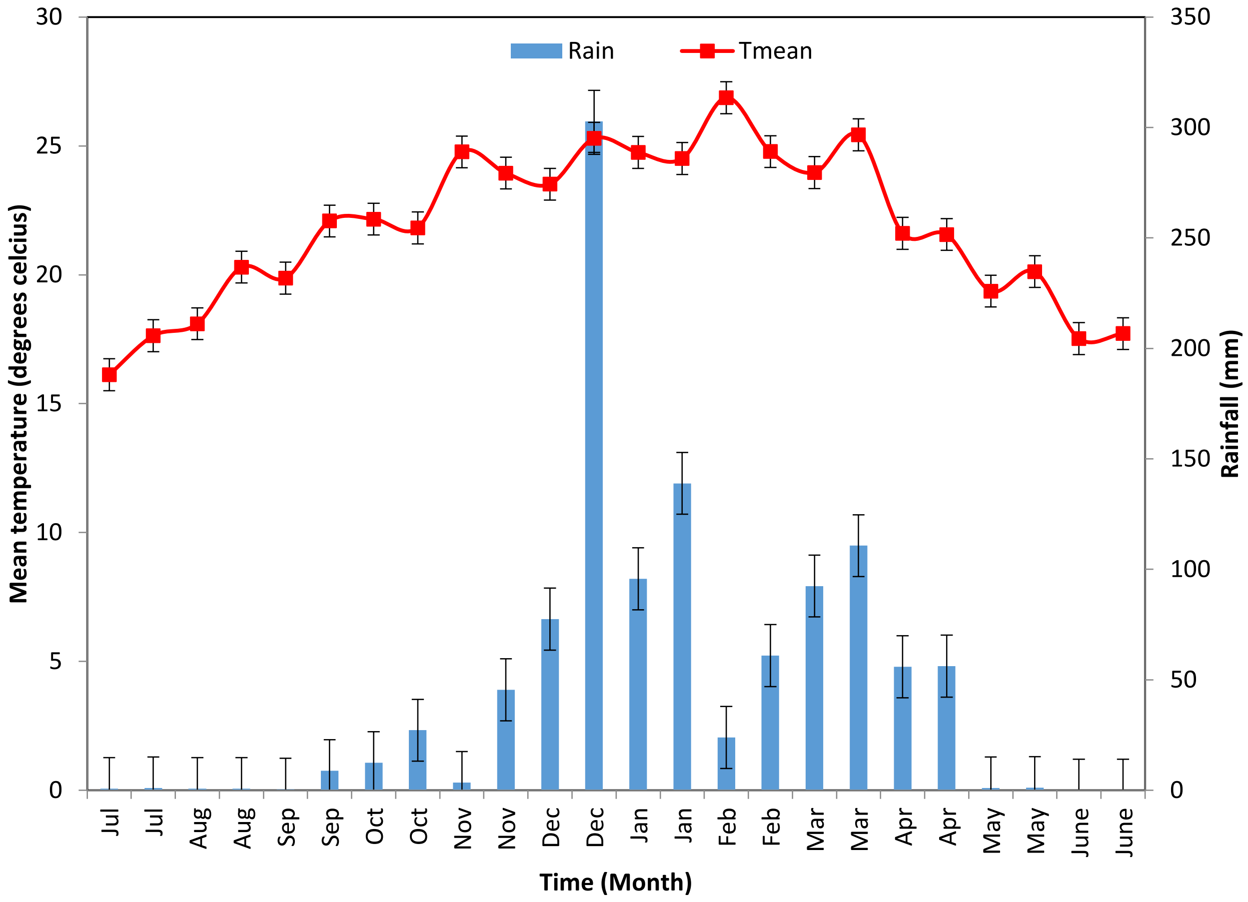


Figure 10.1 Rainfall totals and mean monthly temperatures for Thohoyandou (1984-2015)

10.2.2 Experimental design

The FAO AquaCrop model 5.0 of 2015 that was calibrated and validated using data collected in 2014 and 2015 respectively at the University of Venda's Experimental Station, Thohoyandou was used for simulating future biomass and yield of chickpea crop for the years ranging from 1950 to 2100. Future heat use efficiency and water use efficiency were calculated from grain yield, accumulated growing degree days and transpiration, respectively, which were simulated by AquaCrop model. The model used daily climate datasets that were computed as averages made from 15 Global circulation models (GCMs) from the Coupled Model Intercomparison Project phase 5 (CMIP 5). Datasets were recommended in accordance with CMIP 5 agreement of medium mitigation representative pathway scenario (RCP 4.5) and high representative pathway emissions scenario (RCP 8.5).

10.2.3 Development of AquaCrop simulations

The model was run based on the following planting date conditions:

i) Using the planting dates that are currently being used by farmers in the region for growing chickpea, i.e. 1 May, 14 May and 28 May representing early, normal and late planting dates respectively.

ii) Using futuristic optimal planting dates that were recommended by AquaCrop model 5.0 developed using future probabilistic climate data. These planting dates are presented in Fig 10. 2

The first simulation scenario was designed to investigate the impact of climate change on chickpea biomass and grain yield, using the current planting dates. The second scenario was designed to test the usefulness of the recommended planting dates (by the model) as adaptive strategy to climate change.

10.2.3.1 Development of planting date recommendations by AquaCrop model

The crop parameters for chickpea already calibrated in Chapter 8 were used for determining planting dates. A medium maturity (Range 3 cultivar) with 130 days life cycle was used for the simulations. A temperature criteria in the AquaCrop crop file was used for determining the planting dates. This involved selecting a chickpea base temperature of 8 ^{o}C in the model and uploading the start search date and month (from April to end of June). Selection of planting date within this range was based on "a day with daily minimum air temperature in a 14-day period; of at least 8 ^{o}C". The 14 days relate to time from planting to seedling emergence, whilst 8 ^{o}C is the base temperature for chickpea. Fig 10.2 depict a series of planting dates that were recommended by the model from 1950 until 2100.

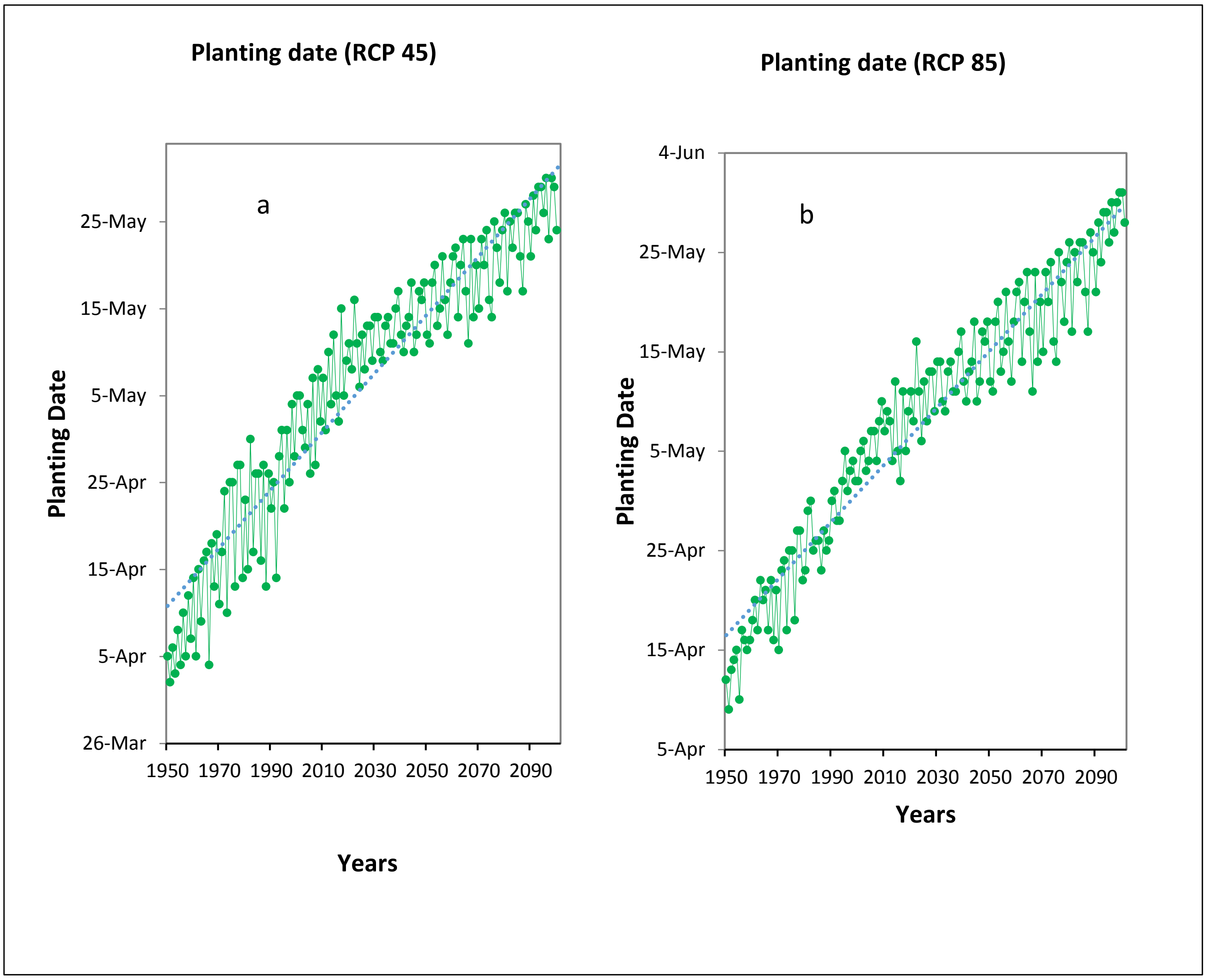


Fig 10.2 Futuristic optimal planting dates that were recommended by AquaCrop model 5.0

10.2.3.2 Calculation of water use efficiency of grain yield (WUE_g)

This study adopted the physiological definition of WUE as the ratio of grain yield to crop transpiration (Sinclair et al., 1984; Anwar et al., 2000). Thus, WUE_g was calculated for RCP 4.5 and 8.5 in all the planting date treatments according to equation 10.1 below (Sinclair et al., 1984; Anwar et al., 2000). The simulated transpiration and grain yield from AquaCrop model were used to calculate WUE in the study.

$$WUE = \frac{Grain\ yield\ (t\ ha^{-1})}{transpiration\ rate\ (mm)}\ \ x\ 100\ \% \qquad 10.1$$

Transpiration (Tr): AquaCrop calculates transpiration as a product of crop coefficient (K_{cb}) and the evaporative power of the atmosphere (ETo). This calculation is done by considering water stress factor (Ks) as shown in equation 10. 2. In circumstances where water shortage provokes closure of stomatal openings, a stress coefficient (Ks_{sto}) is considered.

$$Tr = K_s.(K_{cbx}.\ CC^*).ETo \qquad 10.2$$

Where CC* is crop canopy cover adjusted for inter-row micro-advection.

Grain yield (Y): AquaCrop simulates grain yield as a product of above ground biomass and the harvest index as shown in equation 10.3.

$$Y = f_{HI}.HI_o.B \qquad 10.3$$

Where f_{HI} is a multiplier factor which considers various stresses that may affect harvest index (HI) from its reference value. HI is the ratio of grain yield to total dry matter of the crop and is affected by water and temperature stress before the beginning of yield formation, at flowering and during yield formation. Thus HI is constantly adjusted during yield formation (Raes et al., 2011) and is affected by water stress during various stages of crop development.

The model simulated aboveground biomass for each day during crop cycle using equation 10.4 (Raes et al., 2011). The aboveground biomass was calculated by the model as a function of temperature stress coefficient, water productivity and the summation of the ratio of crop transpiration to the reference evapotranspiration.

$$B = K_{sb}.W^{P^*}\sum\frac{T_r}{ETo} \qquad 10.4$$

Where K_{sb} is the temperature stress coefficient. WP* is water productivity and is normalised for place and climate. T_r is crop transpiration and is normalised for climate by reference evapotranspiration for each day of transpiration.

10.2.3.3 Calculation of Carbon dioxide productivity (CP)

CP was defined as the fraction of grain yield (kg ha^{-1}) per unit volume of carbon dioxide concentration. CP is not calculated in AquaCrop model and hardly any literature has defined this parameter. Thus CP was calculated for RCP 4.5 and 8.5 in all the planting date treatments, according to equation 10.5 below. The simulated grain yield from AquaCrop model for the years 1950-2100 together with carbon dioxide concentration adopted from measurements made at Mauna Loa observatory in Hawaii (USA) was used to calculate CP.

$$CP = \frac{Grain\ yield\ (t\ ha^{-1})}{Carbon\ dioxide\ concentration\ (\ ppm)} \qquad 10.5$$

10.2.3.4 Calculation of Heat use efficiency (HUE$_g$)

AquaCrop model does not calculate HUE but computes growing degree days (GDD) using equation 10.6; is based on the parameterised base temperature and upper temperature threshold for the crop. In this study, a base temperature of 8 ^oC (Thangwana and Ogola 2012) and an upper temperature threshold (32 ^oC) adopted from experiments by Devasirvatham et al., (2012) were used.

$$GDD = \frac{T_{max}+T_{min}}{2} - T_{base} \qquad 10.6$$

Where, T_{max} is the maximum temperature for the day, and T_{min} is the minimum temperature for the day, T_{base} is the temperature below which no growth takes place.

GDD units were calculated for each day from the date of planting until date of physiological maturity and summed up to give one cumulative heat units value (AGDD). HUE$_g$ was calculated for RCP 4.5 and 8.5 in all the planting date treatments using equation 10.7 (Rao et al., 1999). The simulated grain yield together with accumulated growing degree days, both from AquaCrop model for the years 1950-2100, were used to calculate HUE$_g$.

$$HUE = \frac{Grain\ yield\ (t\ ha^{-1})}{Accumulated\ growing\ degree\ days\ (\ o_C.day)} \quad x\ 100\ \% \qquad 10.7$$

10.2.4 Data analysis

The non-parametric Mann-Kendall test was used to assess a significant trend in biomass, grain yield, heat use efficiency and water use efficiency of chickpea over the years 1950 to 2100. The cumulative sum test was used to determine the presence of change point in simulated data. The level of variance in simulated yield was evaluated by the variability test.

10.2.4.1 Mann- Kendall test (MK test)

MK test was used for trend-detection for biomass, grain yield, heat use efficiency and water use efficiency of chickpea. MK test is computed as follows:

$$Z_{MK} = \begin{cases} \frac{s-1}{\sqrt{var\ s}} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s+1}{\sqrt{var(s)}} & if\ s < 0 \end{cases} \qquad 10.8$$

Z_{MK} is the normalised MK test statistic, *S* is the MK test statistic and is defined as follows:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sign\ (x_j - x_i) \qquad 10.9$$

The variance of S in the x values is given as follows:

$$Var\ (S) = \frac{1}{18}[n\ (n-1)(2n+5) - \sum_{i=1}^{m}(t_i - 1)(2t_i + 5)] \qquad 10.10$$

Where *xj* and *xi* are sequential data values (Kendal, 1975; Mann, 1945). m is the number of tied groups (a tied group is a set of sample data having the same value), ti is the number of data points in the ith group and n is the length of data set (Kendal, 1975; Mann, 1945).

Xlstat, (2016) software was used to perform to the MK test. The null hypothesis was tested at 95% confidence level for all parameters under evaluation.

10.2.4.2 Variability test

The variability test was performed by computing the coefficiency of variance (CV) as follows:

$$CV = \frac{S}{\bar{X}} \quad x\ 100\ \% \qquad \text{(Hennemuth et al., 2013)} \qquad 10.11$$

Where S is the standard deviation and $\bar{X}$ is the statistical mean.

10.2.4.3 The cumulative sum test (Cumsum)

Cumsum test was performed to find out in which year was an abrupt/sudden change in temperature, ETo, AGDD and planting dates. The test was conducted only in datasets where Mk test showed significant trend. The cumsum test was computed as follows:

$$S_K = \sum_{t=1}^{k}(x_t - \bar{x}), \text{ k = (1, 2…, n)} \quad \text{(Hennemuth et al., 2013)} \quad 10.12$$

Where t is time in years, k is dataset.

The possible abrupt change was observed when S_k was at maximum (Navares and Aznarte, 2017).

10.3 Results

10.3.1 Aboveground biomass.

Chickpea biomass varied with planting date and with the representative pathway emission scenario. The results showed a significant (P value <0.001) increase in biomass for the years from 1950 to 2100 in both representative pathway emission scenarios (RCP 4.5 and 8.5). Planting dates that were recommended by AquaCrop model recorded highest biomass compared to early, normal and late planting dates (Fig10.3). The late planting date recorded the lowest biomass. RCP 8.5 had higher biomass compared to RCP 4.5.

In all planting dates, biomass gradually increased during the 1950s up until 2010, and started falling until the year 2040, before it sharply increased up until the year 2100 (Fig10.3). In RCP 4.5 scenario, planting dates that were recommended by AquaCrop model showed a 24.5% increase in biomass from 2.0 t ha^{-1} in 1950 to 2.49 t ha^{-1} in 2010, where it fell by 3.8% and stabilized at 2.4 t ha^{-1} in 2040, before rising by 79.2% to 4.3 t ha^{-1} in 2100 (Fig10.3 a). Biomass in early planting date increased gradually by 19% from 2.1 t ha^{-1} in 1950 to 2.5 t ha^{-1} in 2010 but fell by 4.2% to 2.4 t ha^{-1} in 2040, before increasing by 45.8% to 3.5 t ha^{-1} in 2100 (Fig10.3 c). Similarly, biomass for normal planting date was 1.67 t ha^{-1} in 1950s and slightly increased by 18.6% to 1.98 t ha^{-1} in 2012, where it fell by 13.14% and stabilized at 1.75 t ha^{-1} in 2040, before it rose by 31.4% to 2.3 t ha^{-1} in 2100 (Fig10.3 e). Biomass for the late planting date fell by 4.3% from 1.95 t ha^{-1} in 1950s to 1.87 t ha^{-1} in 1980, where it rose by 15.5% to 2.16 t ha^{-1} in 2010 before falling steadily by 16.8% and stabilized at 1.85 t ha^{-1} in 2040, but finally rose steadily by 16.8% to 2.16 t ha^{-1} in 2100 (Fig10.3 g).

Under RCP 8.5 scenario, planting dates recommended by AquaCrop model (Fig10.3 b) showed a similar increase in biomass by 20% from 2.05 t ha^{-1} in 1950s to 2.46 t ha^{-1} in 2030, but remained stable until 2040 before it finally rose by 85.8% to 4.57 t ha^{-1} in 2100. Biomass for the early planting date was slightly above 2.1 t ha^{-1} in 1950 and sharply rose by 14.3% to 2.4 t ha^{-1} in 1955, before falling slightly by 4.3% to 2.3 t ha^{-1} in 1970, where it remained steady until 1980 and rose sharply by 8.7% to 2.5 t ha^{-1} in 2010 (Fig10.3 d). From this period, biomass started falling and got stable at 2.3 t ha^{-1} 2040 where it increased steadily until it reached 2.8 t ha^{-1} in 2100. Biomass for the normal planting date was 1.67 t ha^{-1} in 1950s, increased by 5.3% to 1.76 t ha^{-1} in 2030 and finally rose by 63.6% to 2.88 t ha^{-1} in 2100 (Fig10.3 f). Biomass for the late planting date fell by 6% from 1.94 t ha^{-1} in 1950s to 1.83 t ha^{-1} in 2030 but finally rose by 26.2% to 2.31 t ha^{-1} in 2100 (Fig10.3h).

The variability test showed different coeffient of varience (CV) in biomass in all planting dates (Table 10.1). RCP 4.5 had lower CV compered to RCP 8.5. Lowest CV (6.6, and

8.8%) for RCP 4.5 and 8.5, respectively was observed on late planting date, whilst highest CV of 17.3% was recorded in AquaCrop recommended planting dates in RCP 4.5 and in early planting date (27.3%) in RCP 8.5. Cumulative sum tests on biomass depicted (Table 10. 3) abrupt changes in RCP 4.5 scenario, in the years 1960, 1980, 2010 and 2040 in aquaCrop recommended planting dates, and in the years 1995, 2010, 2040 and 2060 in early planting date, 1975, 1995, 2010, and 2040 in normal planting date and 1975, 2010, 2040 and 2065 in late planting date. In RCP 8.5, abrupt changes were noted in the years 1960, 1980, 2010 and 2040 in aquaCrop recommended planting dates, and in the years 1980, 2000, 2027 and 2040 in early planting date, 1980, 2000, 2010 and 2040 in normal planting date and 1980, 2010, 2040 and 2070 in late planting date.

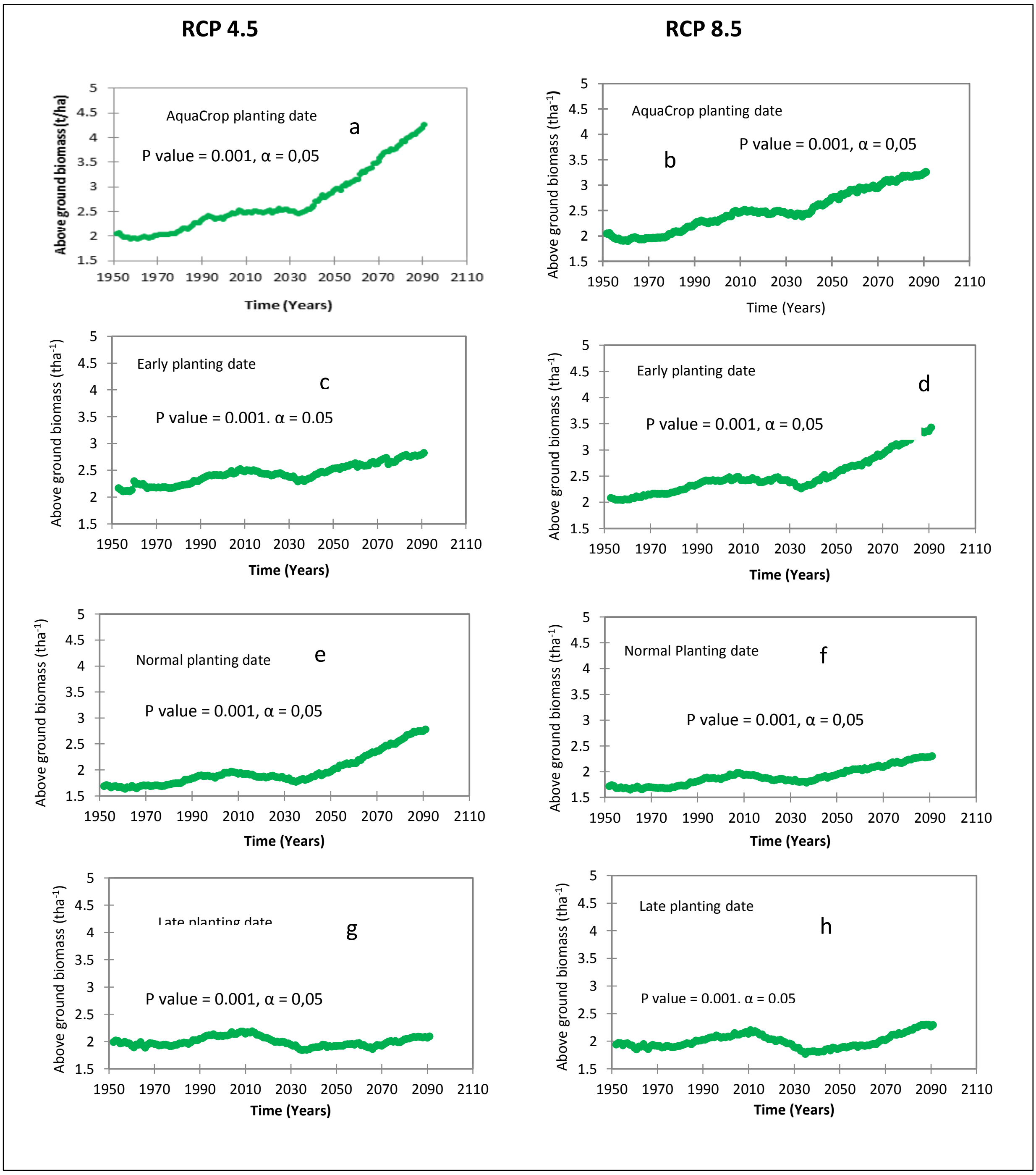


Figure 10.3 Effect of planting date on chickpea Biomass.

Table 10.1 Variability test results for WUE, HUE, biomass and grain yield.

	Coefficient of Variance (%)									
	Grain Yield		**Biomass**		**WUE**		**HUE**		**CP**	
RCP	**4.5**	**8.5**	**4.5**	**8.5**	**4.5**	**8.5**	**4.5**	**8.5**	**4.5**	**8.5**
AquaCrop planting dates	17.2	26.0	17.3	25.6	20.3	29.8	9.2	13.8	6.7	13.8
Early planting date	9.6	28.8	9.3	27.3	20.8	29.7	9.6	16.3	12.9	16.3
Normal Planting date	11.3	18.5	10.7	17.3	22.3	29.3	11.2	18.5	12.9	17.4
Late planting	7.2	9.5	6.6	8.8	14.5	21.6	7.3	9.4	20.4	27.8

Table 10.2 Cumulative Sum test for WUE, CP, HUE, Biomass and Grain Yield

Planting date	WUE_g	HUE	CP	Biomass	Grain Yield
RPC 4.5					
AquaCrop planting dates	2020, 2030 2035, 2060	1980, 2010 2040, 2070	1995, 2010 2040, 2070	1960, 1980, 2010, 2040	2020, 2035 2035, 2060
Early planting dates	2020, 2035 2035, 2060	1955, 1990 2040, 2070	1995, 2010 2040, 2060	1955, 1970 2010, 2040	2020, 2035 2035, 2060
Normal planting dates	2020, 2035 2035, 2060	1975, 2010 2040, 2060	1975, 1995 2010, 2040	1980, 2000 2010, 2040	2020, 2035 2035, 2060
Late planting dates	2020, 2035 2035, 2060	1970, 1990 2010, 2040	1975, 2010 2040, 2065	1970, 2000 2010, 2040	2020, 2035 2035, 2060
RCP 8.5					
AquaCrop planting dates	2020, 2030 2035, 2060	1980, 2010 2040, 2070	1995, 2010 2040, 2070	1960, 1980 2010, 2040	2020, 2035 2035, 2060
Early planting dates	2020, 2035 2035, 2060	1955, 1990 2040, 2070	1960, 2010 2040	1980, 2000 2027, 2040	2020, 2035 2035, 2060
Normal planting dates	2020, 2035 2035, 2060	1975, 2010 2040, 2060	1975, 1995 2010, 2040	1980, 2000 2010, 2040	2020, 2035 2060
Late planting dates	2020, 2035 2035, 2060	1970, 1990 2010, 2040	2000, 2010 2040	1980, 2010 2040, 2070	2020, 2035 2035, 2060

10.3.2 Effect of planting date on chickpea grain yield.

Chickpea grain yield showed a significant (P value <0.001) increase with time in the years from 1950 to 2100 in both representative pathway emission scenarios (RCP 4.5 and 8.5). Grain yield varied with planting dates and with the representative pathway emission scenarios (Fig 10.4). AquaCrop recommended planting dates recorded highest grain yield whilst late planting dates had the lowest yield. The high representative pathway scenario (RCP 8.5) showed a greater yield compared to the medium representative pathway scenario (RCP 4.5) for the period from 1950 to 2100.

In RCP 4.5 scenario, grain yield in planting dates that were recommended by AquaCrop model was 1.07 t ha^{-1} in 1953 and fell by 8% to 0.99 t ha^{-1} in 1961 (Fig 10.4 a). From this period, the yield rose gradually by 26.3% until it stabilised in 2010 at 1.25 t ha^{-1} before it rose sharply by 34.4% in 2040 until it reached a yield of 1.68 t ha^{-1} in 2100. In early planting date, grain yield was 1.08 t ha^{-1} in 1955 and gradually increased by 17.6% and stabilized at 1.27 t ha^{-1} in 2010 (Fig 10.4 c). From this period the yield fell steadily by 10.4% to 1.15 t ha^{-1} in 2040, where it rose sharply by 46% to 1.68 t ha^{-1} in 2100. In normal planting date, grain yield was 0.77 t ha^{-1} in 1954, and slowly fell by 5.5% to 0.73 t ha^{-1} in 1977 before rising steadily by 15.1% to 0.84 t ha^{-1} in 2010 (Fig 10.4 e). From this period, the yield fell gradually by 12% and reached a yield of 0.75 t ha^{-1} in 2040, before it rose sharply by 33.3% to 1.0 t ha^{-1} in 2100. In late planting date, grain yield was 0.72 t ha^{-1} in 1954, slowly fell by 7.4% to 0.67 t ha^{-1} in 1966 and remained stable until 1985 when it rose by 16.4% to 0.78 t ha^{-1} in 2010 (Fig 10.4 g). From this period, the yield fell sharply by 23.8% to 0.63 t ha^{-1} in 2040, where it stabilized and rose by 17.5% to 0.74 t ha^{-1} the year 2100.

In RCP 8.5 scenario, planting dates recommended using AquaCrop model recorded a yield of 1.08 t ha^{-1} in 1954, which further fell by 8% to 1.0 t ha^{-1} in 1961 (Fig 10.4 b). From this period, the yield rose gradually by 24% and stabilised at 1.24 t ha^{-1} in 1992, before it began to rise steadily in 2040 until it reached a yield of 2.21 t ha^{-1} in 2100. In early planting date, grain yield was 1.04 t ha^{-1} in 1955, and rose by 19.2% to 1.25 t ha^{-1} in 1995, remained stable for years until 2040 when it rose steeply by 66.4% to 2.08 t ha^{-1} in 2100 (Fig 10.4 d). In normal planting date, grain yield was 0.75 t ha^{-1} in 1954 and rose by 12% to 0.84 t ha^{-1} in 2010 (Fig 10.4 f). From this period, the yield fell by 13.5% to a yield of 0.74 t ha^{-1} in 2040 before it rose steadily by 64.9% to 1.22 t ha^{-1} in 2100. Furthermore, in late planting date (Fig 10.4 h), grain yield was 0.69 t ha^{-1} in 1952, remained stable from that period until 1977 where it began to rise and reached a yield of 0.77 t ha^{-1} in 2010. From this period, grain yield fell by 26.2% until it stabilized at 0.61 t ha^{-1} in 2040 before it rose persistently by 32.8% to 0.81 t ha^{-1} in 2100.

The variability test showed different CVs in grain yield amongst all planting dates (Table 10.1). RCP 4.5 had lower CVs compered to RCP 8.5. Lowest CV (7.2, and 9.5%) for RCP 4.5 and 8.5 respectively was observed on late planting date, whilst highest CV of 17.2% was recorded in AquaCrop recommended planting dates in RCP 4.5 and in early planting date (28.8%) in RCP 8.5. Cumulative sum tests on grain yield showed (table 10.2) abrupt changes in RCP 4.5 scenario, in the years 1960, 1980, 2010 and 2040 in AquaCrop recommended planting dates, and in the years 1995, 2010, 2040 and 2060 in early planting date, 1975, 1995, 2010, and 2040 in normal planting date and 1975, 2010, 2040 and 2065 in late planting date. In RCP 8.5, abrupt changes were noted in the years 1096, 1980, 2010 and 2040 in aquaCrop recommended planting dates, and in the years 1980, 2000, 2027 and 2040 in early planting date, 1980, 2000, 2010 and 2040 in normal planting date and 1980, 2010, 2040 and 2070 in late planting date.

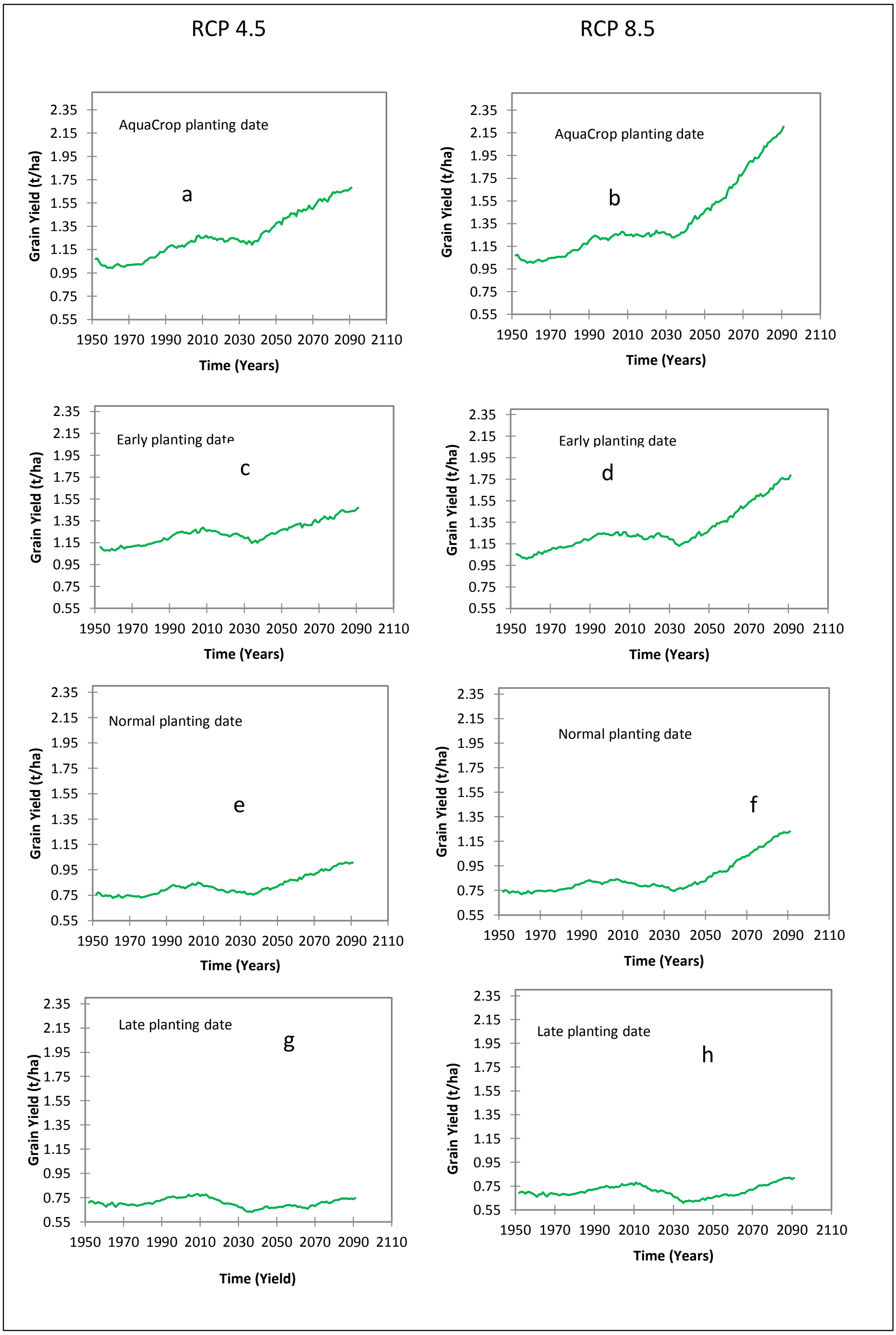


Figure 10.4 Effect of planting date on chickpea Grain yield. . a & b are planting dates generated by AquaCrop model, c & d are early planting dates, e & f are normal planting

dates and g & h are late planting dates.   All the trends were significant at P-value 0.001 and α = 0.05

10.3.3 Water use efficiency

Fig 10.5 depicts graphs of MK test results on the effect of planting date on water use efficiency of grain yield, computed as annual averages from 15 GCMs datasets. Time series analysis of mean water use efficiency (WUE) revealed statistically significant (P value <0.0001) increase in efficiency for the years from 1950 to 2100 in both representative pathway emission scenarios (RCP 4.5 and 8.5) (Fig 10.5). However, RCP 8.5 showed greater water use efficiency compared to the medium representative pathway scenario (RCP 4.5). Highest WUE_g in both RCP 4.5 and RCP 8.5 was observed in planting dates that were recommended by AquaCrop model. Whilst lowest WUE_g in both RCP 4.5 and RCP 8.5 was observed in late planting dates. In RCP 4.5, WUE_g increased by 33% during the period from 1950 to 2030 using planting dates recommended by AquaCrop (Fig10.5 a), whilst the increase was 20% using early planting dates (Fig10.5 c) and 19% using normal planting dates (Fig10.5 e). The late planting date showed WUE_g to increase by 26% from 1950 to 2030 (Fig10.5 g).

Furthermore, planting dates that were recommended by AquaCrop model showed 100% increase in WUE_g for the period between 2030 and 2100, whilst early planting date had 123%, and the normal planting date had an increase of 82%. The late planting date showed WUE_g to increase by 49% from 2030 to 2100.

In RCP 8.5, WUE_g increased by 19% during the period from 1950 to 2030 using planting dates recommended by AquaCrop (Fig10.5 b), whilst the increase was 29% when using early or normal planting dates (Fig 10.5 d and f). The late planting date showed WUE_g to increase by 36% from 1950 to 2030 (Fig10.5 h). Furthermore, planting dates that were recommended using AquaCrop model showed 38% increase in WUE_g for the period between 2030 and 2100, whilst early planting date had 123%, and the normal planting date had an increase of 47%. The late planting date showed WUE_g to increase by 22% from 2030 to 2100.

The variability test showed different co-efficient of variation (CVs) for WUE amongst all planting dates (Table 10.1). Lowest CV (14.5 - 21.6%) for WUE was observed on late planting date, whilst early planting date and planting dates that were recommended using AquaCrop model recorded highest CVs (20.3%- 29.7%). Cumulative sum tests on WUE time series depicted abrupt changes in efficiency in the years 2020 and 2035 under RCP 4.5 and in the years 2020, 2030 2035 and 2060 under RCP 8.5 (Table 10.2) in all planting dates.

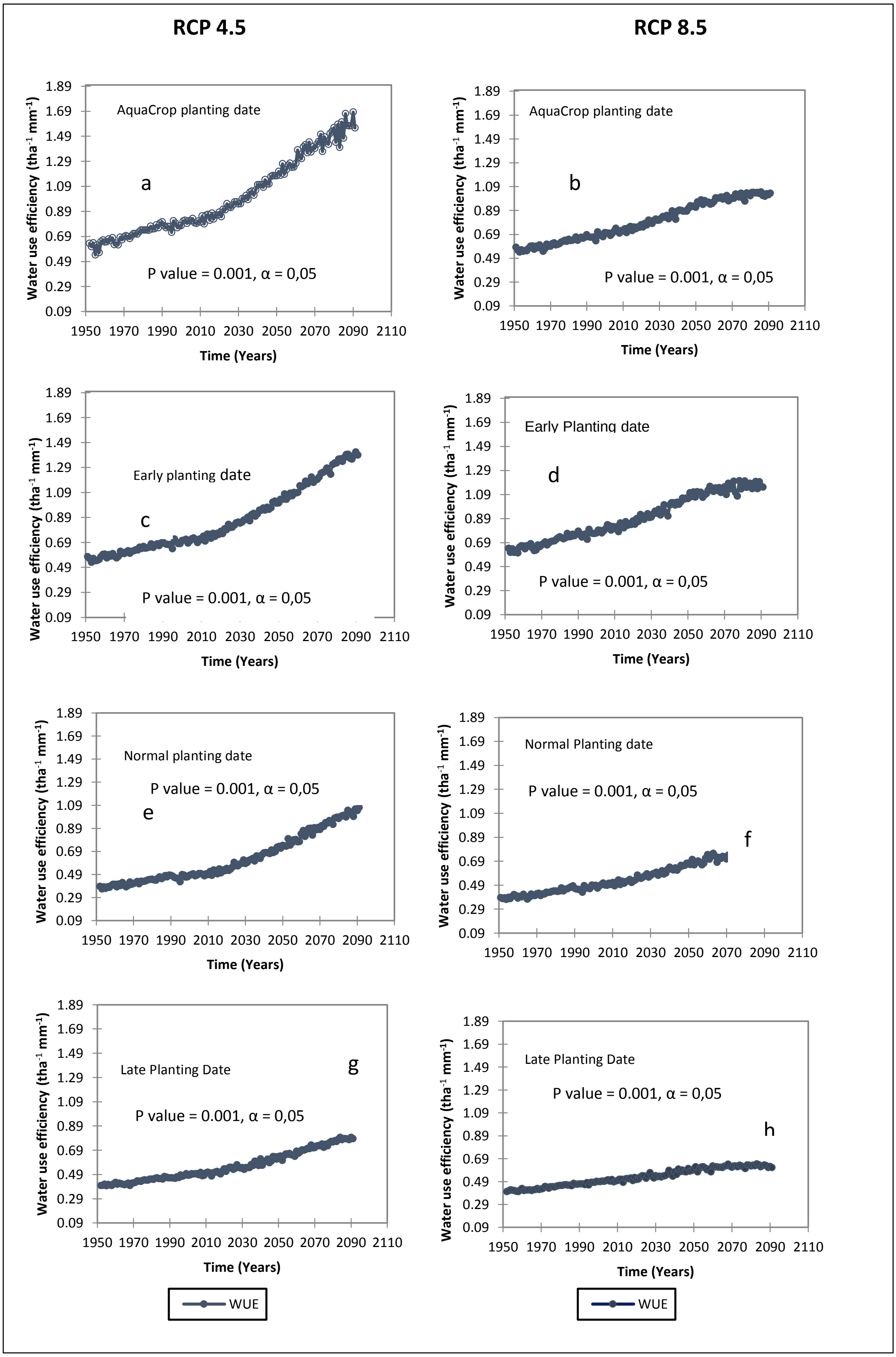

RCP 4.5
RCP 8.5
AquaCrop planting date
a
P value = 0.001, α = 0,05
AquaCrop planting date
b
P value = 0.001, α = 0,05
Early planting date
c
P value = 0.001, α = 0,05
Early Planting date
d
P value = 0.001, α = 0,05
Normal planting date
P value = 0.001, α = 0,05
e
Normal Planting date
P value = 0.001, α = 0,05
f
Late Planting Date
g
P value = 0.001, α = 0,05
Late Planting Date
P value = 0.001, α = 0,05
h
Water use efficiency (tha-1 mm-1)
1.89 1.69 1.49 1.29 1.09 0.89 0.69 0.49 0.29 0.09
1950 1970 1990 2010 2030 2050 2070 2090 2110
Time (Years)
WUE

Figure 10.5. Effect of planting date on chickpea water use efficiency. a & b are planting dates generated by AquaCrop model, c & d are early planting dates, e & f are normal planting dates and g & h are late planting dates.

10.3.4 Carbon dioxide productivity (CP)

CP showed a significant decreasing trend (P value <0.0001) with time from 1950 to 2100 in all planting dates. CP was observed to vary with planting date and also with the representative pathway emission scenario. The early planting date and planting dates that were recommended using AquaCrop model recorded highest CP, whilst the late planting date had the lowest CP. In RCP 4.5 scenario, planting dates that were recommended by AquaCrop model (Fig10.6 a) had a CP of 0.360 t ha^{-1} pmm^{-1} in 1950s and it decreased by 9.1% to 0.330 t ha^{-1} pmm^{-1} in 1995, but eventually increased by 12.1% to 0.370 t ha^{-1} pmm^{-1} in 2010, before decreasing sharply by 32.1% to 0.280 t ha^{-1} pmm^{-1} in 2040. CP for the early planting date was 0.350 t ha^{-1} pmm^{-1} in 1950 and remained stable until 2010 before it eventually fell by 29.6% to 0.270 t ha^{-1} pmm^{-1} in 2040 and remained stable at that value until 2100 (Fig10.6 c). CP for the normal planting date (Fig10.6 e) was 0.240 t ha^{-1} pmm^{-1} in 1950s and slightly fell by 4.3% to 0.230 t ha^{-1} pmm^{-1} in 2012, where it fell sharply by 27.8% and stabilized at 0.180 t ha^{-1} pmm^{-1} in 2031, before it slowly rose by 27.8% to 0.230 t ha^{-1} pmm^{-1} in 2100. CP for the late planting date was observed to slowly fell by 15% from 0.230 t ha^{-1} pmm^{-1} in 1950s to 0.200 t ha^{-1} pmm^{-1} in 2010, where it sharply fell by 37% to 0.145 t ha^{-1} pmm^{-1} in 2040 and remained stable until 2100 (Fig10.6 g).

In RCP 8.5 scenario, planting dates that were recommended by AquaCrop model (Fig10.6 b) had a CP of 0.345 t ha^{-1} pmm^{-1} in 1950, fell by 7.8% to 0.320 t ha^{-1} pmm^{-1} in 1965 and rose by 10.9% to 0.355 t ha^{-1} pmm^{-1} in 2010, before falling by 26.8% and stabilized at 0.280 t ha^{-1} pmm^{-1} in 2040, where it remained stable until 2100. Furthermore, CP for the early planting date was 0.330 t ha^{-1} pmm^{-1} in 1950 and slowly rose by 6.1% to 0.350 t ha^{-1} pmm^{-1} in 2010, where it fell sharply by 34.6% to 0.260 t ha^{-1} pmm^{-1} in 2040 and started falling slowly over the years until it reached a CP of 0.220 t ha^{-1} pmm^{-1} in 2100 (Fig10.6 d). The normal planting date had a CP of 0.240 in 1950 and gradually fell by 2.1% to 0.235 t ha^{-1} pmm^{-1} in 2010 before it fell sharply by 38.2% to 0.170 t ha^{-1} pmm^{-1} in 2040, where it slowly fell by 7.6% to 0.158 t ha^{-1} pmm^{-1} in 2100 (Fig10.6 f). Moreover, CP for the late planting date (Fig10.6 h) was 0.226 t ha^{-1} pmm^{-1} in 1950, but gradually fell by 12.4% to 0.201 t ha^{-1} pmm^{-1} in 2010, where it sharply fell by 39.6% to 0.144 t ha^{-1} pmm^{-1} in 2040, and gradually fell by 3.6% to 0.139 t ha^{-1} pmm^{-1} in 2100.

The results showed different co-efficient of variations (CVs) in CP amongst all planting dates (Table 10.1). RCP 4.5 had lower CVs compered to RCP 8.5. Lowest CV (6.7, and 13.8%) for

RCP 4.5 and 8.5, respectively was observed on AquaCrop recommended planting dates, whilst late planting dates recorded highest CVs (20.4%, 27.8% for RCP 4.5 and 8.5, respectively. Cumulative sum tests on CP time series depicted (Table 3 abrupt changes in efficiency in RCP 4.5, in the years 1995, 2010, 2040 and 2070 in AqauCrop recommended planting dates, and in the years 1995, 2010, 2040 and 2060 in early planting date, 1975, 1995, 2010, and 2040 in normal planting date and 1975, 2010, 2040 and 2065 in late planting date. In RCP 8.5, abrupt changes were noted in the years 1995, 2010, 2040 and 2070 in AquaCrop recommended planting dates, and in the years 1960, 2010, and 2040 in early planting date, 1975, 1995, 2010 and 2040 in normal planting date and 2000, 2010, and 2040 in late planting date.

10.3.5 Heat use efficiency of grain yield (HUE_g)

Averaged across 15 GCMs, HUE_g was generally shown to increase in all planting dates. Time series evaluation of mean HUE_g for all planting dates showed a significant (P value <0.0001) increase in HUE_g for the period from 1950 to 2100 in both RCP 4.5 and 8.5. HUE_g was observed to vary with planting date and also with the representative pathway emission scenario. Planting dates that were recommended using AquaCrop model recorded highest HUE_g compared to early, normal and late planting dates. The late planting date had the lowest HUE_g.

In all planting dates, HUE_g was observed to follow a sinusoidal periodic motion, characterised by a gradual increase in HUE_g during the 1950s up until 2010, and started felling until 2040s before increasing sharply up until 2100 (Fig10.6). In RCP 4.5 scenario, planting dates that were recommended by AquaCrop model (Fig10.6 a) showed a 13.9% increase in HUE_g from 0.072 t ha^{-1} $^oC.day^{-1}$ in 1950s to 0.082 t ha^{-1} $^oC.day^{-1}$ in 2010 where it fell by 9.3% and stabilized at 0.075 t ha^{-1} ^oC in 2040, before rising sustainably by 60% to 0.12 t ha^{-1} $^oC.day^{-1}$ in 2100. HUE_g for the early planting date (Fig10.6 c) increased gradually by 10% from 0.07 t ha^{-1} $^oC.day^{-1}$ in 1950s to 0.077 t ha^{-1} $^oC.day^{-1}$ in 1995 and slowly fell by 6.9% to 0.072 t ha^{-1} $^oC.day^{-1}$ in 2040s, before increasing sharply by 48.6% to 0.107 t ha^{-1} $^oC.day^{-1}$ in 2100. HUE_g for the normal planting date (Fig10.6 e) was 0.053 t ha^{-1} $^oC.day^{-1}$ in 1950s and slightly increased by 9.4% to 0.058 t ha^{-1} $^oC.day^{-1}$ in 2012, where it fell sharply by 23.4% and stabilized at 0.047 t ha^{-1} $^oC.day^{-1}$ in 2031, before it rose by 34% to 0.063 t ha^{-1} $^oC.day^{-1}$ in 2100. HUE_g for the late planting date (Fig10.6 g) was observed to fell by 4.5% from 0.070 t ha^{-1} $^oC.day^{-1}$ in 1950s to 0.067 t ha^{-1} $^oC.day^{-1}$ in 1960, where it rose by 19.4% to 0.08 t ha^{-1} $^oC.day^{-1}$ in 2010 before falling steadily by 14.3% and stabilized at 0.07 t ha^{-1} $^oC.day^{-1}$ in 2040 and finally rose by 27.1% to 0.089 t ha^{-1} $^oC.day^{-1}$ in 2100.

Similarly, in RCP 8.5 scenario, planting dates that were recommended by AquaCrop model (Fig10.6 b) showed a 16% increase in HUE_g from 0.075 t ha^{-1} $^oC.day^{-1}$ in 1950s to 0.087 t ha^{-1} $^oC.day^{-1}$ in 2010 where it fell by 14.5% and stabilized at 0.076 t ha^{-1} ^oC in 2040, before rising by 31.6% to 0.1 t ha^{-1} $^oC.day^{-1}$ in 2100. HUE_g for the early planting date (Fig10.6 d) increased gradually by 9.1% from 0.055 t ha^{-1} $^oC.day^{-1}$ in 1950s to 0.06 t ha^{-1} $^oC.day^{-1}$ in 1990 and fell slowly by 11.1% to 0.054 t ha^{-1} $^oC.day^{-1}$ in 2040s, before increasing by 66.7% to 0.09 t ha^{-1} $^oC.day^{-1}$ in 2100. Furthermore, HUE_g for the normal planting date (Fig10.6 f) was 0.055 t ha^{-1} $^oC.day^{-1}$ in 1950s and slightly decreased by 3.8% to 0.053 t ha^{-1} $^oC.day^{-1}$ in 1960, before it rose by 3.8% back to 0.055 t ha^{-1} $^oC.day^{-1}$ in 2009 and fell sharply by 17% but stabilized at 0.047 t ha^{-1} $^oC.day^{-1}$ in 2031 and finally rose steadily by 19.1% to 0.056 t ha^{-1} $^oC.day^{-1}$ in 2100. HUE_g for the late planting date (Fig10.6 h) was relatively constant at around 0.054 t ha^{-1} $^oC.day^{-1}$ during the period between 1950 and 1970s and gradually rose by 13% to 0.061 t ha^{-1} $^oC.day^{-1}$ in 2010, where it fell by 13% and stabilized at 0.054 t ha^{-1} $^oC.day^{-1}$ in 2040 and finally rose steadily by 37% to 0.074 t ha^{-1} $^oC.day^{-1}$ in 2100.

The variability test showed different co-efficient of variation (CVs) in HUE amongst all planting dates (Table 10.1). RCP 4.5 had lower CVs compered to RCP 8.5. Lowest CV (7.3, and 9.4%) for RCP 4.5 and 8.5 respectively was observed on late planting date, whilst normal planting date recorded highest CVs (11.2%, 18.5% for RCP 4.5 and 8.5 respectively. Cumulative sum tests on HUE_g time series depicted (Table 10.2) abrupt changes in efficiency in RCP 4.5, in the years 1960, 2010, and 2040 in aquaCrop recommended planting dates, and in the years 1960, 1995, 2012 and 2040 in early planting date, 1960, 1975, 2010, 2030 and 2060 in normal planting date and 1960, 1970, 1975, 2010, 2030 and 2060 in late planting date. In RCP 8.5, abrupt changes were noted in the years 1980, 2010, 2040 and 2070 in aquaCrop recommended planting dates, and in the years 1955, 1990, 2040 and 2070 in early planting date, 1975, 2010, 2040 and 2060 in normal planting date and 1970, 1990, 2010, and 2040 in late planting date.

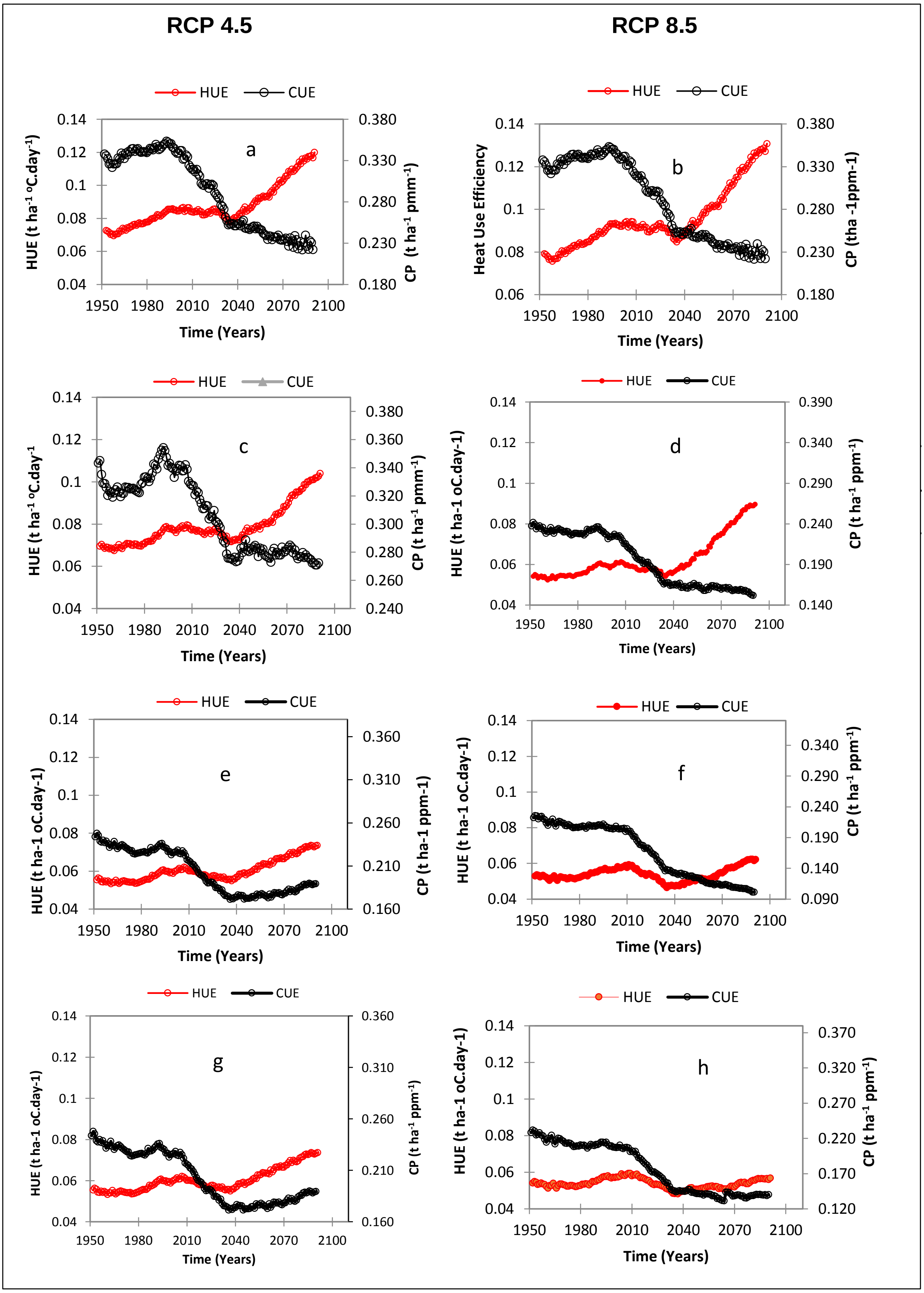

RCP 4.5
RCP 8.5
HUE
CUE
a
b
c
d
e
f
g
h
HUE (t ha-1 oC.day-1)
Heat Use Efficiency
CP (t ha-1 ppm-1)
CP (tha -1ppm-1)
Time (Years)
1950 1980 2010 2040 2070 2100

Figure 10.6. Effect of planting date on chickpea heat use efficiency and carbondioxide productivity. a & b are planting dates recommended by AquaCrop model, c & d are early planting dates, e & f are normal planting dates and g & h are late planting dates. All the trends were significant at P-value 0.001 and α = 0.05

A Pearson's product-moment correlation was run to assess the relationships between chickpea grain yield and biomass, WUE, HUE, and CP for each planting date treatment (Table 10.3). In RCP 4.5 scenario, the results for the AquaCrop recommended planting dates showed a significant ($P< 0.001$) strong positive correlation ($r > 0.9$) between grain yield and biomass, WUE and HUE, whilst a no correlation was observed between grain yield and CP. Biomass explained about 98%, WUE 86%, and HUE explaining 85% of the variation in grain yield. Early planting date showed a strong positive correlation ($r > 0.8$, and $p < 0.0001$) between grain yield and biomass, WUE, and HUE, whilst a fair correlation ($r = 0.384$, and $p < 0.0001$) between grain yield and CP was observed. Biomass explained about 97%, WUE 63%, and HUE 99% and CP explaining 15% of the variation in grain yield. Similarly the normal planting date showed a very strong positive correlation ($r > 0.8$, and $p < 0.0001$) between grain yield and biomass, WUE and HUE, whilst CP had a weak negative correlation ($r = -0.259$, and $p = 0.002$ Biomass explained about 96%, WUE 64%, and HUE 99% and CP explaining 10% of the variation in grain yield. The late planting date showed a strong positive correlation ($r > 0.9$, and $p < 0.0001$) between grain yield and biomass and HUE, whilst WUE had a weak negative correlation ($r = 0.407$, and $p< 0.0001$. No correlation was observed between grain yield and CP. Biomass explained about 96%, WUE 17%, and HUE explaining 99% of the variation in grain yield.

In RCP 8.5 scenario, AquaCrop recommended planting dates showed a significant ($P< 0.001$) strong positive correlation ($r > 0.9$) between grain yield and biomass, WUE and HUE, whilst a negative correlation ($r = - 0.519$, and $p < 0.0001$) was observed between grain yield and CP. Biomass explained about 99%, WUE 93%, HUE, 93% and CP explaining 27% of the variation in grain yield. Early planting date showed a strong positive correlation ($r > 0.6$, and $p < 0.0001$) between grain yield and biomass, WUE, and HUE, whilst no correlation between grain yield and CP was observed. Biomass explained about 75%, WUE 62%, and HUE explaining 77% of the variation in grain yield. Similarly the normal planting date showed a very strong positive correlation ($r > 0.9$, and $p < 0.0001$) between grain yield and biomass, WUE and HUE, whilst CP had a good negative correlation ($r = -0.557$, and $p <0.0001$. Biomass explained about 99%, WUE 82%, and HUE 99% and CP explaining 31% of the variation in grain yield. The late planting date showed a strong positive correlation ($r > 0.9$, and $p < 0.0001$) between grain yield and biomass and HUE, whilst WUE had a weak negative correlation (r = 0.361, and p< 0.0001. No correlation was observed between grain yield and CP. Biomass explained about 98%, WUE 13%, and HUE explaining 99% of the variation in grain yield.

Table 10. 3 Correlation between grain Yield and biomass, WUE_g, HUE_g and CP

Planting date	r				R^2				P value			
	Biomass	WUE	HUE	CP	Biomass	WUE	HUE	CP	Biomass	WUE	HUE	CP
RCP 4.5												
AquaCrop recommended Planting date	0.995	0.926	0.923	-0.014	0.989	0.858	0.852	0.001	<0.0001	<0.0001	< 0.0001	0.871
Early Planting date	0.984	0.794	0.999	-0.384	0.968	0.630	0.999	0.147	<0.0001	<0.0001	< 0.0001	< 0.0001
Normal Planting date	0.980	0.798	0.999	-0.259	0.960	0.637	0.999	0.067	<0.0001	<0.0001	< 0.0001	< 0.002
Late Planting date	0.978	0.407	0.999	-0.015	0.956	0.165	0.997	0.001	<0.0001	<0.0001	< 0.0001	0.855
RCP 8.5												
AquaCrop recommended Planting date	0.998	0.963	0.963	-0.519	0.927	0.927	0.270	0.001	<0.0001	<0.0001	< 0.0001	< 0.0001
Early Planting date	0.753	0.618	0.766	-0.007	0.567	0.382	0.587	0.001	<0.0001	<0.0001	< 0.0001	0.932
Normal Planting date	0.993	0.903	0.999	-0.557	0.986	0.816	0.999	0.311	<0.0001	<0.0001	< 0.0001	< 0.0001
Late Planting date	0.987	0.361	0.999	-0.014	0.975	0.131	0.999	0.001	<0.0001	<0.0001	< 0.0001	0.872

10.4 Discussion

Planting dates that were recommended by AquaCrop model recorded the highest increase in biomass and grain yield under both RCP 4.5 and 8.5, suggesting the importance of using decision support tools when determining planting dates for chickpea. The increase in biomass and grain yield across all planting dates was caused by better water use efficiency (WUE) and heat use efficiency (HUE). Carbon dioxide productivity (CP) decreased with climate change as expected because of increase in carbon use.

Although the negative effects of high temperature on chickpea productivity are well documented (Siddique and Sedgley, 1986; Clarke and Siddique, 2004; Wang et al*.,* 2006; Thakur et al*.,* 2010; Devasirvatham et al*.,* 2012), the results of the current study show that both aboveground biomass and grain yield of chickpea will increase with the predicted increase in temperature.

Perhaps, the negative impacts of temperature were off-set by carbon dioxide increase, leading to yield increase. Indeed, it has been reported that the possible increase in atmospheric carbon dioxide levels will improve grain yield in C_3 crops due to improved photosynthesis (Chart-zoulakis and Psarras, 2005; DaMatta et al., 2010). Chart-zoulakis and Psarras (2005) reported that the synergistic benefits of increased carbon dioxide concentration levels together with WUE may offset temperature effects in C_3 plant; WUE is directly related to grain yield (Sinclair et al., 1984). The current study results are in agreement with some earlier studies who have reported that chickpea yield will improve in future (Hajarpoor et al., 2014; Mahomed et al., 2016).

The increase in WUE shown in the study may consequently have been a result of increase in biomass and grain yield that was also recorded in the study. WUE is affected by yield and transpiration ((Sinclair et al., 1984). Although WUE is negatively affected by temperature stress since high temperatures may increase transpiration rate (Ogola et al., 2002), the results show that WUE will improve with increase in temperature. This condition may possibly be due to increase in grain yield which offset the increase in transpiration rate. The increase in HUE was partly caused by sustained yield increase. The results seem to suggest that the increase in temperature will not affect yield possibly until temperatures exceed cardinal temperatures for growth and reproduction (26^{o}C to 32 ^{o}C) of chickpea (Summerfield 1990).

However, Taiz and Zeiger, (1991) argued that future increase in temperature will enhance respiration/photorespiration and suggested higher temperatures to have an adverse effect on net photosynthesis and consequently lower crop yields. Koocheki et al, (2006) reported a likely fall in chickpea yield with climate change in India and attributed the fall to shorter growth period and reduced leaf area index. In addition, Damatta et al., (2010) argued that the increase in temperature above optimal level may reduce biomass and yield but nevertheless suggested that the rise in temperature may facilitate increased biomass and yield through facilitating more energy for translocation of photo assimilates. Chalinor et al., (2007) argued that when optimum temperature is exceeded, the strategy of increasing growing season length may still increase crop yield. However, in the study area, both the planting window and the growing season length increased with climate change and this may strengthen the case of expecting biomass and grain yield increase under climate change scenario.

Furthermore, WUE, HUE, biomass and yield from planting dates that were recommended by aqua Crop model recorded the highest coefficient of variation compared to other planting dates, suggesting a high level of variability in WUE, HUE, biomass and yield of chickpea in future. Therefore, although future yield may improve under climate change, the yield levels will not be stable and may affect planning. However, the CV for all planting dates including planting dates that were recommended by aqua Crop model were reasonably lower indicating stable findings, and thus strengthen credibility of our conclusions.

The study findings clearly indicate the possibility of using planting date as a management strategy in improving chickpea biomass and grain yield under climate change conditions. However the method of determining optimal planting dates for chickpea that may be used in future has always been a limiting factor in chickpea agronomy.

10.5 Conclusion

Chickpea biomass and grain yield were observed to improve with climate change. Planting dates that were recommended using AquaCrop model recorded highest grain yield, whilst late planting date had the lowest yield. The variation in water use efficiency (WUE), heat use efficiency (HUE) and carbon dioxide productivity (CP), biomass and grain yield observed under different planting dates was possibly due to differences in temperature and moisture patterns that were experienced by crops grown in different planting dates. Clearly, the results from the study indicate the possibility of using planting date as a management strategy in improving chickpea biomass and grain yield in the current period and also under climate change scenario. We recommend the need to work on development of a sowing (planting date) criteria for chickpea in the region given the potential importance of planting dates in improving future productivity of chickpea

References

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 2000. Water extraction patterns and water use efficiency of chickpea (Cicer arietinum L.) cultivars in Canterbury. *Agronomy New Zealand*, *30*, pp.109-120.

Birthal, P.S., Khan, M.T., Negi, D.S. and Agarwal, S., 2014. Impact of climate change on yields of major food crops in India: Implications for food security. *Agricultural Economics Research Review*, *27*(2), pp.145-155.

Breusch, T.S. and Pagan, A.R., 1979. A simple test for heteroscedasticity and random coefficient variation. *Econometrica: Journal of the Econometric Society*, pp.1287-1294.

Challinor, A.J. and Wheeler, T.R., 2008. Crop yield reduction in the tropics under climate change: processes and uncertainties. *Agricultural and Forest Meteorology*, *148*(3), pp.343-356.

Chartzoulakis, K. and Psarras, G., 2005. Global change effects on crop photosynthesis and production in Mediterranean: the case of Crete, Greece. *Agriculture, ecosystems & environment*, *106*(2-3), pp.147-157.

Clarke, H.J. and Siddique, K.H.M., 2004. Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research*, *90*(2-3), pp.323-334.

DaMatta, F.M., Grandis, A., Arenque, B.C. and Buckeridge, M.S., 2010. Impacts of climate changes on crop physiology and food quality. *Food Research International*, *43*(7), pp.1814-1823.

de Wit, C.D., Brouwer, R. and De Vries, F.P., 1970. The simulation of photosynthetic systems. In *Proceedings of the IBP/PP technical meeting, Trebon, 14-21 September 1969*(pp. 47-70).

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Tokachichu, R.N., Trethowan, R.M. and Tan, D.K., 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology*, *39*(12), pp.1009-1018.

Ehteramian, K., NoRMoHAMADI, G., Bannyan, M. and Alizadeh, A., 2012. Impacts of climate change scenarios on wheat yield determined by evapotranspiration calculation. *Zemdirbyste Agriculture*, *99*(3), pp.279-286.

Hajarpoor, A., Soltani, A., Zeinali, E. and Sayyedi, F., 2014. Simulating climate change impacts on production of chickpea under water-limited conditions. *Agric. sci. dev*, *3*(6), pp.209-217.

IPCC, 2007. Climate Change (2007). Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

IPCC, 2014. Climate change (2014): impacts, adaptation, and vulnerability. Part B: regional aspects. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.J., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (688 pp).

Jones, C.A., Kiniry, J.R. and Dyke, P.T., 1986. *CERES-Maize: A simulation model of maize growth and development*. Texas A& M University Press.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T., 2003. The DSSAT cropping system model. *European journal of agronomy*, *18*(3-4), pp.235-265.

Kalra, N., Chakraborty, D., Sharma, A., Rai, H.K., Jolly, M., Chander, S., Kumar, P.R., Bhadraray, S., Barman, D., Mittal, R.B. and Lal, M., 2008. Effect of increasing temperature on yield of some winter crops in northwest India. *Current science*, pp.82-88.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N., Meinke, H., Hochman, Z. and McLean, G., 2003. An overview of APSIM, a model designed for farming systems simulation. *European journal of agronomy*, *18*(3-4), pp.267-288.

Kendall, M., 1975. Rank correlation methods (4th edn.) charles griffin. *San Francisco, CA*, *8*.

Kharin, V.V. and Zwiers, F.W., 2000. Changes in the extremes in an ensemble of transient climate simulations with a coupled atmosphere–ocean GCM. *Journal of Climate*, *13*(21), pp.3760-3788.

Kiely, G., 1999. Climate change in Ireland from precipitation and streamflow observations. *Advances in water resources*, *23*(2), pp.141-151.

Koocheki, A., Nassiri, M., Soltani, A., Sharifi, H. and Ghorbani, R., 2006. Effects of climate change on growth criteria and yield of sunflower and chickpea crops in Iran. *Climate Research*, *30*(3), pp.247-253.

Mann, H.B., 1945. Nonparametric Tests against Trend. Econometrics, 13, 245-259. *Mantua, NJ, SR Hare, Y. Zhang, JM Wallace, and RC Francis (1997), A Pacific decadal*.

Mohammed, A., Tana, T., Singh, P., Korecha, D. and Molla, A., 2017. Management options for rainfed chickpea (Cicer arietinum L.) in northeast Ethiopia under climate change condition. *Climate Risk Management*, *16*, pp.222-233.

Nayyar, H., 2005. Putrescine increases floral retention, pod set and seed yield in cold stressed chickpea. *Journal of agronomy and crop science*, *191*(5), pp.340-345.

Ogola, J.B.O., Wheeler, T.R. and Harris, P.M., 2002. Effects of nitrogen and irrigation on water use of maize crops. *Field Crops Research*, *78*(2-3), pp.105-117.

Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E. 2011. FAO crop water productivity model to simulate yield response to water: Reference manual Chapter 1 version 3.1 plus.

Rao, V.U.M., Singh, D. and Singh, R., 1999. Heat use efficiency of winter crops in Haryana. *J. Agrometeorol*, *1*(2), pp.143-8.

Siadat, S.A. and Hemayati, S.S., 2009. Effect of sowing date on yield and yield components of three oilseed rape varieties.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Sinclair, T.R., Tanner, C.B. and Bennett, J.M., 1984. Water-use efficiency in crop production. *Bioscience*, *34*(1), pp.36-40.

Singh, P., Nedumaran, S., Boote, K.J., Gaur, P.M., Srinivas, K. and Bantilan, M.C.S., 2014. Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European journal of agronomy*, *52*, pp.123-137.

Stöckle, C.O., Donatelli, M. and Nelson, R., 2003. CropSyst, a cropping systems simulation model. *European journal of agronomy*, *18*(3-4), pp.289-307.

Summerfield RJ, Virmani SM, Roberts EH, Ellis RH, Walby BJ, Hall SD. Adaptation of chickpea to agroclimatic constraints. Chickpea in the Nineties. ICRISAT, Patancheru, India. 1990:61-72.

Taiz, L. and Zeiger, E., 1991. Plant physiology: Mineral nutrition.

Thakur, P., Kumar, S., Malik, J.A., Berger, J.D. and Nayyar, H., 2010. Cold stress effects on reproductive development in grain crops: an overview. *Environmental and Experimental Botany*, *67*(3), pp.429-443.

Thakur, P., Kumar, S., Malik, J.A., Berger, J.D. and Nayyar, H., 2010. Cold stress effects on reproductive development in grain crops: an overview. *Environmental and Experimental Botany*, *67*(3), pp.429-443.

Waha, K., Müller, C., Bondeau, A., Dietrich, J.P., Kurukulasuriya, P., Heinke, J. and Lotze-Campen, H., 2013. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change*, *23*(1), pp.130-143.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Chapter 11

General discussion

Planting chickpea genotypes at different dates within the same season may expose the crop to different environmental factors (temperature and moisture) during their vegetative and reproduction stages. The variation in temperature and moisture may consequently affect water use efficiency (WUE), heat use efficiency (HUE), and radiation use efficiency (RUE), and carbon dioxide productivity (CP), biomass and grain yield. For example, an early planting date in Southern Africa during winter may expose the crop to extremely low temperatures (less than 8 ^{o}C) which affects WUE, HUE, RUE CP, flower and pod abortion during the early reproductive stage of chickpea. In contrast, late planting of chickpea during the winter season may result in flowering stage coinciding with high temperatures during early reproduction days which may affect fruit set and hence chickpea yield. High temperatures experienced in late planting during reproduction stage may cause moisture stress as potential evapotranspiration exceeds plant available water. Moreover, the high temperatures may hasten crop development and shorten growing season length of the crop. Reduced growing season length and moisture stress are likely to affect WUE, HUE, and RUE and consequently reduce biomass and yield.

Likewise, the increase in global average temperatures and reduction of rainfall expected under climate change may result in crops planted on different dates showing variation in WUE, HUE, RUE, CP, biomass and grain yield in the same way as explained above. Thus manipulation of planting date and genotype may affect biomass accumulation and grain yield of chickpea under climate change conditions.

Therefore, the objective of the study was to determine the effect of planting date and genotype on biomass and yield of chickpea under climate change scenario in North Eastern Region of South Africa. The hypothesis tested was that planting date and genotype has an effect on biomass and yield of chickpea under climate change scenario in North Eastern Region of South Africa.

The simulation results, using 15 GCMs indicated that there is going to be a significant increase in temperature in the region of the current study under both RCP 4.5 and 8.5 (by 4.2 to 5.5 ^{o}C). This increase in temperature will lead to a concomitant increase in ETo and AGDD for chickpea. Moreover, the results from the GCMs show that optimal planting date for chickpea shifted from mid-month of April during 1950 to end of May in 2100. This will reduce chickpea growing season from 140 days to 85 days. The climate change scenario described above was shown to improve aboveground biomass and grain yield of chickpea. Planting dates that were recommended by AquaCrop model recorded the highest increase in biomass and grain yield under both RCP 4.5 and 8.5, suggesting the importance of using decision support tools when determining planting dates for chickpea. The increase in biomass and grain yield across all planting dates was caused by better water use efficiency (WUE) and heat use efficiency (HUE). Carbon dioxide productivity (CP) decreased with climate change as expected because of increase in carbon use.

Although the negative effects of high temperature on chickpea productivity is well documented (Siddique and Sedgley, 1986; Clarke and Siddique, 2004; Wang et al*.,* 2006; Thakur et al*.,* 2010; Devasirvatham et al*.,* 2012), the results of the current study suggest that both aboveground biomass and grain yield of chickpea will increase with the predicted increase in temperature.

Perhaps, the negative impacts of temperature was off-set by carbon dioxide increase, leading to yield increase. Indeed, it has been reported that the possible increase in atmospheric carbon dioxide levels will improve grain yield in C_3 crops due to improved photosynthesis (Chart-zoulakis and Psarras, 2005; DaMatta et al., 2010). Chart-zoulakis and Psarras (2005) reported that the synergistic benefits of increased carbon dioxide concentration levels with WUE may offset temperature effects in C_3 plant; WUE is directly related to grain yield (Sinclair et al., 1984). Our results are comparable with earlier studies that chickpea yield will improve in future (Hajarpoor et al., 2014; Mahomed et al., 2016).

The variation in aboveground biomass and grain yield with planting date clearly showed the importance of manipulation of planting date as a management tool for improved and sustained chickpea productivity under climate change scenario. Similarly, results from the field experiment showed that planting date and genotype significantly affected biomass and grain yield of chickpea. Planting early, particularly under well-watered conditions appeared to be the most suitable for chickpea in this region. In contrast, late planting had lowest biomass and grain yield. The high grain yield in early planting was supported by greater yield components (seed weight and pod weight, number of pods per plant and harvest index). Moreover, plant phenological factors such as plant height and number of branches per plant (total of both primary and secondary branches) were also greater in early planting, with late planting recording lowest values in all the measured parameters. In addition, the greater grain yield in early planting compared to the other sowings was caused by greater intercepted radiation, improved flower retention and minimised water use and pod abortion. Similarly, a number of studies have reported significant effect of planting date and genotype on biomass and grain yield of chickpea (Bahal et al., 1984, Dixit et al*.,* 1993, Hussain et al, 1997, Kabir 2009).

Furthermore, the greater yield in early planting was attributed to better resource use efficiency. For example, water use efficiency (WUE), heat use efficiency (HUE) and radiation use efficiency (RUE) of both grain yield and biomass were greater in early planting compared with normal planting and late planting, particularly where water was not limiting. The results on resource use efficiency were comparable to earlier studies (Anwar, et al, 2003; Jha et al., 2012; Lake and Sadras, 2017; Toyota et al., 2017),

Clearly, the results from the study indicate the possibility of using planting date as a management strategy in improving chickpea biomass and grain yield in the current period and also under climate change scenario. Therefore, planting date may be an important adaptation strategy to ameliorate the effects of climate change, especially amongst resource constrained smallholder farmers. However, given the potential importance of planting dates in improving current and future productivity of chickpea, there is need to work on development of a sowing (planting date) criteria for chickpea in the region. The criteria should clearly state sowing management options as decision support tools for smallholder farmer in the region. For example, minimum soil moisture and temperature thresholds at seed planting period need to be developed in the region.

References

Anwar, M.R., McKenzie, B.A. and Hill, G.D., 2003. The effect of irrigation and sowing date on crop yield and yield components of Kabuli chickpea (Cicer arietinum L.) in a cool-temperate subhumid climate. *The Journal of Agricultural Science*, *141*(3-4), pp.259-271.

Bahl, P.N., Singh, K.P. and Singh, D., 1984. Evaluation of tall chickpea genotypes for normal and late sowings. *Indian Journal of Agricultural Sciences*.

Chartzoulakis, K. and Psarras, G., 2005. Global change effects on crop photosynthesis and production in Mediterranean: the case of Crete, Greece. *Agriculture, ecosystems & environment*, *106*(2-3), pp.147-157.

Clarke, H.J. and Siddique, K.H.M., 2004. Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research*, *90*(2-3), pp.323-334.

DaMatta, F.M., Grandis, A., Arenque, B.C. and Buckeridge, M.S., 2010. Impacts of climate changes on crop physiology and food quality. *Food Research International*, *43*(7), pp.1814-1823.

Devasirvatham, V., Gaur, P.M., Mallikarjuna, N., Tokachichu, R.N., Trethowan, R.M. and Tan, D.K., 2012. Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. *Functional Plant Biology*, *39*(12), pp.1009-1018.

Dixit, J.P., Pillai, P.V.A. and Namdeo, K.N., 1993. Response of chickpea (Cicer arietinum) to planting date and irrigation schedule. *Indian Journal of Agronomy*, *38*, pp.121-121.

Hajarpoor, A., Soltani, A., Zeinali, E. and Sayyedi, F., 2014. Simulating climate change impacts on production of chickpea under water-limited conditions. *Agric. sci. dev*, *3*(6), pp.209-217.

Hussain, A., Nawaz, M. and Chaudhry, F.M., 1998. Radiation interception and utilization by chickpea (Cicer arietinum L.) at different sowing dates and plant populations. *Journal of Agricultural and Marine Sciences [JAMS]*, *3*(2), pp.21-25.

Jha, S.O.M.N.A.T.H., Sehgal, V.K. and Subbarao, Y.V., 2012. Effect of direction of sowing and crop phenotype on radiation interception, use efficiency, growth and productivity of mustard (Brassica juncea L.). *J Agril Physics*, *12*, pp.37-43.

Kabir, A.F., Bari, M.N., Karim, M.A., Khaliq, Q.A. and Ahmed, J.U., 2009. Effect of sowing time and cultivars on the growth and yield of chickpea under rainfed condition. *Bangladesh Journal of Agricultural Research*, *34*(2), pp.335-342.

Lake, L. and Sadras, V., 2017. Associations between yield, intercepted radiation and radiation-use efficiency in chickpea. *Crop and Pasture Science*, *68*(2), pp.140-147.

Mohammed, A., Tana, T., Singh, P., Korecha, D. and Molla, A., 2017. Management options for rainfed chickpea (Cicer arietinum L.) in northeast Ethiopia under climate change condition. *Climate Risk Management*, *16*, pp.222-233.

Siddique, K.H.M. and Sedgley, R.H., 1986. Chickpea (Cicer arietinum L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research*, *37*(3), pp.245-261.

Sinclair, T.R., Tanner, C.B. and Bennett, J.M., 1984. Water-use efficiency in crop production. *Bioscience*, *34*(1), pp.36-40.

Thakur, P., Kumar, S., Malik, J.A., Berger, J.D. and Nayyar, H., 2010. Cold stress effects on reproductive development in grain crops: an overview. *Environmental and Experimental Botany*, *67*(3), pp.429-443.

Toyota, M., Maitree, L. and Chomsang, K., 2017. Changes in radiation interception and R: FR over time and with canopy depth of two soybean cultivars with different branching characteristics. *Plant Production Science*, *20*(2), pp.205-214.

Wang, J., Gan, Y.T., Clarke, F. and McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. *Crop Science*, *46*(5), pp.2171-2178.

Chapter 12

Conclusion and Recommendetions

12.1 Objective 1

To assess the effect of planting date on chickpea flower retention and pod abortion and identify suitable planting date and genotypes for the North Eastern part of South Africa.

12.1.1 Hypothesis 1

Planting date and genotypea has an effect on chickpea flower retention and pod abortion.

12.1.2 Conclusion on objective 1

Number of pods per plant varied with planting date, genotype and year, whilst flower retention and pod abortion varied significantly with genotype and year of planting but was not affected by the main effects of planting date or by the interaction between the treatments in the well watered experiment. In contrast, flower retention and pod abortion were affected by interaction between planting date and genotype and planting date and year and genotype and year in the drier experiment, which was only watered three times (at planting, flowering and podding stage). ICCV9901 recorded the highest flower retention in both early and late planting. Clearly early planting date may be the most suitable sowing date for chickpea in this environment but this may vary with availability of moisture. However, we recommend further investigations using a wider range of sowing dates.

.

12.2 Objective 2

To assess the effect planting date on aboveground biomass and grain yield of chickpea and identify suitable planting date and genotypes with greater aboveground biomass and grain yield in the North Eastern part of South Africa.

12.2.1 Hypothesis 2

Planting date and genotypes have an effect on biomass and yield of chickpea genotypes.

12.2.2 Conclusion on objective 2

Planting date and genotype affected aboveground biomass and grain yield of chickpea in both well watered and in the drier experiment. Planting early, particularly under well-watered conditions appeared to be the most suitable sowing period for chickpea in this region. In contrast, late planting had lowest biomass and grain yield. The high aboveground biomass and grain yield in early planting was supported by greater yield components (seed weight (13.8 gm^{-2}) and pod weight 23 gm^{-2}), number of pods per plant (75 pods $plant^{-1}$) and harvest index (43 %). Late maturing genotypes (Range 4 & 5) showed greater aboveground biomass and grain yield compared with ICCV9901, and Range 1 & 3, but this depended on soil moisture availability.

12.3 Objective 3

To assess the effect of planting date on chickpea water use, water use efficiency and identify suitable planting date and genotypes with greater water use efficiency in the North Eastern part of South Africa.

12.3.1 Hypothesis 3

Planting date and genotype have an effect on chickpea crop water use, water use efficiency (WUE).

12.3.2 Conclusion on objective 3

Water use was, on average, 16% greater in late sowing compared with the control in the well-watered experiment but this response varied with genotype and year of planting. In contrast, grain yield and WUEg was, on average, greater with early sowing (1.7 t ha^{-1} & 7.7 kg ha^{-1} mm^{-1}) compared with the control (1.1 t ha^{-1} & 7 kg ha^{-1} mm^{-1}), respectively but the differences were more pronounced in the well-watered experiment. Late maturing genotypes (Range 4 & 5) showed greater WUE of grain yield (7.3 & 7.1 kg ha^{-1} mm^{-1}). Clearly, sowing at the beginning of the month of May has potential of improving chickpea productivity in this environment but there is need to investigate the possibilities of earlier sowings.

12.4 Objective 4

To assess the effect planting date and genotype on chickpea radiation use, radiation use efficiency and identify suitable planting date and genotypes with greater radiation use efficiency in the North Eastern part of South Africa.

12.4.1 Hypothesis 4

Planting date and genotype have an effect on chickpea crop radiation use and radiation use efficiency (RUE).

12.4.2 Conclusion on objective 4

The proportion of intercepted radiation, total intercepted radiation and radiation use efficiency varied with planting date and genotypes but these effects were not consistent across the two experiments. Early sowing and the late maturing genotypes, Range 4 & Range 5, performed better than the rest of the sowing dates, and the early and medium maturing genotypes, respectively. Clearly, manipulation of management practices like sowing time and genotype selection may improve radiation capture and utilisation of chickpea.

12.5 Objective 5

To assess the effect of planting date and genotype on thermal time of chickpea.

12.5 1 Hypothesis tested

Planting date and genotype have an effect on thermal time of development of chickpea.

12.5.2 Conclusion on objective 5

Planting date and genotype affected themal time of development and heat use efficiency of grain yield of chickpea crop. AGDD was 14% and 27% greater, respectively in early planting compared with normal and late planting date. Highest HUE_g was observed in normal planted crops whilst the late planted crops had the lowest HUE_g in experiments I and II. Early planting date may be the most suitable sowing date to improve thermal time, whilst normal planting date may improve heat use efficiency for chickpea in this environment, but this may vary with availability of moisture. The late maturing Range 4 genotype had the highest HUE_g, which was greater (by 75.7%, 85.7%, 56.7% and 54.8%), respectively compared to Range 1, Range 3, Range 5 and ICCV9901 particulary in the well watered experiment.

12.6 Objective 6

To parameterise and validated AquaCrop model to predict chickpea crop biomass and grain yield in the North Eastern part of South Africa.

12.6 1 Hypothesis tested

AquaCrop model may be parameterised to predict chickpea crop biomass and grain yield in the North Eastern part of South Africa.

12.6.2 Conclusion on objective 6

The model performance was satisfactory, with a good match between the simulated and observed canopy cover (CC), Soil water content (SWC), biomass (B) and grain yield (Y). All the statistical indicators (R^2, RMSE, and MAPE) used to compare field observed and model predicted parameters, showed good model performance. For example, the regression plot of simulated and observed yield showed a good relationship with R^2 values of 0.949, 0.928 and 0.990 for early, normal and late planting dates, respectively, whilst RMSE was 0.135, 0.143 and 0.031 for early, normal and late planting dates. Similarly, SWC had strong regression relationship (R^2 = 0.982, 0.949, 0.954, respectively and a RMSE of 0.226, 0.696 and 0.310, respectively in early, normal and late planting date). The results indicate that the model could be used for evaluating the effects of different planting dates on chickpea yield.

12.7 Objective 7

To determine the effect of climate change on winter planting date for chickpea crop in the North Eastern part of South Africa.

12.7 1 Hypothesis tested

Climate change will affect winter planting date for chickpea crop in the North Eastern part of South Africa.

12.7.2 Conclusion on objective 7

The simulation results, using 15 GCMs indicated that optimal planting date for chickpea could have shifted from mid-month of April during 1950 to end of May in 2100. This could reduce chickpea growing season from 140 days to 85 days. The shift in planting date was caused by a significant increase in temperature in the study area (by 4.2 to 5.5 ^{o}C), under both RCP 4.5 and 8.5. This increase in temperature will lead to a concomitant increase in ETo and AGDD for chickpea.

12.8 Objective 8

To assess the effect of planting date and genotype on biomass and grain yield of chickpea crop under future climate scenarios.

12.8.1 Hypothesis tested

Planting date and genotype have an effect on biomass and grain yield of chickpea crop under future climate scenarios.

12.8.2 Conclusion on objective 8

Chickpea aboveground biomass increased from 2.0 & 2.05 t ha^{-1} in 1950 to 4.3 & 4.57 t ha^{-1} in 2100, respectively in RCP 4.5 and 8.5, whilst grain yield increased from 1.07 & 1.08 t ha^{-1}

in 1950 to 1.68 & 2.21 t ha^{-1} in 2100, respectively under RCP 4.5 and 8.5. Planting dates that were recommended by AquaCrop model recorded the highest increase in aboveground biomass and grain yield compared with early, normal and late planting dates. Late maturing genotypes (Range 4 & 5) showed greater grain yield and biomass, whilst early and medium maturing genotypes had low biomass and grain yield. Clearly, planting date and genotype could affect on biomass and grain yield of chickpea under climate change scenario.

12.9 Recommendations

- The study recommend early planting date together with late maturing chickpea genotypes (Range 4 and 5) in the region so as to improve water use efficiency, radiation use effiency, heat use effiency and aboveground biomass and grain yield of the crop. The early maturing genotype (Range 1) and medium maturing genotypes (Range 3 and ICCV9901) may only be recommended under normal or late planting although there will not be any significant yield advantages compered with late maturing genotypes.
- The study also recommend the use of planting dates generated by AquaCrop model so as to improve biomass and grain yield when chickpea is grown under climate change scenario in Southern Africa. The yield improvement using this AquaCrop planting date is caused by greater water use efficient, radiation use efficient, heat use effiency and corbon dioxide productivity.
- Given the potential importance of planting dates in improving current and future productivity of chickpea shown in the study, there is need to work on development of a sowing (planting date) criteria for chickpea in the region. The criteria should clearly state sowing management options as decision support tools for smallholder farmer in the region. For example, minimum soil moisture and temperature thresholds at seed planting period need to be developed in the region.