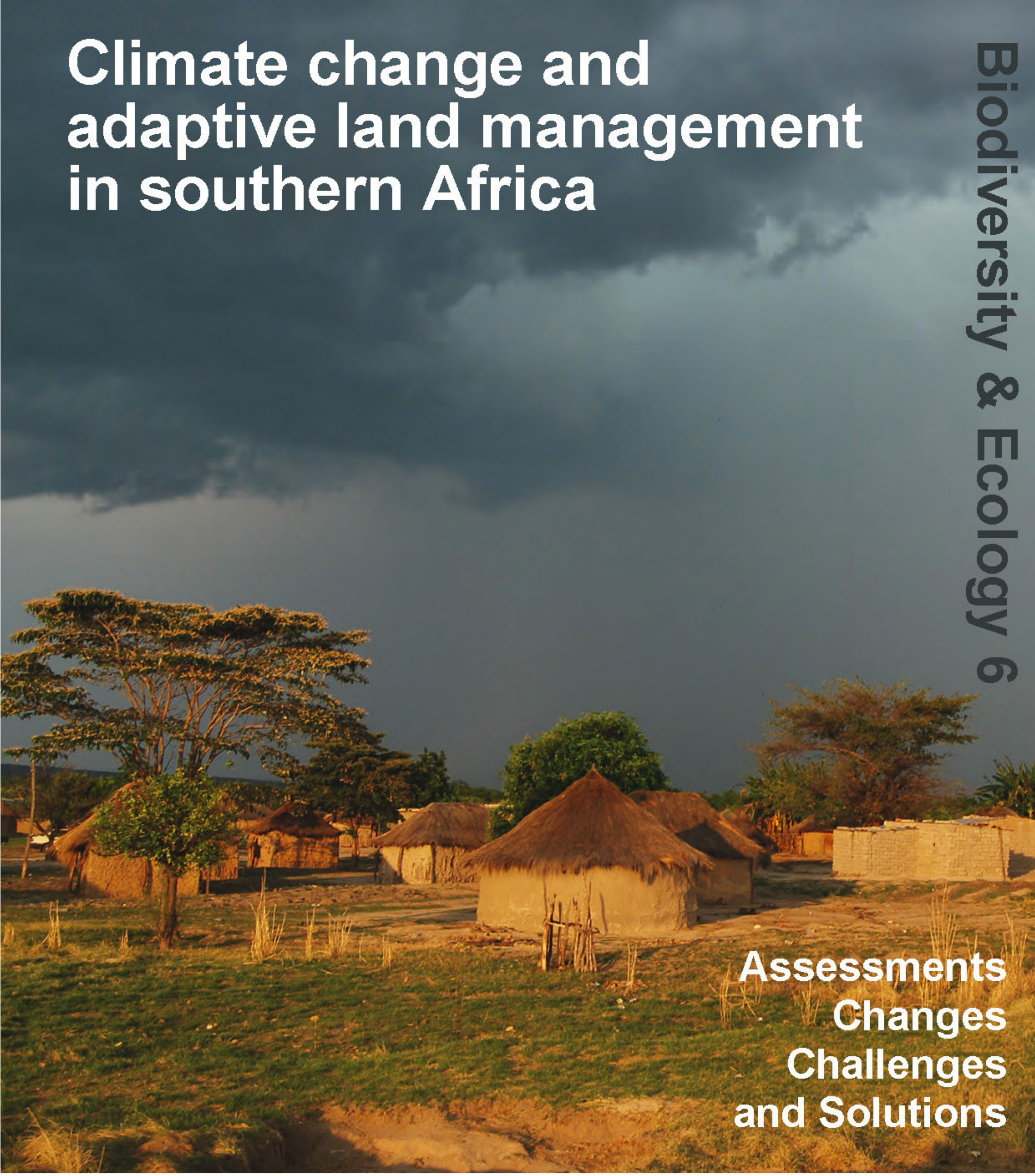
Climate change and adaptive land management in southern Africa



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Climate change and adaptive land management in southern Africa

Assessments, changes, challenges, and solutions

Edited by

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Food security

Grain yield water use efficiency of cowpea (*Vigna unguiculata* L. Walp.) in response to planting dates in Botswana

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Abstract: Ag Southern Africa is characterized by a high degree of rainfall variability affecting agriculture among other sectors. The timing of the rainfall has shifted as a result of climate change, and variability is expected to be even higher in the future. This threatens grain production, which is dependent on rainfall; strategies such as choice of planting date and crop selection based on water use efficiency could help farmers mitigate some of these impacts. This study investigated the effect of planting dates and genotypic differences on grain yield, water use, and water use efficiency of cowpea. Six cowpea genotypes were planted at four different times (November, December, January, and February). The results indicate that cowpea grown in January used moderate amounts of plant-available water, significantly producing a higher average grain yield of 335.2 kg/ha with a water use efficiency of 3.72 kg/ha.mm-1. BCA001 (blackeye) exhibited the highest grain yield and water use efficiency in all the planting dates, indicating broad adaptation, while landrace BCA019 (speckled grey cowpea), has the potential to be bred for drought tolerance and be released as a variety thanks to its earliness and high water use efficiency.

Resumo: A África Austral é caracterizada por um elevado grau de variabilidade da precipitação, afectando a agricultura, entre outros sectores. A altura das chuvas mudou devido às alterações climáticas e prevê-se que a variabilidade será ainda maior. Isto ameaça a produção de grãos, a qual é dependente das chuvas. Logo, estratégias, tais como a escolha da data da plantação e a selecção da cultura com base na eficiência do uso da água, poderão ajudar os agricultores a mitigar alguns desses impactos. Este estudo investigou o efeito das datas de plantação e diferenças genotípicas na productividade e eficiência do uso da água do feijão-frade. Seis genótipos de feijao-frade foram plantados em quatro alturas diferentes (Novembro, Dezembro, Janeiro e Fevereiro). Os resultados indicam que o feijao-frade crescido em Janeiro utiliza quantidades moderadas da água disponível, produzindo maiores productividades médias, de 335,2Kg/ha, com uma eficiência do uso da água de 3,72Kg/ha.mm-1. O BCA001 (Blackeye) exibiu a maior productividade e eficiência do uso da água em todas as datas de plantação, indicando uma adaptação geral, enquanto que a variedade autóctone BCA019 (Speckled grey cowpea) tem o potencial de ser criada para a tolerância à seca e de ser lançada como uma variedade devido à sua precocidade e elevada eficiência do uso da água.

Introduction

Agricultural productivity is believed to be under threat as a result of global change (Metz et al., 2007). This change has resulted in seasonal variability of rainfall, which places farmers at a greater risk of low production and crop losses, especially in sub-Saharan Africa (SADC, 2015). With its semi-arid climate, Botswana has a mean annual rainfall ranging from over 650 mm in the north-east to less than 250 mm in the south-west. The national average rainfall is 475 mm per year, which is half of the global average annual rainfall (CSO, 2013). The rainy season starts either early or much later than the traditional dates, and this has challenged farmers with respect to planting dates. Poor planting date selection may subject crops to water and heat stress during dry spells and critical growth stages, resulting in reduced yield; thus, there is a need for crop species that can efficiently use available water (Lemos & Dilling, 2007). Farmers (landraces) and plant breeders (varieties) have successfully selected life cycle duration and phenology to maximize both the range of environments in which crops grow and their yields, at least for current climates. The major challenge for crop improvement is how to plan for future climate change. According to FAO (2011), enhancing food security while contributing to mitigating climate change requires the transition to agricultural production systems that are more productive and use inputs more efficiently. One strategy that farmers can use to maintain or increase crop yields in the face of the changing climate is the use of drought-tolerant, water use–efficient crop varieties and adjusting of planting dates (Rockstrom & Barron, 2007).

Cowpea is one crop that is indigenous to sub-Saharan Africa, and many wild relatives of the species are found in abundance. In Botswana it is an important multipurpose food legume and the third most cultivated crop after maize and sorghum (CSO, 2013). Cowpea grows best at day temperatures of 25–35°C with an average rainfall of less than 500 mm per annum, and its tolerance to drought is attributed to traits that enable it to capture and use water more efficiently than other legumes (Madamba et al., 2006; Singh et al., 2002). Water use efficiency, which is defined by Tambussi et al. (2007) as the ratio of dry matter produced to the amount of water used, is an important physiological characteristic related to the ability of the crop to cope with water stress. It is an important trait for drought tolerance improvement and can be enhanced by selection of crop varieties and agronomic practices such as time of sowing based on available water, increasing seasonal evapotranspiration (Singh et al., 2012).

Studies by Patel et al. (2008) indicated that water use and water use efficiency in terms of grain yield are influenced by sowing dates; early-sown cowpea genotypes had higher water use efficiency than the late-sown ones. Similar findings were reported by Awasthi et al. (2007) in Indian mustard. According to Bhale & Wanjari (2009), the influence of sowing dates on water use efficiency of crops has implications for the ability of crops to withstand drought conditions. Therefore, characterising crop water use response for cowpea in dryland farming for different planting dates has a positive effect on food security. This study investigated the effect of planting date on grain yield and water use of cowpea under rainfed conditions. Evaluating the WUE of cowpea for different planting dates will generate information useful for the production of cowpea genotypes better adapted to the challenging environment and that exhibit a low demand for water, thereby addressing the rainfall variability associated with climate change. Information generated will address adaptation to changes in climate that influence temperature, season length, optimal planting dates, the occurrence of drought, and crop durations.

Materials and methods

Plant material

Six cowpea genotypes were sourced from farmers and the National Plant Genetic Resources Centre (NPGRC), Department of Agricultural Research (DAR), under the Ministry of Agricultural Development and Food Security in Botswana. Two of the varieties are released varieties by the DAR, whereas the other four are farmer-selected landraces from Hukuntsi (24°1′1″ S, 21°52′8″ E) in the Kalahari Desert and Lecheng (22°39′55″ S, 27°13′12″ E) in the Central District of Botswana (Tab. 1). Selection of both released varieties and genotypes was based on the preferences of local subsistence farmers. Seed materials for these genotypes are available at the Botswana University of Agriculture and Natural Resources (BUAN) Plant Physiology Laboratory, and farmers and researchers can obtain through the corresponding author.

Field experiment

During the 2014/15 season, a field trial was planted at the Botswana University of Agriculture and Natural Resources on-station farm in Sebele (24°34′25″ S, 25°58′00″ E). The site climate is characterized as semi-arid (Luhanga & Andringa, 1990). The soils are shallow, ferruginous tropical soils consisting mainly of medium to coarse grains and sandy loams with low water-holding capacity and subject to crusting after heavy rains (De-Wilt & Nachtengaele, 1996). Cowpea was sown on four dates (10 November, 16 December, 13 January, 6 February) in 2014/15 in a split plot design, with planting dates as the main factor and genotypes as subplots replicated four times. The planting dates chosen represented early (10 November), moderately early (16 December), optimal (13 January), and late (6 February) planting. These were based on recommendations from the Ministry of Agricultural Development and Food Security. Each plot had an area of 9.6 m^2 with a spacing of 0.75 m between rows and 0.20 m between plants. Seedlings were established under irrigation to allow for maximum crop stand until four weeks after planting. Thereafter, the experiment was maintained under rain-fed conditions until data collection was completed.

Data collection

Two inner rows in a plot were tagged, and data were collected on flowering, maturity, and pod grain yield. The number of days to 50% flowering was determined when 50% of plants were at the full bloom (R2) stage (when 50–100% of flowers were open). Days to maturity was recorded when the pods had reached the harvest maturity (RH) stage (when 80% of pods were mature in colour). Seed yield was determined during harvest and values were converted to kg/ha.

During the cropping season, daily temperature was recorded at Sir Seretse

Serial No	ID No	Genotype	Source
1	BCA001	Blackeye[a]	NPGRC-DAR
2	BCA002	Speckled grey[b]	Hukuntsi
3	BCA009	Tswana brown[b]	Hukuntsi
4	BCA013	Tswana cream[a]	NPGRC-DAR
5	BCA016	Speckled brown[b]	Lecheng
6	BCA019	Speckled grey[b]	Lecheng

Table 1: Description of the genotypes used for water use efficiency (WUE) evaluation in Sebele. Germplasm was collected from various sources in Botswana. Superscripts indicate that the genotype is a released variety (a) and a landrace (b).

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Khama International Airport, located 3 km from the site, and monthly averages were calculated. Rainfall data were collected from a site-located rain gauge, and averages were calculated for the entire growing period.

Crop water use

Soil water content (SWC) was measured at the beginning and end of the experiment using a soil moisture probe metre (MPM-160-B, ICT International Pty Ltd) to calculate crop water use (WU) using the water balance equation by Songsri et al. (2009):

$$WU = I + R + \Delta S$$

where I is the irrigation amount (mm), R is rainfall (mm), and ΔS is the difference between the soil moisture at harvest and at planting. Water use efficiency was defined as the ratio of crop grain yield (GY) to total amount of water used using the following equation by Songsri et al. (2009):

$$WUE = \frac{GY}{WU}$$

Data analysis

The collected data were subjected to the statistical analysis of variance by using SAS 9.4. Means were tested and separated using Tukey's honestly significant difference (HSD) post hoc test to analyse differences between experimental factors (planting dates) and treatments (genotypes) at p = 0.05.

Results

Weather conditions

Observed weather characteristics during the study showed a pattern of uneven rainfall distribution and midseason dry spells that were often accompanied by high temperatures (Fig. 1). February was the hottest month, with the succeeding months getting cooler. As a result, the December planting occurred under heat and drought stress. Generally, the temperatures neither exceeded nor went below the cowpea growing temperature thresholds during the growing season for any of the planting dates, which made them suitable for growth. Differences in cumulative rainfall were evident among the different planting dates. The cumulative rainfall amounts were 152 mm, 163.1 mm, 176.4 mm, and 177.2 mm for the November, December, January, and February planting dates, respectively. For all planting dates, the recorded rainfall was less than the crop water requirement, which exposed the cowpea to water deficit.

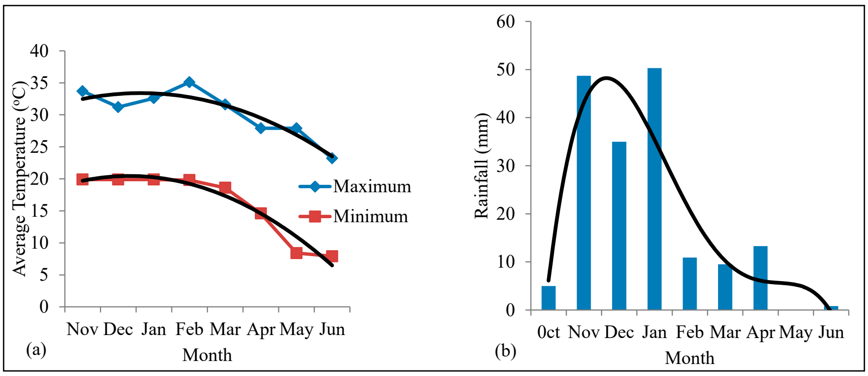

Figure 1: Mean minimum and maximum temperature (a) and rainfall (b) for 2014–2015 season in Sebele, Gaborone, Botswana. The season was characterised by an uneven rainfall distribution and mid-season dry spells, which were often accompained by high temperatures.

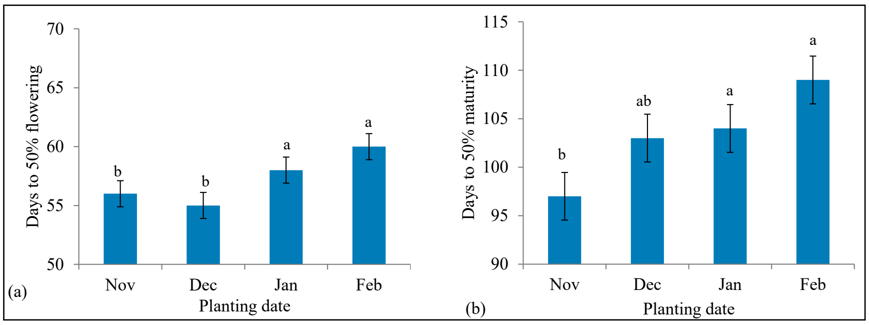

Figure 2: Effect of planting date on mean days to 50% flowering (a) and 50% maturity (b) of cowpea genotypes. The comparison was made between planting dates irrespective of the cowpea genotypes. Error bars indicate standard error of the means. Same letters on the bars of each genotype indicate nonsignificant differences (p > 0.05) between irrigated and rainfed conditions by Tukey's HSD post hoc test.

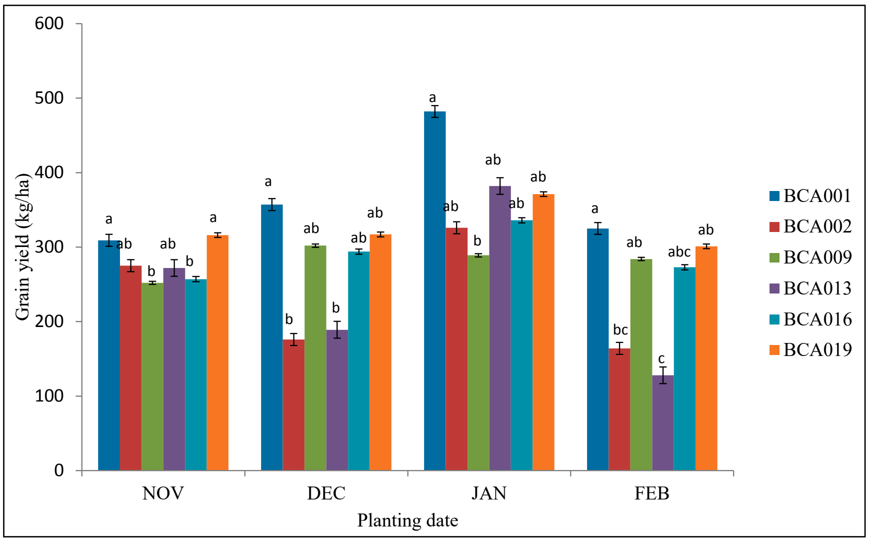

Figure 3: Mean grain yield of cowpea genotypes as influenced by planting date. The highest mean grain yield was recorded in January, and BCA001 had the highest across all the dates in the 2014–2015 season. The dates used were a recommendation from the Ministry of Agricultural Development and Food Security in Botswana. Error bars indicate standard error of the means. Same letters on the bars of each genotype indicate nonsignificant differences (p < 0.05) between irrigated and rainfed conditions by Tukey's HSD post hoc test.

Phenological development

Cowpea planted early (November and December) had a significantly shorter growing season than with late planting (January and February) (Fig. 2). The longest time to flowering and maturity was observed when planting was initiated in February, whereas the opposite was true for November planting. With regard to genotypic performance, a significant difference ($p < 0.05$) among genotypes irrespective of planting dates was also noted in terms of flowering and maturity (Tab. 2). BCA001 and BCA019 flowered and matured early compared to BCA009 and BCA013, which were late in these two phenological traits.

Grain yield

Planting dates significantly influenced cowpea grain yield. The average seed yield ranged from 128 kg/ha to 482 kg/ha. Cowpea planted in January had the highest grain yield, whereas the early and late dates had lower yield, February being the lowest (Fig. 3). Genotypes significantly ($p < 0.05$) varied in grain yield performance for different dates. BCA001 and BCA019 maintained high yield stability among all the dates whereas BCA013 had a significant drop in yield at late planting. BCA001 produced a significantly higher grain yield for all planting dates, indicating that the variety is an ideotype possessing superior grain-yielding ability with broad adaptation traits.

Water use and water use efficiency

Generally WU was suboptimal for all planting dates owing to below-average rainfall. This confirms drought experienced by the genotypes for all the dates. There was a significant variation in WU with respect to planting dates (Fig. 4a). Cowpea planted in November used 50% of plant-available water, while 80%, 65%, and 63% were used for the succeeding dates, respectively. No significant differences were recorded in terms of water use for the January and February planting dates. Genotypic differences were observed for the different sowing dates; generally BCA001 used less water, followed by BCA019 and BCA002 across all planting dates (Fig. 5). For WUE, there was a

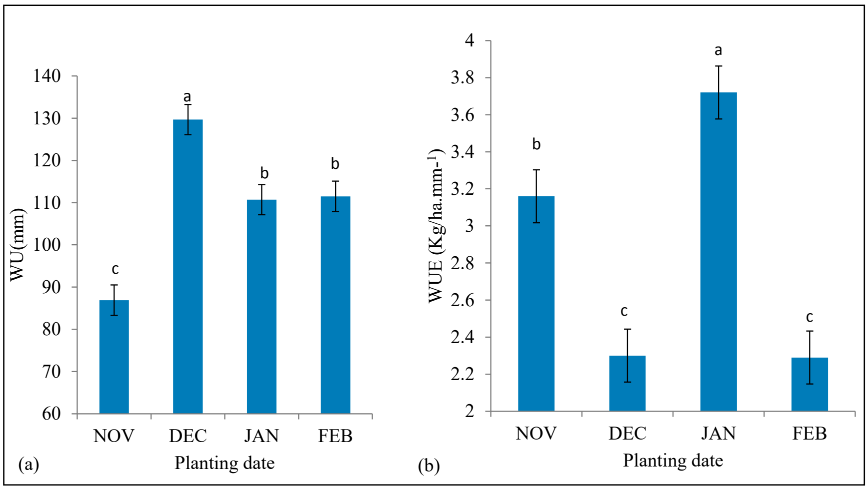

Figure 4: Mean water use (a) and water use efficiency (b) of cowpea as influenced by planting date. Water use was calculated using the soil water balance method, and water use efficiency was computed as the ratio of grain yield to water use. Soil water was measured using a soil moisture probe meter (MPM-160-B, ICT International Pty Ltd). Error bars indicate standard error of the means. Same letters on the bars of each genotype indicate nonsignificant differences ($p < 0.05$) between irrigated and rainfed conditions by Tukey's HSD post hoc test.

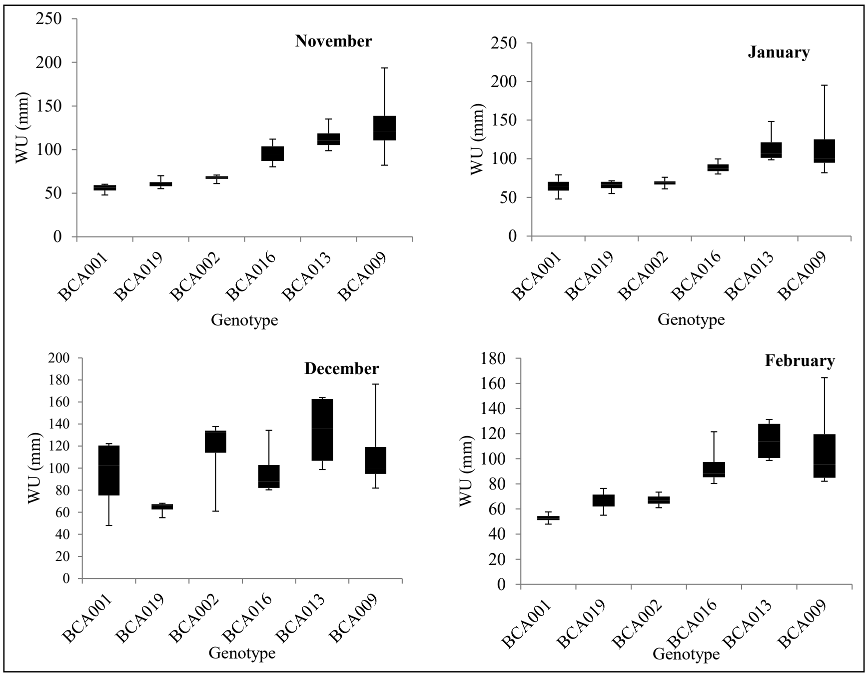

Figure 5: Distribution of water use by genotype for different planting dates. Box plots were used to show the distribution, and less water was used by cowpea planted in November.

Genotype	Days to 50% flowering	Days to maturity
BCA001	45^{d}	72^{e}
BCA002	56^{c}	99^{c}
BCA009	79^{a}	143^{a}
BCA013	60^{b}	113^{b}
BCA016	58^{b}	112^{b}
BCA019	46^{d}	87^{d}
LSD (0.05)	**2.08**	**4.1**

Table 2: Average number of days to 50% flowering and 50% maturity of cowpea genotypes. The averages were pooled data from four planting dates (November, December, January and December) in 2014 to 2015 season. Means followed by the same letter within a column are not significantly different ($p \leq 0.05$) based on the Tukey's HSD post hoc test. BCA001 and BCA019 had the shortest growing season, whereas BCA009 had the longest growing season.

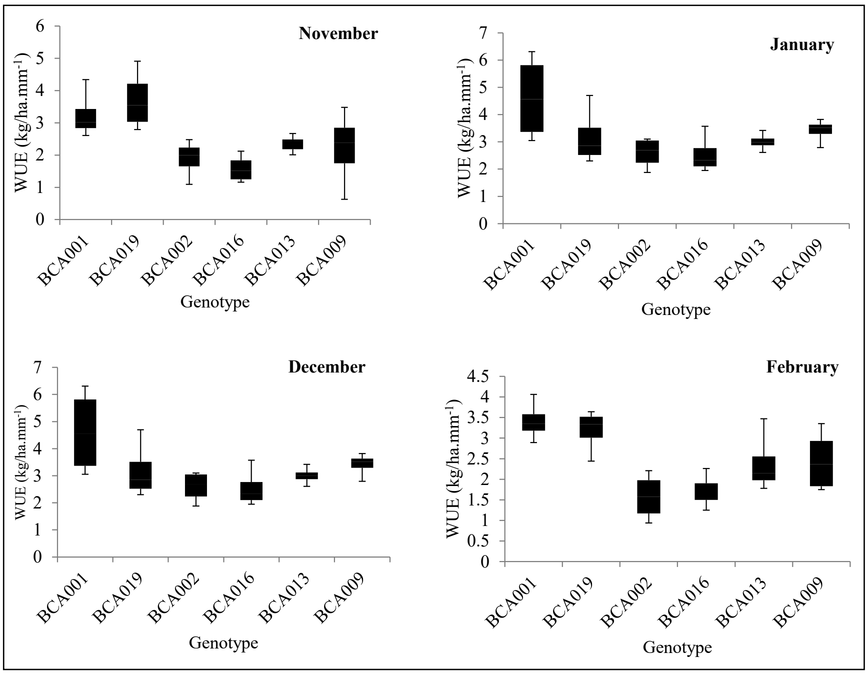

Figure 6: Distribution of water use efficiency by genotype for different planting dates. Box plots were used to show the distribution. BCA001 was the most efficient, with a wider variation.

significant variation across the planting dates, with January being the highest (average of 3.36kg/ha.mm^{-1}) and February being the lowest (2.27 kg/ha.mm^{-1}) (Fig. 4b). There is apparent distinction of WUE between genotype across the planting dates (Fig. 6). BCA001 had the highest WUE for most planting dates, followed by BCA019, whereas BCA016 was the least efficient. On average BCA001 had WUE of 3.78 kg/ha.mm^{-1}, whereas BCA016 was less efficient, with an average of 2.14 kg/ha.mm^{-1}.

Discussion

The study found significant differences among six cowpea genotypes for grain yield, water use, and water use efficiency when tested for four planting dates. There were fewer days to 50% flowering and maturity in early (November and December) planted cowpea. This trend might be ascribable to the higher temperatures and low rainfall recorded between January and February 2015, which was the onset of flowering for early planting. In return, the longer duration of flowering and maturity for late-planted crops could be due to the exposure of plants to fewer high-temperature days. Temperature is undoubtedly the dominant factor that affects flowering and maturity, accelerating flowering and maturity in legumes to avoid pre- and post-anthesis water stress (Agele et al., 2002; Paradwa et al., 2016). While most literature indicates that early planting increased yield in soybean and cowpea (Shegro et al., 2010; Akande et al., 2012), the results obtained here suggest the opposite. The lowest grain yield for early planting could be attributed to lower rainfall received during the growth period, as most plants were dead at the reproductive stage. According to Mugalavai et al. (2008), yields may suffer with either a late onset or early cessation of the growing season, as well as with a high frequency of damaging dry spells within the growing season. For February planting, shortened day length could be the reason for lower yields because when the duration of growth is short, the production of photosynthates becomes low, which affects crop performance negatively (Banik et al., 2000). Generally, most cowpea genotypes showed inconsistency in seed yield. This is an indication of sensitivity to the environment, mainly temperature and rainfall, which caused an interaction between genotype and planting date. These results suggest that most genotypes had the capacity to yield depending on the planting date. Low amounts of rainfall coupled with high temperature for the November planting resulted in less water available for plants and thus lower WU. Although cumulative rainfall was highest for February, planting in this month resulted in a decrease in WUE, which may be attributed to a proportionately larger reduction in seed yield in relation to consumptive water use, as reported by Patel et al. (2008). Cowpea sown in January experienced more evenly distributed rainfall than the earlier dates, 'although [rainfall] was below the recommended amounts of water for optimal growth,' as well as temperatures that were suitable for growth. Shifting the planting time of crops from a period with high evaporative demand to one with low demand is likely to reduce WU, thereby enhancing WUE. This could explain the high WUE recorded in January-planted cowpea (Singh et al., 2012).

Conclusion

This study demonstrated that genotypes and planting date significantly influenced cowpea water use, grain yield, and water use efficiency. Cowpea sown in January matured early, had high grain yield, and was more water use efficient. Amongst the released varieties, BCA001, with a lower number of days to maturity, proved better in terms of grain yield and WUE compared to BCA013 and other landraces across the planting dates. BCA001 could be recommended for any planting date, but for best results planting in January is highly recommended. The landrace BCA019 performed better than all other landraces and also than the released variety BCA013, making it a potential tool for water use efficiency breeding. Although it is a released variety, BCA013 needs to be studied further for drought tolerance and for future improvement. Results from this study suggest that WUE can be enhanced through the selection of varieties and sowing date. Present findings were based on one-year experimentation, and hence this study can be repeated with more genotypes in different agro-ecological zones of Botswana.

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References

Agele, S.O., Olufayo, A. & Iremiren, G.O. (2002). Effects of season of sowing on water use and yield of tomato in humid south Nigeria. *African Crop Science,* **10**, 213–237.

Akande, S.R., Ajayi, S. A., Adetumbi, J.A., Adeniyan, O.N., Ogunbodede, B.A., Owolade, O.F. & Olakojo, S.A. (2012). Planting date effects on cowpea seed yield and quality at southern guinea Savanna of Nigeria. *Proofs,* **34**, 79–88.

Awasthi, U.D., Singh, R.B. & Dubey, S.D. (2007). Effect of sowing date and moisture conservation practice on growth and yield of Indian mustard (Brassica juncea) varieties. *Indian Journal of Agronomy,* **52**, 151–153.

Banik, P., Bagchi, D.K., Sasmal, P.K. & Ghosal, M.N. (2000). Evaluation of Legume growth. *Crop Science Journal*, **185**, 9–14.

Bhale, V.M. & Wanjari, S.S. (2009). Conservation Agriculture: a new paradigm to increase resource use efficiency. *Indian Journal of Agronomy,* **54**, 167–177.

CSO (2013). *2012 annual agricultural survey report.* Government Printer, Gaborone, Botswana.

De-Wilt, P.V. & Nachtengaele, F.O. (1996). *Explanatory notes on soil map of the Republic of Botswana.* Soil Mapping and Advisory Services. Government Printer Press, Gaborone.

FAO (2011). *Climate change, water and food security.* FAO Water Report 36. FAO, Rome.

Lemos, M.C. & Dilling, L. (2007). Equity in forecasting climate: can science save the world's poor? *Science Public Policy,* **34**, 109–116.

Luhanga, P.V. & Andringa, J. (1990). Characteristics of solar radiation at Sebele, Gaborone, Botswana. *Solar Energy,* **44**, 77–81.

Madamba, R., Grubben, G.J., Asante, I.K. & Akromah, R. (2006). Vigna unguiculata (L.) Walp. *Plant Resources for Tropical Africa 1.Cereals and Pulses.* (ed. by M. Brink and G. Belay), pp. 221–229, PROTA Foundation, Wageningen, Netherlands.

Metz, B., Davidson, O.R. Bosch, P.R. & Dave, L.A. (eds.) (2007). *Climate change 2007: mitigation of climate change. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK.

Mugalavai, E.M., Kipkorir, E.C., Raes, D. & Rao, M.S. (2008). Analysis of rainfall onset, cessation and length of growing season for western Kenya. *Agricultural and Forest Meteorology,* **148**, 1123–1135.

Paradwa, C., Karavina, C., Kamota, A., Mandumbu, R. & Nyemba, N. (2016). Evaluation of seasonal rainfall changes on the growth performance of Vigna unguiculata (cowpeas) in Zimbabwe. *Academic Journal of Agricultural Research,* **4**, 67–71.

Patel, I.C., Patel , B.S., Patel, M.M., Patel, A.G. & Tikka, S.B. (2008). Effect of irrigation schedule, dates of sowing and genotypes on yield, water use efficiency and water extraction pattern of cowpea. *Journal of Food Legumes,* **21**, 132–137.

Rockstrom, J. & Barron, J. (2007). Water productivity in rainfed systems: overview of challenges and analysis of opportunities in water scarcity–prone savannas. *Irrigation Science,* **25**, 299–311.

SADC (2015). *Food Security Early Warning System: Agromet update 2014/15 agricultural season.* SADC, Gaborone, Botswana.

Shegro, A., Atilaw, A., Pal, U.R. & Geleta, N. (2010). Influence of varieties and planting dates on growth and development of soybean (*Glycine max* L. Merr) in Metekel zone, North Western Ethiopia. *Journal of Agronomy,* **9**, 146–156.

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

Singh, B.B., Ehler, E.J., Sharma, B. & Freire Filho, F.P. (2002). Recent progress in cowpea breeding. *Challenges and opportunities for enhancing sustainable cowpea production* (ed. by C.A. Fatokun, S.A. Tarawali, B.B. Singh, P.M. Kormawa and M. Tamo), pp. 22-40, Proceedings of the World Cowpea Conference III held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. IITA, Ibadan, Nigeria.

Songsri, P., Jogloy, S., Holbrook, C. C., Kesmala, T., Vorasoot, N., Patanothai, A. & Akkasaeng, C. (2009). Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. *Agricultural Water Management,* **96**, 790–798.

Tambussi, E.A., Bort, A.J. & Araus, J.L. (2007). Water use efficiency in C3 cereals under Mediterranean conditions: a review of physiological aspects. *Annals of Applied Biology,* **150**, 307–321.

References [CrossRef]

Agele, S.O., Olufayo, A. & Iremiren, G.O. (2002). Effects of season of sowing on water use and yield of tomato in humid south Nigeria. *African Crop Science,* **10**, 213–237.

Akande, S.R., Ajayi, S. A., Adetumbi, J.A., Adeniyan, O.N., Ogunbodede, B.A., Owolade, O.F. & Olakojo, S.A. (2012). Planting date effects on cowpea seed yield and quality at southern guinea Savanna of Nigeria. *Proofs,* **34**, 79–88.

Awasthi, U.D., Singh, R.B. & Dubey, S.D. (2007). Effect of sowing date and moisture conservation practice on growth and yield of Indian mustard (Brassica juncea) varieties. *Indian Journal of Agronomy*, **52**, 151–153.

Banik, P., Bagchi, D.K., Sasmal, P.K. & Ghosal, M.N. (2000). Evaluation of Legume growth. *Crop Science Journal*, **185**, 9–14. CrossRef

Bhale, V.M. & Wanjari, S.S. (2009). Conservation Agriculture: a new paradigm to increase resource use efficiency. *Indian Journal of Agronomy,* **54**, 167–177.

CSO (2013). *2012 annual agricultural survey report.* Government Printer, Gaborone, Botswana.

De-Wilt, P.V. & Nachtengaele, F.O. (1996). *Explanatory notes on soil map of the Republic of Botswana.* Soil Mapping and Advisory Services. Government Printer Press, Gaborone.

FAO (2011). *Climate change, water and food security.* FAO Water Report 36. FAO, Rome.

Lemos, M.C. & Dilling, L. (2007). Equity in forecasting climate: can science save the world's poor? *Science Public Policy,* **34**, 109–116. CrossRef

Luhanga, P.V. & Andringa, J. (1990). Characteristics of solar radiation at Sebele, Gaborone, Botswana. *Solar Energy,* **44**, 77–81. CrossRef

Madamba, R., Grubben, G.J., Asante, I.K. & Akromah, R. (2006). Vigna unguiculata (L.) Walp. *Plant Resources for Tropical Africa 1.Cereals and Pulses.* (ed. by M. Brink and G. Belay), pp. 221-229, PROTA Foundation, Wageningen, Netherlands.

Metz, B., Davidson, O.R. Bosch, P.R. & Dave, L.A. (eds.) (2007). *Climate change 2007: mitigation of climate change. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK.

Mugalavai, E.M., Kipkorir, E.C., Raes, D. & Rao, M.S. (2008). Analysis of rainfall onset, cessation and length of growing season for western Kenya. *Agricultural and Forest Meteorology,* **148**, 1123–1135. CrossRef

Paradwa, C., Karavina, C., Kamota, A., Mandumbu, R. & Nyemba, N. (2016). Evaluation of seasonal rainfall changes on the growth performance of Vigna unguiculata (cowpeas) in Zimbabwe. *Academic Journal of Agricultural Research,* **4**, 67–71.

Patel, I.C., Patel , B.S., Patel, M.M., Patel, A.G. & Tikka, S.B. (2008). Effect of irrigation schedule, dates of sowing and genotypes on yield, water use efficiency and water extraction pattern of cowpea. *Journal of Food Legumes,* **21**, 132–137.

Rockstrom, J. & Barron, J. (2007). Water productivity in rainfed systems: overview of challenges and analysis of opportunities in water scarcity–prone savannas. *Irrigation Science*, **25**, 299–311. CrossRef

SADC (2015). *Food Security Early Warning System: Agromet update 2014/15 agricultural season.* SADC, Gaborone, Botswana.

Shegro, A., Atilaw, A., Pal, U.R. & Geleta, N. (2010). Influence of varieties and planting dates on growth and development of soybean (*Glycine max* L. Merr) in Metekel zone, North Western Ethiopia. *Journal of Agronomy,* **9**, 146–156. CrossRef

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

Singh, B.B., Ehler, E.J., Sharma, B. & Freire Filho, F.P. (2002). Recent progress in cowpea breeding. *Challenges and opportunities for enhancing sustainable cowpea production* (ed. by C.A. Fatokun, S.A. Tarawali, B.B. Singh, P.M. Kormawa and M. Tamo), pp. 22-40, Proceedings of the World Cowpea Conference III held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. IITA, Ibadan, Nigeria.

Songsri, P., Jogloy, S., Holbrook, C. C., Kesmala, T., Vorasoot, N., Patanothai, A. & Akkasaeng, C. (2009). Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. *Agricultural Water Management*, **96**, 790–798. CrossRef

Tambussi, E.A., Bort, A.J. & Araus, J.L. (2007). Water use efficiency in C3 cereals under Mediterranean conditions: a review of physiological aspects. *Annals of Applied Biology*, **150**, 307–321. CrossRef