Identifying high-yielding dryland wheat cultivars for the summer rainfall area of South Africa

The area planted under dryland wheat (Triticum aestivum L.) in the summer rainfall area (SRA) of South Africa declined from approximately 450 000 ha in 2005 (Agricultural Statistics 2012) to 60 000 ha in 2013 (Crop Estimates Committee 2014). A high risk of yield loss due to increased variability of rainfall coupled with rising temperatures is suspected to be among the major causes of the latest disinterest in dryland wheat production in this important farming region of South Africa (Blignaut et al. 2009; van der Westhuizen and Trapnell 2015). Whilst breeding research has made significant milestones in improving resistance of dryland wheat to pests and diseases in South Africa (Smit et al. 2010), little systematic work has been carried out with the specific objective of breeding dryland wheat cultivars that have tolerance to drought.

Drought tolerance in wheat is a complex trait influenced by genotype and environment with a high level of genotype? Environment interaction (Rampino et al. 2006; Tuberosa and Salvi 2006). In the SRA, drought on dryland wheat normally results from a combination of low air humidity, hot and dry winds, as well as low soil moisture supply during critical stages of crop growth. The crop stages at which these events occur vary across geographic regions and seasons, and this variability is likely to increase due to climate change (Thomas et al. 2007; Wiid and Ziervogel 2012). There is a challenge for breeders to develop cultivars that give adequate yields in drought seasons, and high yields in good seasons.

Since the 1980s, the Agricultural Research Council– Small Grain Institute (ARC-SGI) conducts a National Wheat Cultivar Evaluation Program (NWCEP) annually to evaluate and characterise all wheat cultivars from all seed companies on an objective and scientific basis. The trials serve as an independent assessment of cultivar performance over a number of geographic regions. Many new, improved dryland wheat cultivars were released for the SRA over the past decade and evaluated for yield over several seasons under the NWCEP. As preliminary work towards development of high-yielding and drought tolerant cultivars, it was important to explore the diversity within the current genetic pool of cultivars. The objective of the current study was to identify outstanding cultivars that produced the highest, most stable yield under variable rainfall conditions of the SRA over the recent period from 2003 to 2012.

The SRA (predominantly the Free State province) is commonly divided into four distinct geographical regions, based on crop production potential (Hensley et al. 2006). Very little or no rainfall is received during dryland wheat planting time in the winter months, through vegetative growth (May to September) in these geographic regions (Figure 1). Germination and vegetative growth are dependent on conserved soil moisture, whereas successful reproductive growth is largely determined by spring rainfall. Approximately 260–300 mm rainfall is received during the growth period of wheat from May to December (Figure 1), mostly during reproductive growth.

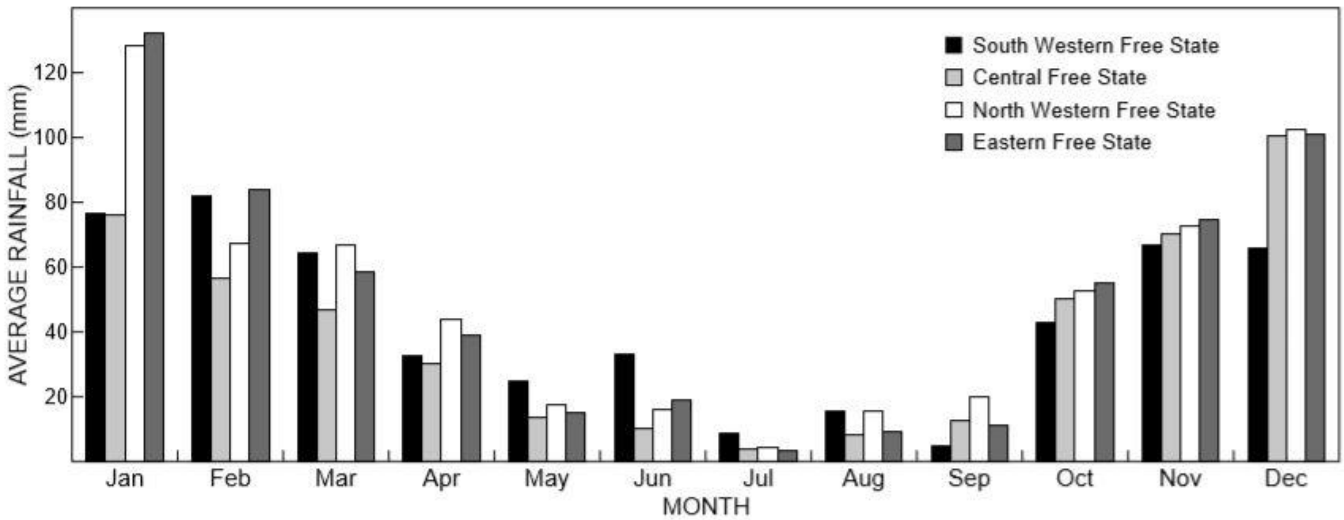

Figure 1: Monthly rainfall distribution in dryland wheat production regions of the summer rainfall area of South Africa (30-year means (source: Agricultural Research Council's agro-climate database; http://155.240.219.9/agromet/Login_Screen.php?btn_Login=CONTINUE)

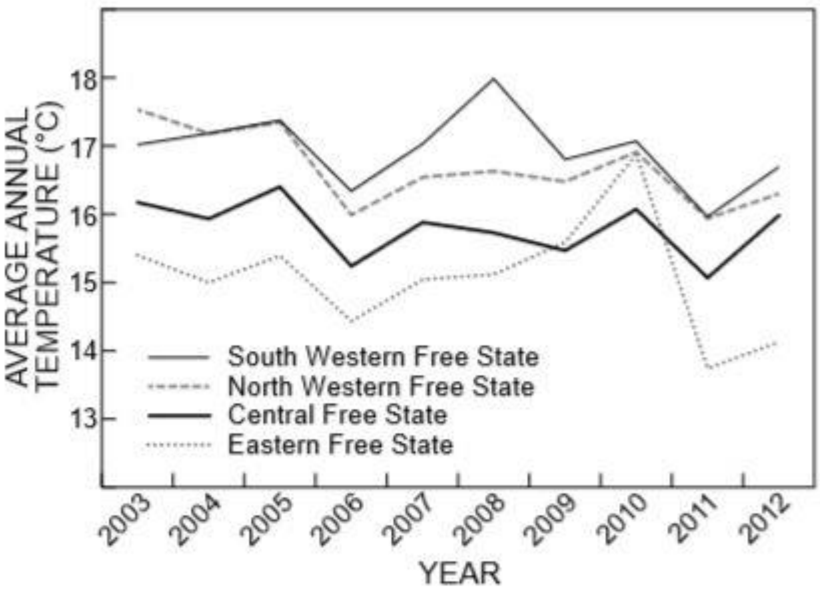

Figure 2: Average atmospheric temperature in dryland wheat production regions of the summer rainfall area of South Africa during from 2003–2012 (source: Agricultural Research Council's agro-climate database; http://155.240.219.9/agromet/Login_Screen.php?btn_Login=CONTINUE)

Although there is a paucity of information on the water requirements of dryland wheat and evapotranspiration (ET) under the climatic conditions of the SRA, studies elsewhere show that maximum yields (7.0 t ha−1) for dryland winter wheat generally require 400–800 mm seasonal ET, and a threshold of 200 mm for minimum profitable yield (Musick et al. 1994; Zhang and Oweis 1999; Kang et al. 2003). Dryland wheat in the SRA is therefore frequently produced under drought conditions. Farmers try to mitigate this drought through extremely efficient farming, which encompasses summer fallows, reduced tillage, precise fertiliser application, as well as proper timing of planting. A combination of high water table, high precipitation storage efficiency of soils and relatively low average annual temperatures (Figure 2) enhances success of the summer fallow–dryland winter wheat rotation, not duplicated anywhere else in the world.

The South Western Free State (SWFS) is the warmest and driest of the four regions and generally has the lowest average annual rainfall during critical stages of dryland wheat reproductive growth from September to December (Figure 1). It experiences higher temperatures (Figure 2) and hence has a higher evaporation requirement than the other three production regions. The North Western Free State (NWFS) also experiences high temperatures, but has higher rainfall. A high water table is often present within the deep (500–1 000 mm) yellow sandy loam soils that characterise most parts of the region. The Central Free State (CFS) receives moderate summer rainfall and moderate temperatures, hence a low evaporation requirement, but it has relatively shallow (250–500 mm) duplex soils. Lastly, the Eastern Free State (EFS), which has the highest crop production potential, receives higher rainfall during critical stages of dryland wheat growth (Figure 1), experiences low average temperatures (Figure 2) resulting in considerably low evaporation requirement.

Entries for the NWCEP over a recent period of 10 years from 2003 to 2012 are presented in Table 1. Test sites on farmers' fields within production regions of the SRA were always systematically chosen in such a way to represent specific production situations. Trials were planted at the designated sites in a randomised complete block design with four replicates. Plots consisted of five rows that were 5 m long with an inter-row spacing of 450 mm. Recommended seed rates were used for all cultivars. In the NWFS and EFS, which have higher crop production potential, fertiliser was applied at a higher rate of 50 kg N, 25 kg P and 12.3 kg K ha−1, in line with farmer practice. For the drier SWFS and CFS, the rates were 35 kg N, 18 kg P and 8.6 kg K ha−1. All seeds were chemically treated for smut diseases and early infestation by aphids (Diuraphis noxia). Weed control was performed when necessary using both mechanical and chemical means to keep the crop weed free. Two planting dates (early and later planting), two weeks apart, were tested in each of the four production regions of the SRA in order to adequately sample the planting window. Both plantings were carried out each year in all production regions except for the early crop of 2008 in the CFS, which was not planted because of severely dry conditions during that particular period.

Table 1: Entries of the National Wheat Cultivar Evaluation Program under dryland conditions in the summer rainfall area of South Africa (2003–2012)

Cultivar	Year of entry into the cultivar evaluation program									
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Elands	■	■	■	■	■	■	■	■	■	■
Gariep	■	■	■	■	■	■	■	■	■	■
PAN 3118	■	■	■	■	■	■	■	■	■	■
Matlabas	■	■	■	■	■	■	■	■	■	■
Caledon	■	■	■	■	■	■	■	■	■	
Komati	■	■	■	■	■	■	■	■		
Betta-DN	■	■	■	■	■	■	■	■		
Limpopo	■	■	■	■	■	■	■	■		
PAN 3364	■	■	■	■	■	■	■			
PAN 3349	■	■	■	■	■	■	■			
PAN 3377	■	■	■	■	■	■	■			
SST 399	■	■	■	■	■	■				
SST 966	■	■	■	■	■	■				
PAN 3191	■	■	■	■						
Nossob	■	■	■							
PAN 3235	■	■	■							
PAN 3120		■	■	■	■	■	■	■	■	■
SST 322		■	■	■	■	■	■			
SST 334		■	■	■	■	■				
SST 322/D		■	■	■						
SST 334/D		■	■	■						
PAN 334/D		■	■							
SST 332		■	■							
PAN 3377/D			■	■						
SST 935			■	■	■	■				
PAN 3122				■	■	■				
SST 356				■	■	■	■	■	■	■
PAN 3144				■	■	■	■	■	■	
PAN 3355				■	■	■	■	■	■	
SST 946				■	■	■				
SST 347				■			■	■	■	■
SST 344				■	■	■				
SST 344/D				■	■	■				
PAN 3368					■	■	■	■	■	■
PAN 3161						■	■	■	■	■
PAN 3172						■	■	■	■	■
PAN 3379						■	■	■	■	■
SST 374								■	■	■
SST 387								■	■	■
SST 398									■	■
Senqu									■	■
Koonap									■	■
SST 316										■
SST 317										■
PAN 3195										■

The wheat yield data used in the current study is available from reports of the NWCEP, also published as production guidelines by the ARC-SGI annually for the entire period (2003–2012). It is also available online from the ARC website (http://www.arc.agric.za/arc-sgi/Pages/ ARC-SGI-Homepage.aspx). Low-yielding cultivars were continuously replaced with newly released ones in the cultivar evaluation trials, but the better-adapted cultivars did remain in the trials for an extended period. Therefore, the series of cultivar performance data over 10 years has many missing values and methods such as AMMI (additive main effects and multiplicative interaction) could not be applied for the analysis of genotype? Environment interactions. Combined data for all cultivars were subjected to an unbalanced analysis of variance (GenStat 17th Edition; VSN International, Hemel Hempstead, UK) and means were separated using the least significant difference (LSD) at the 5% level of significance. Yield differences between stress and non-stress environments can be used to define drought tolerance of cultivars (Passioura 1997). The evaluation of cultivars in different crop production potential regions and across years of highly variable rainfall (Figure 3) therefore presented an opportunity to identify cultivars that resist drought, while also producing high and stable yield.

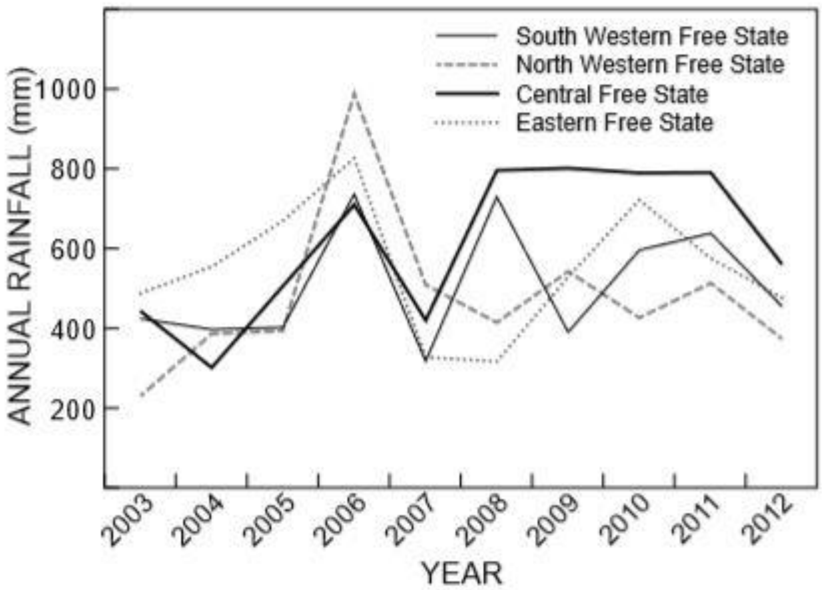

Figure 3: Average annual rainfall in dryland wheat production regions of the summer rainfall area of South Africa from 2003–2012 (source: Agricultural Research Council's agro-climate database; http://155.240.219.9/agromet/Login_Screen.php?btn_Login=CONTINUE)

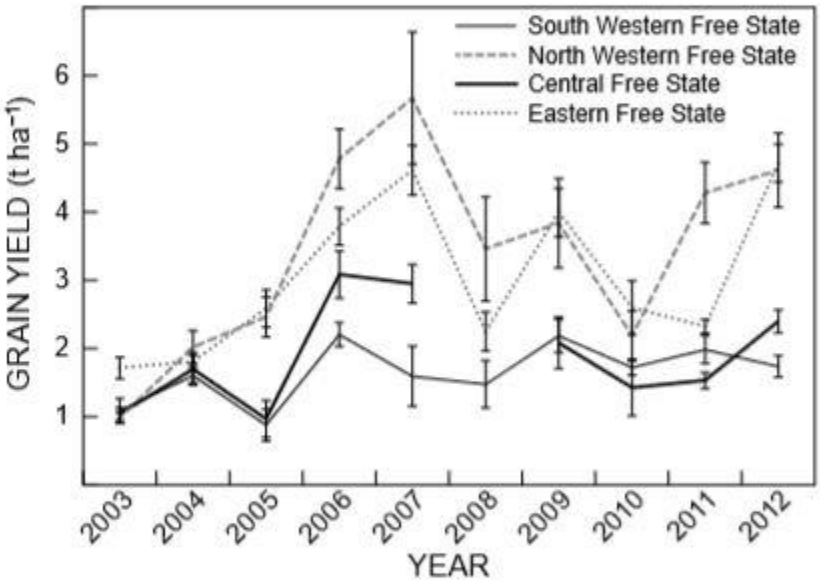

Figure 4: Mean cultivar performance of early-planted wheat in dryland wheat production regions of the summer rainfall area during the period from 2003 to 2012. The error bars represent 2 standard deviations of the mean

Mean yields of both early and later plantings were lowest in the SWFS (where it is driest), but were highest in the NWFS and EFS (Figures 4 and 5). Based on the large standard deviations of the means presented in Figures 4 and 5, it appeared that considerable genetic variation exists among the cultivars in terms of yield potential under both dry and wetter conditions. The coefficient of variation (CV) is a measure of spread that describes the amount of variability relative to the mean. It can be used to estimate the amount of yield fluctuation risk associated with a cultivar. The CV alone is not an ideal measure for describing genotypic stability because its rank order is usually induced; e.g. consistently low-yielding cultivars across targeted environments may have low CVs, and may not be good cultivars to recommend. It is always best when recommendations for stable cultivars consider both the low CV and the actual mean yield. A combination of high yield and relatively low CV implies that a cultivar consistently produced high yield in the target environments. Selecting out yielders that have a low CV can enable breeders to select simultaneously for high and stable grain yield in a reliable way (Ortiz et al. 2001; Mustatea et al. 2009). As alluded to earlier, low-yielding cultivars were continuously replaced with newly released ones in the cultivar evaluation trials, but the top-performing cultivars did remain in the trials for an extended period. Only the top-performing cultivars, which lasted in the trials for an extended period of at least five years or more out of the 10-year period, were considered for further analysis. Mean yields and CVs for these cultivars were calculated and are presented in Table 2.

Outstanding cultivars that had above-average yield and a lower-than-average CV can be identified from Table 2. For early plantings, these cultivars were SST 347, PAN 3120, SST 356, PAN 3377, Matlabas, PAN 3161, PAN 3368, PAN 3379 and PAN 3144. For later plantings, the cultivars were PAN 3355, PAN 3118, SST 347, SST 356, PAN 3161, PAN 3379 and PAN 3144. These cultivars are recommended for adoption by farmers, as well as possible utilisation by researchers in improving drought tolerance of wheat in the SRA.

These cultivars had the best 'phenotypic plasticity', referred to as the ability to give stable yield in both good and dry environments (Via et al. 1995). We therefore recommend the use of these cultivars to generate an elite gene pool for breeding drought tolerant and high-yielding cultivars adapted to the SRA. As explained by Rasmusson and Phillips (1997), breeding progress could be achieved from selecting within an elite gene pool by crossing 'good' with 'good'. In addition, further studies are recommended to identify their physiological and morphological mechanisms of adaptation to dry conditions, including the genetic basis.

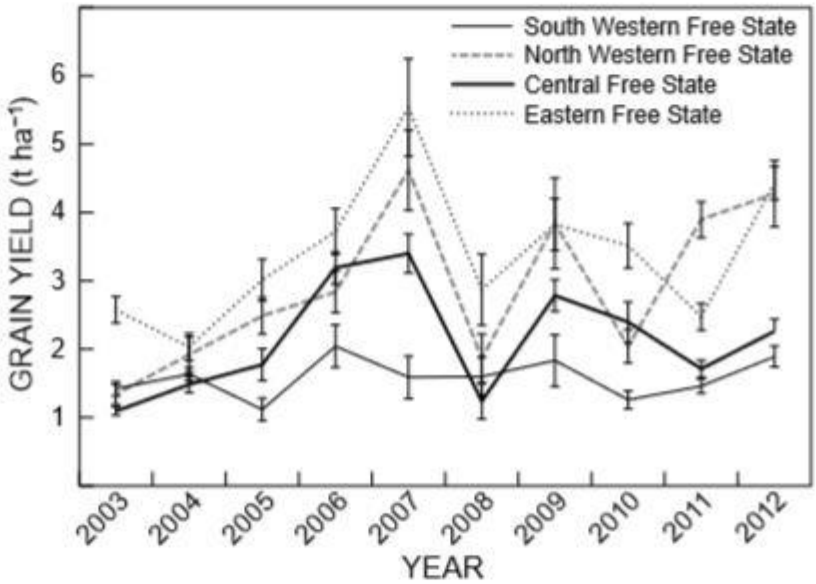

Figure 5: Mean cultivar performance of late-planted dryland wheat in production regions of the summer rainfall area during the period from 2003 to 2012. The error bars represent 2 standard deviations of the mean

Table 2: Ranking of dryland wheat cultivars that were evaluated for at least five years or more from 2003 to 2012 across the summer rainfall area of South Africa, based on the mean yield and coefficient of variation

Cultivar	Number of years evaluated	Mean yield ($t\ ha^{-1}$)	SD	Yield stability (CV; %)
Early-planted crops				
SST 347*	5	3.11	1.19	38.3
PAN 3120*	9	3.06	1.42	46.6
SST 356*	7	3.01	1.15	38.1
PAN 3377*	7	2.95	1.27	43.1
Matlabas*	10	2.93	1.35	45.9
PAN 3161*	5	2.86	1.27	44.2
SST 966	6	2.81	1.61	57.4
PAN 3355	6	2.80	1.33	47.6
PAN 3118	10	2.78	1.33	47.8
PAN 3368*	6	2.76	1.29	46.7
PAN 3379*	5	2.70	1.16	43.1
PAN 3144*	6	2.68	1.17	43.7
PAN 3364	7	2.56	1.18	46.0
PAN 3349	7	2.44	1.26	51.4
Gariep	10	2.44	1.15	47.2
Elands	10	2.44	1.11	45.7
Komati	8	2.37	1.15	48.3
SST 399	6	2.35	1.52	64.6
Caledon	9	2.32	0.99	42.8
Betta-DN	8	2.17	1.03	47.3
Limpopo	8	2.15	1.05	48.7
SST 322	5	1.42	0.73	51.3
Average	7.3	2.60		47.1
Later-planted crops				
SST 966	6	3.09	1.71	55.2
PAN 3161*	5	2.86	1.21	42.3
PAN 3379*	5	2.83	1.13	39.8
PAN 3355*	6	2.82	1.25	44.4
SST 347*	5	2.81	1.06	37.8
PAN 3368	6	2.79	1.35	48.5
SST 356*	7	2.78	1.09	39.3
PAN 3144*	6	2.63	1.18	44.6
PAN 3118*	10	2.60	1.14	44.0
PAN 3377	7	2.53	1.16	46.0
Gariep	10	2.52	1.05	41.7
Elands	10	2.51	1.06	42.3
Matlabas	10	2.51	1.16	46.3
Caledon	9	2.46	1.06	43.2
PAN 3349	7	2.41	1.13	46.9
Komati	8	2.39	1.13	47.5
PAN 3364	7	2.38	1.06	44.3
Limpopo	8	2.28	1.06	46.7
Betta-DN	8	2.22	1.06	47.6
SST 322	5	2.11	0.86	40.7
Average	7.3	2.58		44.5
$LSD_{0.05}$		0.17		

* Outstanding cultivars that show a combination of above-average yield and stability

Acknowledgements

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