Grain yield of selected crops at four climate analogue locations in Zimbabwe

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Abstract

Predicted warmer climates are likely to negatively affect production systems and expose smallholder farmers in sub-Saharan Africa, whose adaptive capacity is limited mainly due to poverty, to food insecurity. We studied the performance of selected varieties representing short, medium and long duration growth periods of four crops (maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L.) at two pairs (wet and dry) of 2050s climate analogue sites. Climate analogues, based on 30 years metereological data, were identified in smallholder areas of Zimbabwe. The sites were Kadoma (722 mm annual mean rainfall; 21.8°C annual mean temperature) which was the higher-temperature analogue site for Mazowe (842 mm annual mean rainfall; 18.2°C annual mean temperature) for wetter areas, and Chiredzi (541 mm annual mean rainfall; 21.3°C annual mean temperature) which was the higher-temperature analogue site for Matobo (567 mm annual mean rainfall: 18.4°C annual mean temperature) for drier areas. First season (2011/12) results showed that for the wetter pair, maize and groundnut grain yields were significantly higher at the cooler site (Mazowe). Sorghum yields were not significantly different between the sites and there was no grain yield for cowpea at the cooler site due to a fungal disease. Varietal yield differences were only significantly higher ($P<0.05$) at the cooler site for groundnut where the short duration variety had the highest yield (3809 kg/ha) and the medium duration variety the lowest yield (1420 kg/ha), compared with 140-355 kg/ha at the hotter site where growth was poor for all varieties. For the drier sites, maize, sorghum and cowpea grain yields were higher at the cooler site (Matobo) compared with the hotter sites (Chiredzi) but varietal differences were not significant. Results for the second season (2012/13) will be presented.

Introduction

Crop productivity and food systems are predicted to be affected by changing climate which is likely to affect crop variety preferences by farmers across varying agro-ecological regions in future (Gregory *et al.*, 2005). In Zimbabwe, conditions for growing early low yielding maize varieties are projected to shift more into currently wetter regions experiencing changing conditions suitable for growing long duration high yielding varieties (Nyabako and Manzungu, 2012). Reduction of crop yields is likely to effect a fall in crop revenue by as much as 90% (Carter *et al.*, 2007). The changes in crop production patterns is more likely to affect the marginalised smallholder farmers, who already experience low productivity due to current socio-economic and biophysical challenges characterising the drier areas of sub-Saharan Africa thereby impacting negatively on food security (Matarira *et al.*, 1995). These changes call for a focus on adaptive cropping strategies that will serve as mitigation measures against drastic changes in peoples' livelihoods (Eriksen *et al.*, 2011).

Exposing communities to various crop variety options than those they traditionally grow might be a way forward in preparing these farmers for the future. Crop breeding has to be in tandem with changing climate. As the conditions in the wetter areas get drier and warmer, it is important for farmers to realise that they can no longer continue with high yielding crop varieties that take long to mature but rather move to shorter duration varieties to ensure food security is maintained. It is against this background that different crops and their varieties were grown on climate analogues and their reference sites. The crops were selected based on farmer preferences and suitability to different climatic conditions whilst the varieties were selected based on the number of days to maturity. The days to maturity vary from crop to crop and is influenced by crop genotype, climatic and environmental factors (Bruns, 2009). As these factors change, it is important that research informs on climate risk mitigation varietal cropping options, which farmers can adopt to minimise climate change shocks such as total crop failure due to droughts. The dilemma for farmers is to ascertain whether crop varieties will still perform to expected yield potential given the anticipated climatic changes. A study was carried out to assess the performance of selected crops and their varieties under different climatic regimes. It was hypothesized that as temperatures increase with climate change, short duration crop varieties will be better adapted to these climates.

Materials and methods

Site description

The study was conducted at two climate analogue sites; wet and dry and their respective reference sites classified as cool and hot. The hot/wet analogue site was Kadoma (722 mm annual mean rainfall; 21.8^{o}C annual mean temperature) which represented the 2050s climate in the cool/wet reference site Mazowe (842 mm annual mean rainfall; 18.2^{o}C annual mean temperature). The hot/dry analogue site was Chiredzi (541 mm annual mean rainfall; 21.3^{o}Cannual mean temperature) which represented the 2050s climate in the cool/dry reference site Matobo (567 mm annual mean rainfall: 18.4^{o}C annual mean temperature). The 2011/12 season rainfall totals (Table 1) were recorded.

Table 1: 2011/12 seasonal rainfall cumulative totals for selected sites

Site	Rainfall (mm)
Matobo	278
Chiredzi	462.8
Mazowe	673.6
Kadoma	577.5

Soil samples were collected at the beginning of the first season (2011/12) from three sites for site characterization. A summary of soil chemical properties from the top 15 cm from the two study sites is given in Table 2.

Table 2: Soil characterization on analogue and reference sites

Site	pH	Olsen- P (mg kg^{-1})	Total P (%)	Mineral N (mg kg^{-1})	Total N (%)	Organic C (%)
Matopos	5.3	0.1	0.01	3.7	0.04	0.8
Mazowe	5.6	0.5	0.1	2.4	0.1	1.6
Kadoma	6.1	0.5	0.04	3.7	0.1	1.3

Experimental design and management

The experiment on crop varieties was set up as a completely randomised block design with four crops (Table 3), each with three varieties replicated three times in 30-54 m^{2} plots.

Table 3: Crop varieties

Crop	Early maturing variety	Medium maturing variety	Late maturing variety
Maize	SC403	SC513	SC727
Sorghum	Macia	SDSL89473	Pato
Groundnut	Nyanda	Natal common	Makhulu red
Cowpea	CBC1	CBC2	Landrace

Land preparation was done using a SC6 tractor drawn disc plough and planting furrows were opened using hand hoes. The plant spacing used was based on national extension recommendations for each crop. Maize was planted at 90cm (between rows) x 30cm (in-row) giving an approximate 37037 plants per hectare, sorghum 75cm x 20cm (approximately 66 666 plants per hectare) whilst groundnut and cowpea were planted at 45cm x 15cm (approximately 148 148plants per hectare). Compound D (7N:6P:6K) fertilizer was applied as basal at planting at a rate of 286 kg ha^{-1} for all crops at the dry sites and at 300 kg ha^{-1} at the wet sites. The experiment was managed under rain-fed conditions at all sites.

Thinning was performed two weeks after emergence for all crops. Ammonium nitrate was applied (above ground) to maize and sorghum plots as top dressing fertilizer at a rate of 58 kg ha^{-1} at the dry sites and 150 kg ha^{-1} at wet sites six weeks after planting. The fertilizer was placed 5cm away from the plants and left uncovered. Gypsum was applied to groundnuts at flowering at a rate of 250kg ha^{-1}. All the plots were hand hoe weeded three times using hand-hoes with the first weeding performed two weeks after planting. Armyworm (*Spodoptera exempta*) and other leaf eaters were controlled by spraying carbryl (1-naphthyl methylcarbamate) 85% WP. Aphids were controlled several times in cowpea by spraying diamethoate (O,O-Dimethyl S-(N methylcarbamoylmethyl) phosphorodithioate).

Data collection

Net plots of 3 x 4 m were marked within the experimental plot. Grain yields were determined by harvesting crop in the net plots at physiological maturity. Grain sub samples for maize and sorghum were collected and oven dried to 12.5% moisture. The net plot grain weights were then corrected to 12.5% moisture and yield calculated. For groundnut and cowpeas net plots of 11 rows x 4 running metres were harvested at physiological maturity (cowpea; dry pods and groundnut after browning of leaves). The harvested crops were cleaned and sun dried for three days and then shelled. The grain was weighed and corrected to 10% content and resultant yields were calculated.

Statistical analysis

Grain yields were analyzed using analysis of variance (ANOVA) in GenStat 14th edition (VSN, 2011). The standard error of differences (SED) of the means ($P < 0.05$) was used to separate site and variety means.

Results

Grain yields at wet sites

At the wet sites, maize (Table 4) and groundnut (Table 5) yields were significantly different between the cool and hot sites ($P < 0.05$). Varietal differences were only observed for groundnuts. For maize, yields were higher at the cooler sites for all varieties. The late duration variety gave the highest yields (5937 kg ha^{-1} at Mazowe, 3979 kg ha^{-1}at Kadoma), followed by the early duration (5083 t ha^{-1} at Mazowe, 3373 kg ha^{-1} at Kadoma) and lastly the medium duration (4857 kg ha^{-1} at Mazowe, 2529 kg ha^{-1} at Kadoma), although differences were not significant across varieties ($P > 0.05$). Sorghum yields ranged from 2000-5500 kg ha^{-1} at both sites; however, the yields were neither affected by site nor variety.

Groundnut varieties were significantly different ($P>0.05$) between the two wet sites with higher yields recorded on the wetter site, Mazowe (1420-3809 kg ha^{-1}). (Table 5). The yields were low at the hot site, Kadoma (140-158 kg ha^{-1}) due to poor establishment of the crop. The cowpea yields were obtained at

Kadoma, a comparison between sites was not made as the crop was affected by a fungal disease at the cool site (Mazowe) and hence no grain yields were obtained.

Table 4: Maize and sorghum grain yields at Kadoma (hot/wet) and Mazowe (cool/wet), Zimbabwe in the 2011/12 season

	Maize				Sorghum	
	SC403	SC513	SC727	Macia	SDSL89473	Pato
Kadoma	3373	2529	3979	3121	5468	3928
Mazowe	5083	4857	5937	5223	2007	3861
P values						
Site		0.005			0.088	
Variety		0.198			0.396	
Interaction		0.902			< 0.001	
SED						
Site		547.1			251.7	
Variety		672.0			308.2	
Interaction		952.3			435.9	
LSD						
Site		1238			560.8	
Variety		1520			686.8	
Interaction		2154			971.3	

Table 5: Groundnut and cowpea grain yields at Kadoma (hot/wet) and Mazowe (cool/wet), Zimbabwe in the 2011/12 season

	Groundnut			Cowpea		
	Nyanda	Natal common	Makhulu red	CBC1	CBC2	Landrace
Kadoma	158	355	140	1250	1546	976
Mazowe	3809	1420	2094	-	-	-
P values						
Site		< 0.001			-	
Variety		0.015			0.138	
Interaction		0.007			-	
SED						
Site		259.0			-	
Variety		317.2				
Interaction		448.6			-	
LSD						
Site		577.1			-	
Variety		706.9			671.7	
Interaction		999.6			-	

Grain yields at dry sites

At the dry sites, maize, sorghum (Table 6) and cowpea (Table 7) yields were significantly different between the cool and hot sites ($P < 0.05$). The cool site (Matobo) had the highest crop yields for all crops and across all varieties although varietal differences were not significantly different. Crops and their varieties established well at Chiredzi; however a series of dry spells ranging between 9 to 15 days with no rainfall during the months of January and February affected crop growth and ultimately the crop yields.

Table 6: Maize and sorghum grain yields at Chiredzi (hot/dry) and Matobo (cool/dry), Zimbabwe in the 2011/12 season

	Maize			Sorghum		
	SC403	SC513	SC727	Macia	SDSL89473	Pato
Chiredzi	75	150	245	26	185	15
Matobo	2523	2152	3450	2374	2337	1781
P values						
Site		< 0.001			< 0.001	
Variety		0.435			0.235	
Interaction		0.556			0.412	
SED						
Site		445.4			173.5	
Variety		545.6			212.5	
Interaction		771.5			300.5	
LSD						
Site		992.5			386.6	
Variety		1216			473.5	
Interaction		1719			669.6	

Table 7: Groundnut and cowpea grain yields at Chiredzi (hot/dry) and Matopos (cool/dry), Zimbabwe in the 2011/12 season

	Groundnut			Cowpea		
	Nyanda	Natal common	Makhulu red	CBC1	CBC2	Landrace
Chiredzi	169.8	431.0	298.1	254.6	93.9	27.0
Matopos	409.9	431.9	415.8	856.8	1167.0	1153.0
P values						
Site		0.303			< 0.001	
Variety0.593	0.927					
Interaction		0.685			0.358	
SED						
Site		110.2			156.0	
Variety		135.0			191.1	
Interaction		190.9			270.2	
LSD						
Site		245.6			347.6	
Variety		300.7			425.7	
Interaction		425.3			602.0	

Table 8: Crop grain yields averaged by site for the 2011/12 season

Site	Maize	Sorghum	Groundnut	Cowpea
Kadoma	3289	4172	218	1257
Mazowe	5305	3697	2441	-
P value	0.005	0.088	< 0.001	
Chiredzi	157	75	299.6	125.2
Matobo	2708	2164	419.2	1058.9
P value	< 0.001	< 0.001	0.303	< 0.001

Discussion

At the wet sites, the reference site which was cooler (Mazowe) had higher maize and groundnut yields. Maize yields were higher in the wet areas with late maturing varieties (SC727) giving higher yields averaging 3.9-5.9 t ha^{-1} in wet/hot and wet/cool areas respectively. The higher grain yields at cooler sites might be explained by more available water for crop use. The late maturing maize variety SC727 gave the highest yields at both the reference and analogue sites. The cowpea was affected by a fungal disease at the cool/wet site as it tends not to do well in poorly drained and cool areas (Davis *et al*., 2007).

At the dry sites, all crop yields were highest at the cooler site, with maize yields of yields ranging from 0.07t/ha to 0.2t/ha in dry/hot and 2.5t/ha to 3.4t/ha dry/cool areas respectively. This was attributed to low, poorly distributed rainfall and several dry spells during the planting season (2011/12). Maize crop production varies with variation in spatial and temporal patterns of both total annual and planting season rainfall (Oseni and Masarirambi, 2011). The future climate for Matobo (current conditions at Chiredzi) may not favour crop production as yields were all lower than 0.5t ha^{-1} (Table 9).

All the three maize varieties (SC403, SC513 and SC727) yield performances were below the potential yield performances (SeedCo, 2011). This might have been attributed to the poor in-season rainfall distribution that prevailed at the sites. The maize varieties performed as expected in yield differences between the early (low yielding) compared to the late (high yielding) varieties as they are characterised by the production seed house SeedCo. Farmers currently producing high maize yields on wet cool sites (Mazowe) are likely to experience a decline in crop productivity as is currently occurring in the wet hot site (Kadoma). This might prompt the farmers to shift to short duration varieties that are, however, low yielding to adjust to the changes in climatic conditions. This is likely to affect household food security since maize is the staple food. Given this decline in maize yields, it will be of interest to look at the adaptation strategies employed by the rural poor in resolving food insecurity challenges. The decline in maize yields will not only affect food security but livelihoods in general as most farmers in wetter areas of Zimbabwe depend on maize production as a livelihood strategy.

Sorghum is mostly grown in the drier parts of Zimbabwe (Rao and Mushonga, 1987) and with the wetter regions expected to experience reduced rainfall and frequent droughts the crop might be a preference for the wetter regions in the future. Macia matured early and was not affected by in-season dry spells therefore giving yields ranging from 2.3t ha^{-1} in dry sites to 5.2t ha^{-1} in wet sites a performance that is consistent with the observations made by Saadan *et al.* (2000) except for Chiredzi site where the yields were severely affected by end of season dry spell. The medium duration sorghum variety SDSL 89473 showed some consistency in yields across dry and wet sites. Sorghum is one among the few resilient crops that can adapt well to future climate change conditions, particularly the increasing drought, soil salinity and high temperatures (http://www.icrisat.org/crop-sorghum.htm); however its preference by farmers might be hampered by labour involved in processing, taste and bird scaring. Though sorghum displayed consistently high yields its promotion might mean a lot of work has to be done on food product improvement, for farmers to take it up as an alternative cereal crop.

The performance of legumes in this trial shows some promising results especially for cowpea; however a shift to legume production will not be a likely solution considering suppressed markets similarly observed as a constraint in Malawi (Brand, 2011). This calls for genotypic improvement of maize varieties that are of both short duration and high yielding characteristics to ensure food security is achieved.

Cautious climate change adaptive measures have to be gradually introduced to avoid shocks associated with a future decline in crop productivity in the climate analogue sites. In dry sites some considerations have to be made on alternative livelihood options other than crop production as yields obtained from reference site (Chiredzi) for all test crops and their varieties were too low to sustain household cereal and legume food requirements. Livestock farming might be considered an option supported by supplementary fodder production to complement feed requirements during critical month of animal feed shortages.

Conclusions

We conclude that as temperatures increase with climate change, short duration varieties of maize will be better suited for the currently wet-cool environment. All sorghum and cowpea varieties may continue to give high yields however groundnut yields will decline significantly. At the currently cool-dry sites, we conclude that even the short duration varieties will give low yields and as such, lead to food insecurity.

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