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Yield of Drought-Stressed Sweet Potato in Relation to Canopy Cover, Stem Length and Stomatal Conductance

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Abstract

Sweet potato is generally considered as a drought tolerant crop, however, due to large genotypic differences, appropriate genotypes adapted to drought conditions must be identified. The aim of the study was to investigate the suitability of canopy cover, stem length and stomatal conductance to differentiate performance of sweet potato genotypes subjected to drought stress. Seven sweet potato cultivars and six elite lines were subjected to three water treatments, namely, a control (100%) treatment which received the full complement of plant available water (PAW) once soil water had depleted to 70% PAW, while the other two treatments received 60% (mild stress) and 30% (severe stress) of the calculated water that the control treatment received in rainout shelters. Pearson correlations were performed on measured parameters yield, leaf area index (LAI), stem length and stomatal conductance (g_s). Genotypic differences were observed for LAI values and indicated that the cultivar Purple Sunset was better adapted to soil moisture stress at the mild stress and severe stress conditions than the other cultivars included in the trials. The cultivars Purple Sunset and Blesbok indicated a better ability to adapt to moisture stress, with regards to stem length, by outperforming the other genotypes in Trials 1 and 3. Drought had a severe effect on the yield of all the genotypes, especially at severe stress. Resisto, Bophelo and 199062.1 produced the highest yield at the mild stress, with significant correlations between yield and the parameters LAI, stem length and stomatal conductance. This indicated that above-ground growth had a direct influence on plant growth below-ground. The correlations also indicated that LAI and stomatal conductance played a more important role than stem length in achieving yield, and, thus, could be useful screening methods for drought tolerance of sweet potatato.

Keywords: leaf area index, root yield, stomatal conductance, sweet potato, water regimes

1. Introduction

Sweet potato, *Ipomoea batatas* L. (Lam.), is generally seen as a drought tolerant crop, but the selection for appropriate genotypes for drought conditions remains a priority. Drought is a global problem that inhibits the growth of plants and leads to yield losses (Cattivelli et al., 2008). Canopy development of most crops are always negatively affected by drought conditions. Although some species and more specific cultivars do have the ability to withstand drought for certain periods of time, it is important that these cultivars must have the ability to produce a reasonable yield notwithstanding the poor canopy development during drought conditions. It is known that leaf area in sweet potato plants decreases as water stress increases (Nedunchezhiyan et al., 2012). Leaf area index (LAI), which measures canopy cover as leaf area per unit ground surface area, is an indication of the leaf material in an ecosystem or trial area. This can then be an indication of the effectiveness of photosynthesis, estimation of soil water availability, and some other processes that might be a link between the plant and the environment (Bréda, 2003). It was noticed by Lewthwaite and Triggs (2012), with sweet potato cultivars planted in the field, that clones which showed a large reduction in canopy cover under water deficit also experienced very large reductions in yield. Van Heerden and Laurie (2008) also noticed large reductions in yield for cultivar Resisto which could be directly linked to low LAI values under water deficit conditions.

Large decreases in stem length were observed by Van Heerden and Laurie (2008) in sweet potato cultivars that were deprived of soil water. Stomatal conductance concerns the relationship between carbon assimilation and water loss by transpiration (Ludlow, 1980). Stress-inducing environmental changes not only damage the photosynthetic process, but also affect stomatal movement, light absorption and the biochemical pathways for CO_2 fixation (Cornic, 2000). Although the response of stomata to environmental and physiological factors is complex, it is known that stomatal conductance varies with leaf irradiance, leaf temperature, atmospheric water vapour pressure deficit and CO_2 concentration (Cowan & Farquhar, 1977). Whereas the general trend is a decrease in stomatal conductance in drought stress conditions, Van Heerden and Laurie (2008) indicated that a decline in conductance is transient in less severe drought conditions in sweet potato plants. Bahar et al. (2009) reported positive relations between g_s (stomatal conductance) and yield in bread wheat, while these relations were not clear in durum wheat. In sweet potato potted plants subjected to drought, Yooyongwech et al. (2014) detected a decline in stomatal conductance, but unfortunately the yield was not determined to check for a possible correlation.

By means of subjecting sweet potato cultivars to normally irrigated and water stressed conditions, Ekanayake and Collins (2004) were able to classify different cultivars with regard to their ability to adapt to drought. Lewthwaite and Triggs (2012) observed significant differences in most of the genotypes evaluated, with the higher irrigated ones producing a higher yield, although some genotypes did not show any difference in yield at different irrigation levels. Furthermore, a severe reduction in sweet potato root yield and a parallel decline in biomass at severe water reduction were reported by Van Heerden and Laurie (2008). In pot experiments to screen sweet potato cultivars, Saraswati et al. (2004) found severe reductions in biomass of sweet potato plants, which was associated with a reduction in the wet and dry root mass of the drought stressed treatment plants.

The objective of this study was to observe and identify relationships between yield and different morphological parameters for use as drought screening tools in the future to identify drought tolerant sweet potato cultivars/lines.

2. Materials and Methods

Three drought stress trials (Trial 1, Trial 2 and Trial 3) were executed at the Agricultural Research Council, Roodeplaat-Vegetable and Ornamental Plant Research Institute (ARC-VOPI), Pretoria, South Africa (25.604°S, 28.345°E; 1189 m altitude) across two seasons (2009/2010 and 2010/2011). The details of the three trials are indicated in Table 1. Sweet potato cuttings were planted in soil prepared to normal cultivation practices. Plants were grown for three weeks in each trial before drought stress commenced. Water management was done through monitoring of soil water content by means of a capacitance probe (Ventek CC, Pretoria, South Africa). Readings were taken daily and soil water calculated. Cultivar Resisto was used as control in all three trials.

Table 1. Information on Trial layout and design for three research Trials conducted at ARC-VOPI

Trials	Type of site	# Entries and repeats	Trial design	Irrigation treatments	Spacing and plot size	Fertilization
Trial 1 (2009/2010)	LR	4 cultivars 3 repeats	Split plot	100%, 60%, 30%	0.8 × 0.3 m (3 rows of 6 plants)	1:0:1 (37) 500 kg ha^{-1} – at planting $(NH_4)_2SO_4$ 130 kg ha^{-1} at 14, 30 DAP K_2SO_4 200 kg ha^{-1} at 20, 40 DAP
Trial 2 (2009/2010)	SR (stress) Open field (control)	35 cultivars 2 repeats	CRBD	100%, 30%	0.8 × 0.3 m (7 rows of 5 plants in each repeat)	1:0:1 (37) 500 kg ha^{-1} – at planting $(NH_4)_2SO_4$ 130 kg ha^{-1} at 14, 30 DAP K_2SO_4 200 kg ha^{-1} at 20, 40 DAP
Trial 3 (2010/2011)	LR	8 cultivars 3 repeats	Split plot	100%, 30%	0.8 × 0.3 m (6 rows of 3 plants	1:0:1 (37) 500 kg ha^{-1} – at planting $(NH_4)_2SO_4$ 130 kg ha^{-1} at 14, 30 DAP K_2SO_4 200 kg ha^{-1} at 20, 40 DAP

LR = Large rainout shelter; SR = Small rainout shelters; CRBD = Complete randomized block design; DAP = Days after planting.

2.1 Trial 1

Four cultivars, namely, Resisto, W-119, Purple Sunset and Isondlo, were planted in soil prepared in a large rainout shelter (LR). In Trial 1, each treatment consisted of 3 rows containing 6 plants per row. Trial 1 contained border rows around the trial area, as well as between water treatments to prevent water contamination. The plants in Trial 1 were irrigated by means of a line-source overhead irrigation system through spray nozzles, with border rows receiving the same quantities as the respective treatment plants. In Trial 1, the 100% treatment (control) received the full complement of plant available water (PAW) once depleted to 70%, while the other two treatments received 60% and 30% of the calculated water that the control received. This resulted in gradual drying out of the soil in both the 60% (mild stress) and 30% (severe stress) water treatments. Fertilizer was applied to the soil based on soil analysis as per recommendation (Table 1). Measurement of canopy cover and stomatal conductance took place twice during the trial period, namely, at 60 and 90 days after planting (DAP). Readings for stomatal conductance were done with a SC-1 conductance meter (Decagon, Pullman, WA, USA), whereas canopy measurements were done with a Li-Cor 2200 plant canopy analyzer (LI-COR, Lincoln, Nebraska, USA) according to the manufacturer's recommendations. For stomatal conductance, three leaves per plant and three plants per repeat were measured. For canopy measurements, a total of 5 readings were done for each of the three repeats between 10 am and 2 pm. Stem length was also measured, at the same time as the LAI measurements, by using a piece of string. Three plants per repeat were identified and the stem length was measured non-destructively from the point of soil contact to the apical tip. Storage roots of trial plants (excluding border plants) were harvested manually at 150 days after planting, for each cultivar and for each repeat per treatment. The root mass was determined and the yield calculated in tons per hectare.

2.2 Trial 2

Sweet potato top cuttings, of 35 cultivars were planted in prepared soil. The cultivars were subjected to two irrigation treatments with two repeats per treatment, the stressed treatment in a small rainout shelter (SR), and the control treatment in adjacent open field. Border rows were planted around each repeat to prevent water contamination. Each repeat, per treatment, consisted of 5 plants per cultivar established 30 cm apart with rows 80cm apart from each other. Overhead sprinkler irrigation was used with two water treatments, namely, the drought treatment, where the PAW was kept at 30%, while the well watered treatment was irrigated when PAW had depleted to 70%. Normal rainfall was recorded in the open field treatment. Fertilizer was applied to the soil based on soil analysis as per recommendation (Table 1). Measurements of canopy cover, stomatal conductance, stem length and yield determination were done as described for Trial 1.

2.3 Trial 3

Sweet potato top cuttings of eight cultivars were planted in prepared soil in a LR. Trial 3 consisted of two treatments comprising of three repeats per treatment. Border rows were planted around the trial area, as well as in between treatments to prevent water contamination. Each repeat consisted of three plants established 30 cm apart in six rows 80 cm apart. The irrigation type was the same as Trial 1, but for the severe stress treatment (30%) the PAW was kept at 30% while the control (100%) was irrigated when the PAW had depleted to 70%. Fertilizer was applied to the soil based as per recommendation (Table 1). Measurement of canopy cover, stomatal conductance and stem length as well as determination of yield was done following the same procedure as Trial 1.

2.4 Statistical Analysis

Analysis of variance (ANOVA) was performed with data for each trial (Trial 1, 2 and 3) separately. The data was analysed as a split-plot with water treatments as main plots and cultivars as sub plots to test for significant effects. The repeated measurements over time were included in the ANOVA as a sub-subplot factor. Means of significant effects were separated using Fisher's t-LSD (least significant difference) at the 5% level of significance. For Trials 1 and 2, stomatal data was log transformed to normalize the data and to stabilize variances. Pearson's coefficient of correlation between LAI, stem length, stomatal conductance and yield was determined. Statistical analyses were done using GenStat *for Windows* 15th Edition (VSN International, Hemel Hempstead, UK). Yield reduction, as compared to control, was calculated by subtracting the weight value of the drought stressed cultivar from the control, and expressing the yield decline as a percentage of the control.

3. Results and Discussion

3.1 Trial 1

Significant effects were detected in LAI of the four cultivars in reaction to drought stress in Trial 1 (Figure 1). All the cultivars showed the effect of deprived soil water, especially between the control and mild moisture stress treatments. Lewthwaite and Triggs (2012) also observed a decline in canopy cover of certain sweet potato genotypes planted under both drought and wet conditions. At 60 DAP, cultivars Isondlo and W-119 were the only cultivars to experience a significant decrease in canopy cover between the control and mild moisture stress treatments, namely, a 91% and an 85% reduction, respectively (Figure 1). At 60 DAP, no significant decline in LAI values was noticed between the mild and severe moisture stress treatments.

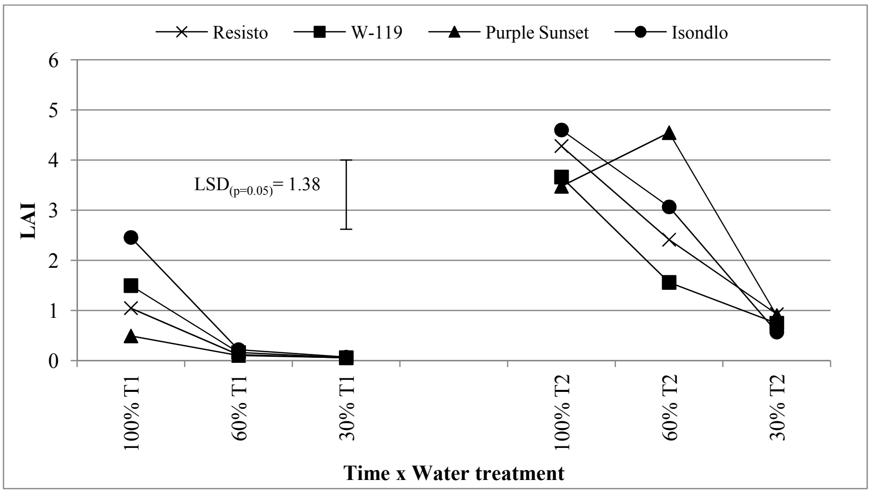

Figure 1. Leaf area index (LAI) of four sweet potato varieties subjected to drought treatment in Trial 1
T1 = 60 days after planting (DAP), T2 = 120 DAP, 100% = control, 60% = mild stress, 30% = severe stress.

No significant differences in the canopy cover could be detected between the cultivars at 120 DAP for the control treatment (Figure 1), but significant differences could be detected at mild moisture stress conditions. Cultivars Purple Sunset and Isondlo were least affected by the mild stress and probably have a better ability to withstand the drought conditions. No significant difference in LAI values could be detected between the cultivars at 120 DAP at severe stress conditions. This was not unexpected due to the severe stress the plants received, and that the plants were nearing the end of their growth cycle. The increase and significant difference in LAI values between 60 DAP and 120 DAP at control and mild stress conditions was probably due to the continued growth of the plants, and due to the fact that they were relatively small at the first time of measurement. Purple Sunset did not show a decline at the mild stress condition, which might be due to better coping strategies with the drought condition, although at severe stress, the cultivar had the same response as the other three cultivars.

Significant differences in stem length were detected between the cultivars at mild stress and control conditions (Figure 2). In the control treatment, there was a continuation in stem growth as seen at both 60 DAP and 120 DAP. This indicated that the plants were well watered and did not experience any stress. A significant decrease in stem length in all of the cultivars was also observed when comparing the control to the severe stress condition, which is in agreement with the findings of Nedunchezhiyan et al. (2012).

Figure 2 also indicates that at control and mild stress conditions, Purple Sunset, with regard to stem length, outperformed all the other cultivars significantly, but at severe stress conditions, the difference became insignificant. This is an indication that although the growth of Purple Sunset is heavily retarded at low soil water conditions, this cultivar is better adapted to mild stress as compared to the other cultivars. At 120 DAP, this cultivar performed even better by having significantly outgrown the other cultivars at mild stress conditions. It is also evident that cultivar Isondlo is a relatively slow grower, compared to the other cultivars, as the stem length measurement showed little increase for the control treatment of the first measurement compared to the second measurement. It is clear that cultivar Purple Sunset outperformed the other cultivars, except at severe stress conditions. This is quite interesting as in Figure 1 Purple Sunset also displayed good canopy cover at mild stress conditions during the second measurement. This might indicate that the cultivar does have the ability to adapt to drought at acceptable levels of soil water and could be rated as drought tolerant under these specific growth conditions.

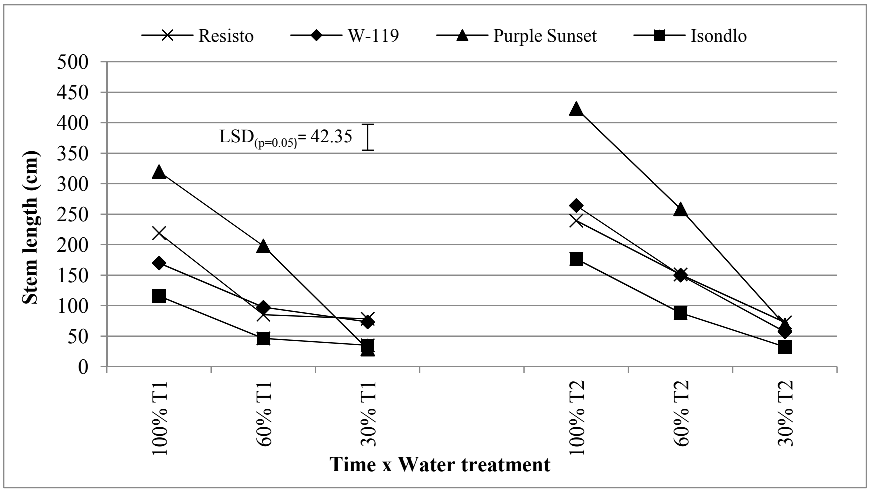

Figure 2. Stem length, taken at two time intervals during the season, of four sweet potato cultivars subjected to drought in Trial 1

T1 = 60 days after planting (DAP), T2 = 120 DAP, 100% = control, 60% = mild stress, 30% = severe stress.

Stomatal conductance values (Figure 3) between the control and stress (mild and severe stress) treatments declined throughout the duration of the trial. This is expected, since the soil continues to dry out and the leaf water potential will be having an influence on stomatal conductance (Liang et al., 2002). Stomatal conductance significantly decreased at 60 and 120 DAP, with a more pronounced decline at 120 DAP (Figure 3). Bloch et al. (2006) reported that stomatal conductance values in sugar beet plants declined with water stress, but the differences were insignificant. Van Heerden and Laurie (2008), however, reported a severe decline in stomatal conductance values for sweet potato plants subjected to drought stress.

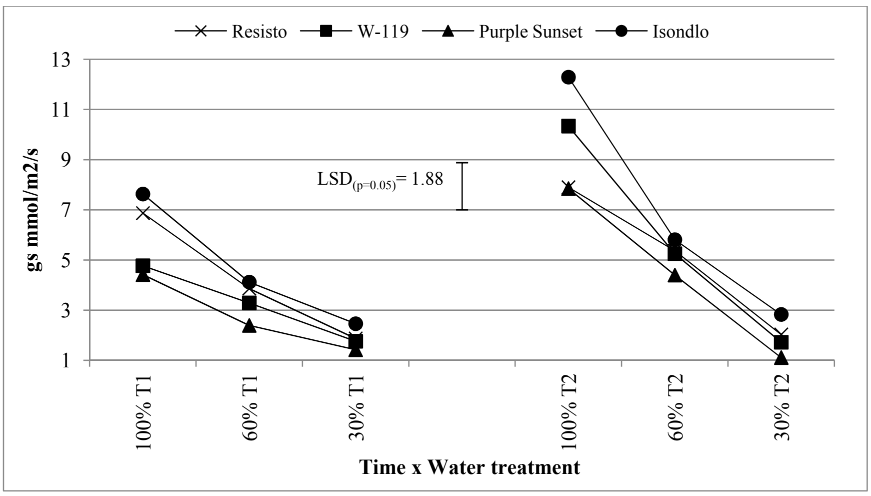

Figure 3. Transformed values of stomatal conductance differences between control and drought stressed conditions taken at two time intervals during the season for four sweet potato cultivars in Trial 1

T1 = 60 DAP (days after planting); T2 = 120 DAP; 100% = control; 60% = mild stress; 30% = severe stress.

Differences in stomatal conductance values between cultivars became less pronounced as the stress increased to 120 DAP (Figure 3) and is probably due to the early stage of the trial, and the drought was only being experienced for a relatively short time by the plants since the start of the experiment. Significant differences were observed between the cultivars in the control treatment, probably due to their genotypic differences in non-stressed conditions. As the stress progressed, fewer differences were observed between the cultivars. At the severe stress treatment, no significant difference was observed, clearly indicating that all cultivars included were similarly affected by the severe moisture stress. This is somewhat in contrast to the observations of Bloch et al.

(2006) who could not find significant differences between sugar beet cultivars subjected to drought conditions.

It is shown in Figure 4 that the drought stress had a severe impact on the root yield of all sweet potato cultivars and significant differences between the different treatments were found (Lewthwaite & Triggs, 2012). In comparison with the findings of Ekanayake and Collins (2004), who managed to classify genotypes according to their reaction to drought, significant genotypic differences were not observed at treatments other than the control. A significant reduction in yield was observed in all the cultivars at the severe stress treatment, while only W-119 displayed significant differences from the control at mild stress conditions. Although W-119 produced the highest yield at control conditions, it displayed high sensitivity towards drought with a yield decline of 99% at severe stress conditions, and a yield decline of 65% at mild stress conditions. Although no significant differences could be detected between the cultivars, Resisto, Purple Sunset and Isondlo showed less sensitivity, since the yield ratios were better when comparing the control and mild stress treatments. The yield loss for Purple Sunset, Isondlo and Resisto was 25, 31 and 40%, respectively, at the mild stress treatment. This indicated that these cultivars could adapt better to the lower quantities of water applied. Less water could be used, for instance, in the production of Resisto, since a reduction of 40% in irrigation resulted in only a 15% loss in yield. For Resisto, this was in alignment with the results obtained by Van Heerden and Laurie (2008), who indicated a severe decline in yield of the cultivar Resisto only under severe stress conditions. From our results it appeared that the severe stress treatment was too harsh with regard to the provision of sufficient yield data, which is not contributing to the aim of being used in the selection criteria for screening for drought tolerance.

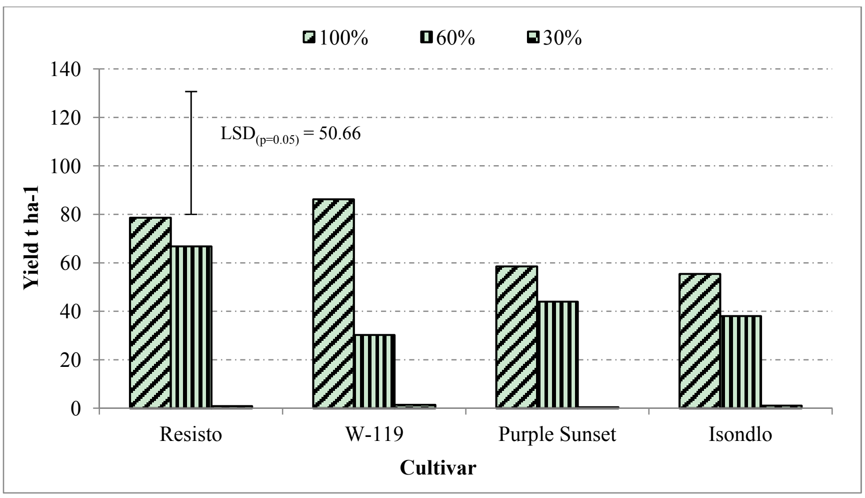

Figure 4. Root yield (t ha^{-1}) of four sweet potato cultivars subjected drought stress conditions in Trial 1

100% = control; 60% = mild stress; 30% = severe stress.

3.2 Trial 2

The LAI values of the 35 cultivars planted at severe stress and the open field were compared to each other. From these values the five best and five poorest performers are presented in Table 2 for discussion with the cultivars used in Trials 1 and 3.

Table 2. Leaf area index (LAI) values of 13 sweet potato breeding lines and cultivars subjected to drought and control treatments in Trial 2 at 60 and 120 days after planting

Variety	60 DAP		120 DAP		% improvement
	100%	30%	100%	30%	
Isondlo#	5.39	3.02	5.37	3.12	2.1
Purple Sunset#	5.07*	1.52	4.09	3.62	58.6
2005-1-16	5.16*	2.47	7.00*	2.80	-7.9
2005-12-2	5.79*	1.24	4.88	2.41	27.9
2006-3-4	6.20*	2.99	4.48	3.49	29.7
2006-4-4	4.00	2.18	5.77*	1.55	-27.6
2006-4-5	5.77*	2.67	7.67*	1.57	-25.8
2006-7-3	4.61	2.77	3.98	2.11	-7
Impilo	5.07	3.64	6.25*	2.80	-27.2
Resisto#	5.98*	1.00	4.37*	1.58	19.4
W-119#	4.79*	1.57	5.11	3.10	27.9
Blesbok#	4.68*	1.07	5.20*	1.77	11.2
Zapallo	4.22*	0.43	5.37	3.42	36.3
Mean	5.13	2.04	5.34	2.56	9.04
$LSD_{(P=0.05)}$ = 2.46					
$MSE_{df=70}$=1.44					

60 DAP = 60 days after planting; 120 DAP = 120 days after planting;

100% = control in open field; 30% = severe stress in small rainout shelter (SR);

Cultivars also used in Trial 1 and 3;

*Significant difference at $P \leq 0.05$ between control and severe stress for a specific variety x time x water combination.

Significant differences between the treatments were obtained. This in agreement with results obtained by Nedunchezhiyan et al. (2012), who observed significant differences in LAI values of sweet potato plantings at different soil water levels. In the present study, the cultivars Isondlo, Purple Sunset, Resisto, W-119 and Zapallo, as well as breeding lines 2005-12-2 and 2006-3-4, showed increasing canopy coverage at 120 DAP when the severe stress treatment is compared to the control treatment (Table 2). The cultivar Purple Sunset seemed to be the least affected by the drought treatment, displaying the highest percentage improvement, which suggests drought tolerance. The breeding line 2006-4-4 and cultivar Impilo indicated sensitivity towards the drought treatment at 120 DAP, since a decline in canopy cover was observed compared to the values at 60 DAP. At 60 DAP, five lines did not display significant differences between the control and the severe stress treatments, namely, Isondlo, 2006-4-4, 2006-7-3, Impilo and Lethlabula. This is in contrast with 120 DAP, where 16 of the 35 cultivars (data not shown) did not show significant differences between the control and severe stress treatments. Isondlo, 2006-7-3 and Lethlabula did not differ significantly between the severe stress and control treatments at both 60 and 120 DAP, which gives an indication that the cultivars might have the ability to adapt to the drought stress conditions.

Entries that showed significant differences in LAI between the control and the severe stress treatments at 60 DAP and at 120 DAP, included Purple Sunset, 2006-3-4, Beauregard, W-119 and Zapallo (Table 2). The cultivar Resisto displayed a slightly higher value at 120 DAP in Trial 2, which was consistent with the results obtained in Trial 1. The decline in LAI values that Resisto displayed was also consistent with the results obtained by Van Heerden and Laurie (2008), although only vine length was measured. The increasing trend of LAI values at the severe stress treatment level from 60 DAP to 120 DAP might indicate better adaptability towards the severe stress conditions for specific varieties. The contrary might also be true, so that varieties displaying a decline in LAI values exhibit sensitivity towards the drought conditions.

A significant decline (P ≤ 0.05) in conductance values was also observed in Trial 2 (Table 3). The difference between control and severe stress became more pronounced as the stressed progressed at 120 DAP. This was demonstrated by Van Heerden and Laurie (2008), where the difference in stomatal conductance values between the control and severe stress treatments of the cultivar Resisto became increasingly larger as the stress progressed.

Table 3. Stomatal conductance (g_s), in mmole/m^2/s, of 13 sweet potato cultivars and breeding lines subjected to drought and control conditions in Trial 2 at 60 and 120 days after planting (DAP)

Variety	60 DAP		120 DAP		% decline
	100%	30%	100%	30%	
Isondlo#	14.87	7.95*	11.75	3.36	24.9
Purple Sunset#	12.01	5.34*	15.36	5.03	11.7
2005-1-16	11.17	7.21	17.2	4.95*	35.8
2005-12-2	13.10	5.90	14.29	4.19*	15.7
2006-3-4	13.37	7.85	15.82	5.64*	23.1
2006-4-4	11.15	7.20	15.45	4.49*	35.3
2006-4-5	13.39	9.20	16.77	4.43*	42.1
2006-7-3	15.18	5.98*	16.7	3.46*	18.7
Impilo	13.37	7.45	13.28	2.13*	39.7
Resisto#	15.00	5.19*	13.21	2.82*	13.2
W-119#	12.98	5.36*	13.38	4.79*	5.5
Blesbok#	12.01	4.37*	14.13	2.57*	18.2
Zapallo	14.29	7.35*	12.83	2.57*	31.4
Mean	13.32	6.80*	14.67	3.99*	24.8
$LSD_{(p=0.05)}$ = 6.24					
$MSE_{(df=70)}$ = 5.802					

60 DAP = 60 days after planting; 120 DAP = 120 days after planting;

100% = control in open field; 30% = severe stress in small rainout shelter;

Cultivars also used in Trial 1 and 3;

*Significant difference at P ≤ 0.05 between control and severe stress for a specific variety x time x water combination.

The breeding lines 2006-3-4, 2006-4-4 and 2006-4-5, and cultivars Impilo and Jewel did not show significant differences in conductance values between the control and stress treatments early in the trial at 60 DAP (Table 3), which could be due to successful osmotic adjustment (Blum, 2005), but probably due to an increase in stress as significant differences were observed at 120 DAP. This is somewhat in contrast with the findings of Bloch et al. (2006) who observed less differences between the genotypes as the stress progressed, while subjecting sugar beet genotypes to drought stress. The cultivar Purple Sunset displayed the least decline in stomatal conductance and is regarded as quite drought tolerant, since it also exhibited high values of LAI and stem length. It can be concluded that Purple Sunset is able to keep water loss to a minimum, while upholding growth in the drought conditions. Table 3 further indicates that for the control treatment, stomatal conductance values of Trial 2 were higher than that of Trial 1. This could be due to rainfall, resulting in more vigorous growth of the plants compared to controlled water application in a rainout shelter.

Drought stress severely reduced root yield in Trial 2 compared to the control treatment (Table 4). These results correspond well with results obtained in Trial 1, and again confirmed the results obtained by Ekanayake and Collins (2004), Lewthwaite and Triggs (2012) and Gomes et al. (2005) who found large reductions in sweet potato yield under drought conditions. The total yield of Resisto was reduced by 96%, which is comparable to that of Trial 1. The yield reduction correlates well with the findings of Van Heerden and Laurie (2008) who observed a reduction of 80% in yield when the cultivar Resisto was subjected to drought stress. A significant reduction in yield from the control to severe stress treatments was observed for all the cultivars (Table 4). The breeding lines 2006-3-4 and 2006-4-4, and cultivar Impilo indicated the least reduction in yield loss, thereby indicating promise for adapting to drought conditions.

In Trial 2 the cultivar Zapallo produced the highest yield, and W-119 and Blesbok the lowest yields under control conditions, while the breeding line 2005-7-4 produced the highest yield and Tanzania the lowest yield under severe drought stress conditions. The cultivar Ndou experienced the biggest decline in yield, while the breeding line 2006-4-4 displayed the least, which would be an advantage to breeders in selecting suitable drought tolerant cultivars/breeding lines.

Table 4. Total yield (t ha^{-1}) of 13 sweet potato cultivars in Trial 2 subjected to control and severe drought stress conditions

Variety	Treatment		% reduction
	100%	30%	
Isondlo#	45.29	9.06	79.9
Purple Sunset#	47.62	7.73	83.7
2005-1-16	42.16	6.59	84.3
2005-12-2	35.20	2.63	92.5
2006-3-4	56.91	12.52	78.0
2006-4-4	52.85	13.59	74.4
2006-4-5	50.75	9.79	80.7
2005-7-4	38.69	7.99	79.3
Impilo	63.04	11.19	82.2
Resisto#	40.36	1.66	95.8
W-119#	34.13	4.60	86.5
Blesbok#	34.13	0.87	97.4
Zapallo	72.53	4.40	93.9
Mean	47.20	7.12	85.3
$LSD_{(p=0.05)}$ = 10.922			
$MSE_{(d.f.=68)}$= 19.29			

100% = control in open field; 30% = severe stress in small rainout shelters;

Cultivars also used in Trial 1 and 3.

3.3 Trial 3

The LAI values of the eight sweet potato cultivars in Trial 3 were compared to each other in two different water applications during the growth season (Figure 5). As expected, the plants subjected to severe stress displayed significantly lower values, compared to the control, showing a clear pattern in each of the two periods of measurement.

A significant decline in LAI values between the control and severe stress treatments were seen for all of the cultivars (Figure 5), where Mvuvhelo displayed the largest difference and Resisto the least. The small difference in LAI values for Resisto between the severe stress and control treatments, could be due to either reader error or possible water contamination during irrigation. It was further observed, in the control treatment, that the LAI values of all the cultivars, except Mvuvhelo, was lower at the 120 DAP compared to 60 DAP, which could be contributed to plant aging, resulting in a lower LAI value. Somda and Kays (1990), when investigating the growth of sweet potato, also found a decline in canopy cover of sweet potato plants, although the decline was only observed 16 weeks after planting. In the present study, the second measurement was done at 120 days after planting. It could be argued that the plants are already in an aging state, which could contribute to leaf shedding and the production of smaller leaves due to less water being used.

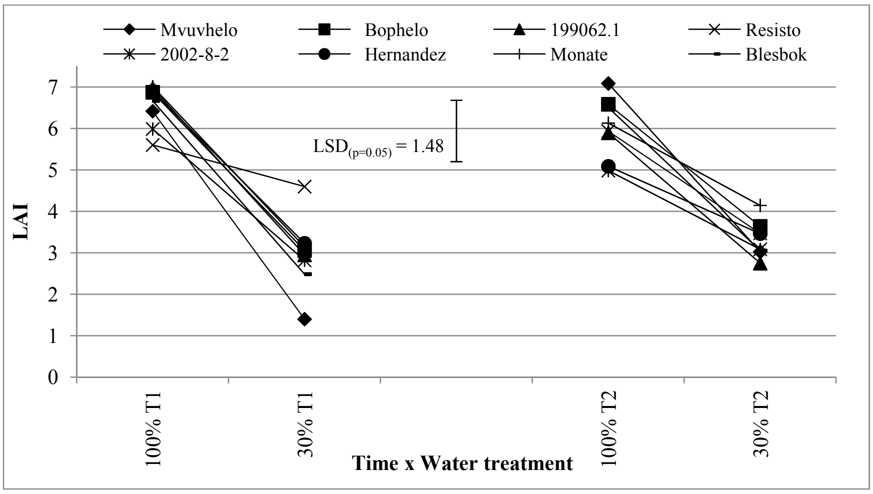

Figure 5. LAI values at two times during the season for eight sweet potato cultivars subjected to drought stress in Trial 3

T1 = 60 days after planting (DAP); T2 = 120 DAP; 100% = control; 30% = severe stress.

At severe stress, for both times of measurements, the majority of the cultivars displayed higher LAI values at 120 DAP. However, Mvuvhelo showed significant differences (Figure 5). The cause of that could be better adaption ability of cultivar Mvuvhelo to drought conditions by switching off non-essential processes to survive the drought. A significant increase in LAI values was observed from 60 DAP to 120 DAP, which can be attributed to the plants still being in the above-ground exponential growth phase. This is somewhat in contrast to the observation of Nedunchezhiyan et al. (2012) who observed a decline in LAI values from 95 DAP until harvest. The canopy cover of the sweet potato cultivars were affected by the drought conditions imposed in the three trials, as seen in declining values from control to mild stress and/or severe stress treatments. Although the plants seemed to grow reasonably well at mild stress, the severe stress proved too harsh to provide the plant with any chance to adapt to drought.

It was also evident that there was no stress imposed in the control treatment as the plants continue to develop a larger canopy at 120 DAP, although in some cases it was not significant (Figure 5). It was shown in Trial 3 that the plants at severe stress, although having stunted growth, continued to grow despite diminishing soil water quantities. This suggests that a reasonable amount of root growth had taken place, ensuring water uptake or that adaption had forced the plant to shut down certain mechanisms to ensure survival.

Stem length measurements between the cultivars and breeding lines were found to differ significantly in Trial 3 (Figure 6). Stem length values can give an indication of the success that a specific cultivar would have to overcome the drought condition with regard to canopy growth (Deblonde & Ledent, 2001). In Figure 6, the cultivar Blesbok showed the greatest promise to uphold growth throughout the experiment for the control treatment. This was interesting, since Blesbok did not show any promise in terms of canopy expansion in the same experiment with regard to the control treatment. This might give an indication that shoot growth is continuing despite the drought and that smaller leaves are formed to minimize excess transpiration. Cultivar 199062.1 had the shortest stems in all the treatments.

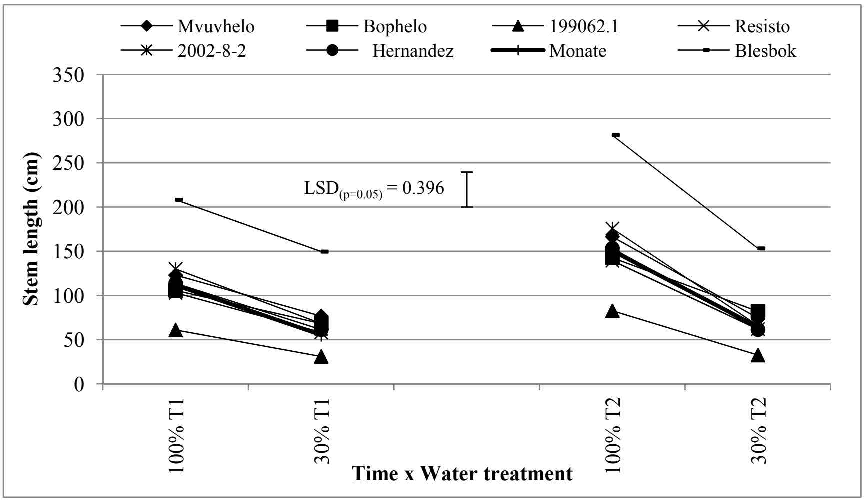

Figure 6. Stem length taken at two time intervals during the season for eight cultivars subjected to drought in Trial 3

T1 = 60 days after planting (DAP), T2 = 120 DAP, 100% = control; 30% = severe stress.

It is noticeable that there was a sharp increase in stem length for the cultivar Blesbok in all the treatments that outclassed all the other cultivars (Figure 6). Despite this promising outlook, it was shown, Figure 4, that there was a significant difference between the LAI values of this cultivar at the control and severe stress treatments. This then confirms earlier suggestions than the plants produce long stems at severe stress, but the leaves are small and probably have an impact on the yield due to the decrease in size caused by the stress.

Cultivars Resisto, 2002-8-2, Hernandez, Monate and Blesbok showed significant differences in stem length between the control and severe stress treatments at 60 DAP (Figure 6). This indicated that these cultivars were affected by the drought, causing retarded growth. Stem growth was severely hindered at severe stress conditions, and small to insignificant differences were detected among the cultivars. This implies that the stress was too severe and that a mild stress treatment would be more appropriate for distinguishing between the cultivars. From these results it is also evident that stem length is a parameter that can be used in conjunction with other screening parameters, but not alone. For example, Blesbok showed promising results of shoot growth under drought conditions, but had poor canopy cover. However, Pace et al. (1999) indicated that cotton plants had similar stem length in the drought stress and control treatments, while the canopy cover between the control and stress treatments differed vastly.

A severe reduction (significant) in stomatal conductance was observed in Trial 3 from the control to severe stress treatments (Figure 7). This is in agreement with the findings of Van Heerden and Laurie (2008) who observed a clear difference between the conductance of the control plants compared to those values of the stressed sweet potato plants. The non-significant differences between the genotypes at the severe stress treatment at 120 DAP could be due to the severe water deficiency in the soil causing the plants to close their stomata to prevent moisture loss to such an extent that all the plants were almost on the same level of survival. Due to the high variability in stomatal conductance, it would be difficult to establish genotypic differences using stomatal conductance as a parameter for screening. This was probably due to the fact that either the genotypes are very closely related or that the stress conditions were not more discreetly selected. A treatment between the severe and mild stress treatments might provide the possibility for proper selection between the genotypes.

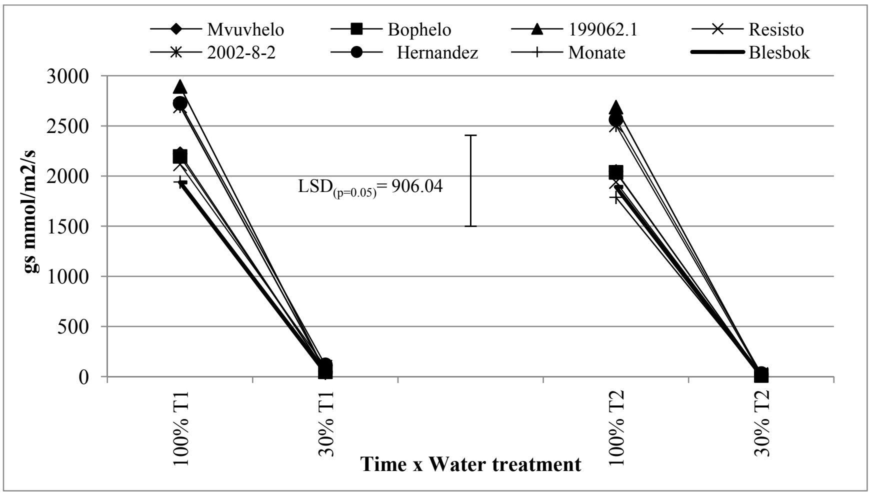

Figure 7. Stomatal conductance taken at two time intervals during the season for eight sweet potato cultivars and breeding lines in Trial 3

T1 = 60 days after planting (DAP); T2 = 120 DAP; 100% = control; 30% = severe stress.

A severe reduction in root yield was observed in Trial 3 (Figure 8). The reduction in yield observed for cultivar Resisto in Trial 3 corresponds well with results obtained by Van Heerden and Laurie (2008), although the yield was on average higher in the severe stress treatment in this study. Additionally, these authors also indicated a large reduction in yield in Resisto under drought conditions that was parallel to a decrease in shoot lengths. This indicated that the results were repeatable. In Trial 3, cultivar 199062.1 produced the highest (112 t ha^{-1}) yield under control conditions, while the cultivar Hernandez displayed the lowest (42.8 t ha^{-1}). Due to their superiority regarding yield under control conditions, it would be an advantage to select 199062.1, Mvuvhelo and Bophelo to be incorporated into a breeding programme for drought tolerance. A significant reduction in yield from the control to the severe stress treatments was observed for all the genotypes. Blesbok indicated the least yield loss (74%), while Resisto experience the highest yield loss (91%). This reduction in yield agrees with the finding of Saraswati et al. (2004) and confirms that sweet potato experiences huge yield losses under severe stress conditions. No significant differences were visible between the genotypes regarding yield at severe stress conditions. The non-significant differences in yield between the genotypes at the 30% treatment raised the question whether the 30 % treatment might be too severe to aid in the in the choice of a selection method for drought tolerant genotypes.

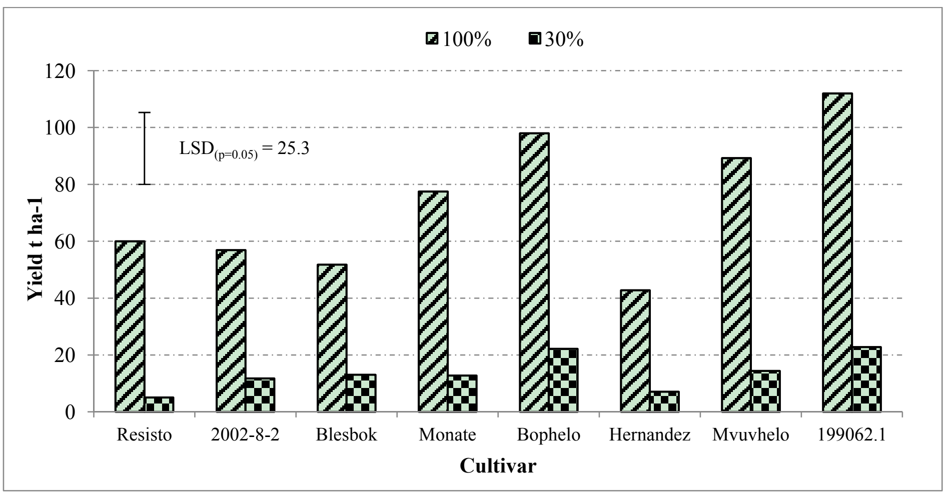

Figure 8. Root yield (t ha^{-1}) of eight sweet potato cultivars and breeding lines subjected drought stress conditions in Trial 3

100% = control, 30% = severe stress.

3.4 Relation of Canopy Cover, Vine Length and Stomatal Conductance to Yield

Yield was positively and significantly correlated with g_s in all three trials (Table 5). The correlation between yield and g_s confirmed the expectation that yield will be reduced when the plant is experiencing a decline in stomatal conductance.

Table 5. Pearson correlation coefficients when comparing root yield with LAI, stem length and stomatal conductance (g_s) in the three trials.

Trial	Parameter		
	LAI	Stem length	g_s
1	0.326	0.526*	0.501*
2	0.711*	-	0.580*
3	0.468*	0.406*	0.701*

* Indicates significant correlation.

The results of Leidi et al. (1998) indicated similar findings in cotton, although the correlation was not as strong. Significant and positive, although not very strong, correlation were found between yield and stem length. This correlates with the findings of Sayre et al. (1995) who also observed less reduction in canopy cover with higher yield in wheat.

A strong correlation between yield and LAI was observed in all three trials, indicating the effect that leaf coverage has on the root production of the plant. These results correlate with the findings of Sayre et al. (1995) who also found a significant correlation between yield and % reduction in plant height in wheat.

5. Conclusion

It is thus concluded that drought had a detrimental effect on the growth of the sweet potato plants to such an extent that no significant differences could be observed under severe drought conditions between the genotypes. Yield was also largely affected by the retarded growth as a result of the drought conditions. Moderate drought stress had a negative effect on all the parameters, but still allowed the opportunity to distinguish between the different genotypes, whereas the severe stress treatment proved otherwise. The correlations obtained indicated that the optimum yield is very much dependant on upholding proper canopy cover, stem length and stomatal conductance. Measurement of leaf area index and stem length related well to yield and can therefore be used as drought screening tools in the future.

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