Sweetpotato cultivar response to prolonged drought

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Abstract

The sweetpotato (*Ipomoea batatas*) plant is tolerant to long periods of drought stress, although storage root yield and quality may be compromised. Root yield is particularly vulnerable to water restriction during the time of plant establishment, as any lignification of developing roots may impair their potential for the lateral thickening associated with carbohydrate storage. Sweetpotato cultivars vary in both their sensitivity and response to drought. In this field study, the growth of sweetpotato clones under prolonged natural drought conditions was compared with growth in a well watered environment. Throughout the growing season, some clones under drought stress underwent an atypical extended period of profuse flowering. While the canopies of clones grown under watered conditions exhibited complete ground coverage by season's end, canopies of drought-affected plants showed a range of clone-specific responses. Insects caused a greater degree of root damage at the water-stressed site, as soil cracking increased insect access to the roots. At harvest, three distinct drought yield responses were demonstrated: lowered root yield, unmodified yield, and increased root yield ($P<0.001$). The cultivar 'Toka Toka Gold' demonstrated a 77% increase in marketable root yield under conditions of water stress, compared with that of the well watered site. The influence of drought on yield components differed with specific clones, both in the number of storage roots formed ($P<0.001$) and average root weight ($P<0.001$). Storage root quality was also affected, with the roots of some clones developing fluting along their main axes, while others were unaffected.

Additional keywords: kumara, water, rainfall, moisture deficit

Introduction

The majority of New Zealand's sweetpotato (*Ipomoea batatas* (L.) Lam.) or kumara crop is grown in the Kaipara District of the Northland region, near the towns of Dargaville and Ruawai. The Northern Wairoa River passes through this cropping district, but as a considerable length of the river is tidal, water quality is brackish and unsuitable for irrigation. Sweetpotato crops are therefore reliant on the volume and seasonal distribution of natural rainfall. In most seasons, the growers' main concern is in avoiding water retention and flooding within their fields. Excess water percolating through the soil profile is initially captured by field tiles, then, along with surface runoff, is diverted from cropping land through open drainage channels into natural waterways. As the spring season approaches, a portion of this runoff is deliberately retained within drainage channels or collected in ponding systems. The only irrigation water applied to the crop is at transplanting, when un-rooted sprouts cut from propagation beds are established in the field (Lewthwaite *et al*., 2011). The water used at transplanting is sourced from the natural runoff retained in channels and catchment ponds. This water is applied along the crest of the ridges in which transplants are inserted, from a tractor drawn water cart. Crop establishment typically takes about three days, depending on soil temperature and moisture levels. Apart from the water applied at establishment, in this district there are no water resources suitable for general irrigation of the crop when rainfall is insufficient for optimum plant growth.

The sweetpotato plant is considered tolerant to long periods of drought stress (Jones, 1961; Constantin *et al*., 1974; Bouwkamp, 1985), but the crop is particularly vulnerable at plant establishment. Yields may be significantly reduced if water stress occurs within the first six weeks from planting (Edmond and Ammerman, 1971). Dry soil conditions can cause newly formed roots to lignify, irreversibly limiting their potential for lateral growth and therefore capacity for carbohydrate storage (Togari, 1950; Ravi and Indira, 1996; Lewthwaite and Triggs, 2009). Prolonged drought may also cause general effects on storage root yield and quality. An inadequate water supply can inhibit canopy development and limit photosynthetic activity, with subsequent effects on storage root yield (Ehara and Sekioka, 1962; Gollifer, 1980). However, the response to drought stress varies with cultivar (Villareal *et al*., 1979). Selection of sweetpotato cultivars based on drought resistance is of international interest (Ekanayake, 1997; Anselmo *et al*., 1998; Laurie *et al*., 2004).

In the 2009-10 season, the New Zealand Government declared the Northland region a drought zone. At planting, sweetpotato growers did not know how long the drought would continue, or its potential effect on their crops. The Plant & Food Research (PFR) sweetpotato programme was conducting cultivar evaluation trials, both within the drought zone and at a well watered site. The work reported here contrasts the growth responses of cultivars from the two sites, providing a guide to the possible consequences of future drought events.

Materials and Methods

Two trials were established to compare cultivar performance. One of the trials was situated at the PFR Pukekohe Research Centre (37° 12′ 26″ S, 174° 51′ 40″ E) and the other on a commercial property at Dargaville (35° 58′ 36″ S, 173° 52′ 17″ E). Sweetpotato cuttings produced at a common site (Pukekohe) were transplanted into the field at both sites, following standard commercial practice. The Dargaville trial was transplanted into the field on 20 November 2009, and watered in by tractor-drawn water-cart. The Pukekohe trial was transplanted into the field on 5 December 2009, and watered in by overhead irrigation. Subsequent weed growth was controlled by herbicides, supported by mechanical scarification and hand weeding. Plant growth at the Dargaville site was primarily influenced by a prolonged natural drought over the production season.

Twelve genetically diverse sweetpotato clones were grown in both field trials, namely: ‘Owairaka Red’ (Lewthwaite, 1998), ‘Beauregard’ (Rolston *et al*., 1987), ‘Toka Toka Gold’ (Lewthwaite, 1998), and nine advanced clones selected in 2004 from segregating seed populations supplied by the International Potato Centre (CIP), Peru. The nine clones were designated S1750 (file number 04N1750), S1757 (file number 04N1757), S1769 (file number 04N1769), S1787 (file number 04N1787), S1801 (file number 04N1801), S1816 (file number 04N1816), S1818 (file number 04N1818), S1819 (file number 04N1819), and S1820 (file number 04N1820).

The field experiments were laid out in row and column designs (Williams and John, 1989). The Pukekohe trial had three replications, while the Dargaville trial had four replications. The trials were guarded by sweetpotato plants on all sides. Each datum plot was two ridges wide and 4 m long. The plots were separated within columns by a 1 m gap, to allow for mechanical harvesting. Individual ridges were 75 cm wide and inter-plant spacing along ridges was 40 cm. Therefore, every plot contained a total of 20 plants, arranged within two ridges each containing 10 plants.

In the absence of irrigation, the soil moisture deficit in the Dargaville area is illustrated by the rainfall distribution over the 2009-10 season, relative to monthly averages based on the 30 immediately preceding seasons (Figure 1). The National Institute of Water and Atmospheric Research (NIWA) soil moisture index models the amount of water held within the soil, allowing for incoming precipitation, outgoing potential evapotranspiration and surface runoff at saturation (Kandel *et al.*, 2005). The degree of water stress based on the NIWA soil moisture index is illustrated in Figure 2.

At the Pukekohe site, rainfall was supplemented with overhead irrigation, applied when the estimated soil moisture deficit reached 50 mm, whereas the Dargaville site received no supplementary water apart from an extended period of watering by cart at plant establishment. Typically commercial growers apply approximately two applications of water by cart at plant establishment; however, because of the 2009-10 season drought, the Dargaville trial received approximately 14 applications of water to facilitate plant establishment. Plant survival at both sites was recorded on a per plot basis in January 2010.

A soil test was taken at Pukekohe on 9 February 2010, with the following analysis: pH 6.9, phosphorus 74 mg/litre (Olsen), potassium 0.64 me/100 g, calcium 12.6 me/100 g, magnesium 1.75 me/100 g, sodium 0.28 me/100 g, cation exchange capacity 20 me/100 g, total base saturation 78%, volume weight 1.04 g/ml, available nitrogen 40 kg/ha and organic matter 3.9%. A soil test was also taken at Dargaville on 9 February 2010, with the following analysis: pH 5.4, phosphorus 18 mg/litre (Olsen), potassium 1.22 me/100 g, calcium 16.3 me/100 g, magnesium 4.16 me/100 g, sodium 0.30 me/100 g, cation exchange capacity 32 me/100 g, total base saturation 68%, volume weight 0.99 g/ml, available nitrogen 173 kg/ha and organic matter 6.4%.

Plant diameter was measured on a per plot basis at Dargaville on 12 April 2010 and at Pukekohe on 13 April 2010, to estimate crop canopy cover. The respective trials were also harvested on these dates. The two trials were harvested mechanically, with a tractor-mounted lifter. Following harvest, the storage roots from each plot were graded based on their maximum width, as only roots with a diameter of greater than 2.5 cm were considered marketable and included in the data analysis. The marketable roots per plot were weighed and counted. Four roots from each plot were cut into pieces, combined, weighed, oven-dried at 80°C, then reweighed to calculate storage root dry matter content. The data were analysed using the REML procedure of the statistical software GenStat (version 11, VSN International Ltd, UK). Curves were plotted using the graphical software SigmaPlot® v10 (Systat Software Incorporated).

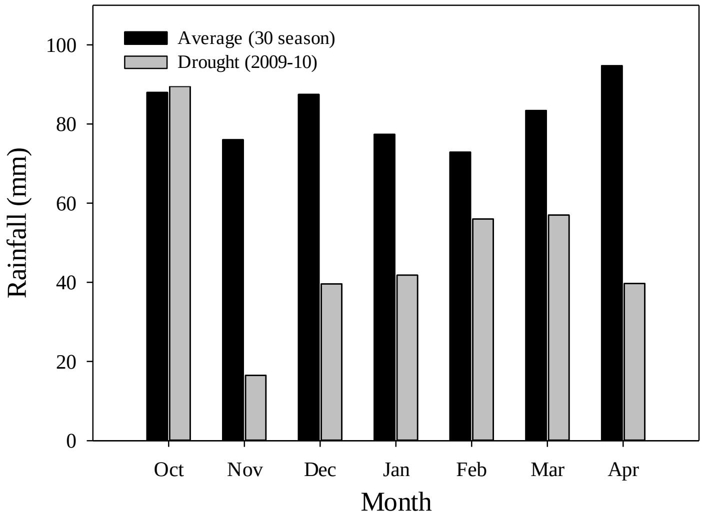

Figure 1: Rainfall at Dargaville, New Zealand, over the 2009-10 commercial sweetpotato (*Ipomoea batatas*) production season, compared with the preceding 30-year monthly averages. Data supplied by the National Institute of Water and Atmospheric Research.

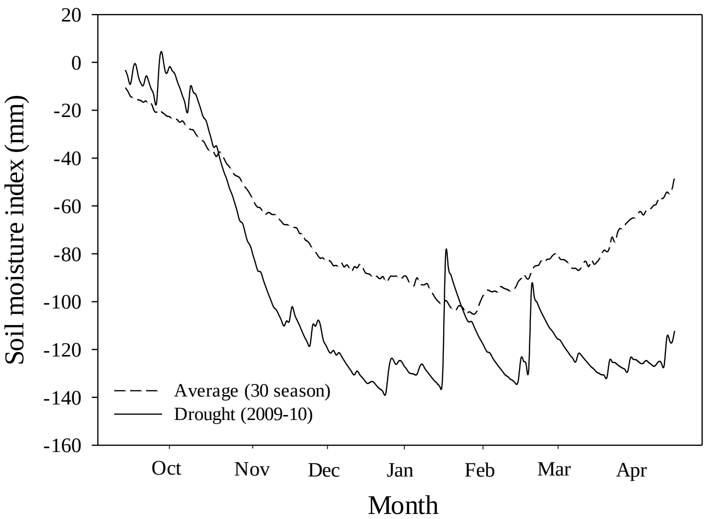

Figure 2: Soil moisture index for Dargaville, New Zealand, over the 2009-10 commercial sweetpotato (*Ipomoea batatas*) production season, compared with the preceding 30-year daily averages. Soil moisture is in deficit for negative index values. Data modelled and supplied by the National Institute of Water and Atmospheric Research.

Results and Discussion

There were no significant differences in plant survival between sites (P=0.73) or between clones within each trial (P=0.43). Initial plant-based indications of moisture stress at Dargaville were clone specific, including early profuse flowering and delayed canopy growth, as has been observed elsewhere (Lebot, 2009). All clones achieved full ground cover under a well watered regime at Pukekohe, while at Dargaville some showed water-limited growth throughout the entire season (Figure 3). Plant canopy growth was significantly reduced in S1819, 'Beauregard', S1818, S1816 and S1787 (P<0.001). In particular, S1818, S1816 and S1787 showed clearly discernable reductions in growth, with S1787 only half-sized by the season's end.

Clones with limited canopy growth showed a similar range of decline in storage root yield (Figure 4). The clone S1819, which had only a small canopy reduction at Dargaville, did not show a significant yield difference between the two sites; while 'Beauregard', with a slightly greater canopy reduction, showed a small but significant yield loss (P<0.001). The greatly reduced canopy growth under water deficit for S1818, S1816 and S1787 resulted in exceptionally large yield reductions relative to their performance at Pukekohe (P<0.001). The yield reductions were particularly marked, as clones S1816 and S1818 had the highest root yields in the Pukekohe trial. The lower yield of 'Beauregard' under drought stress was due to a slight but significant decrease in both root numbers and average root weight (P<0.001, Figures 5 and 6). The extremely low root yields observed for S1818, S1816 and S1787 were due to significant large reductions in both storage root numbers (by 46 to 54%) and in average root weight (by approximately 74%).

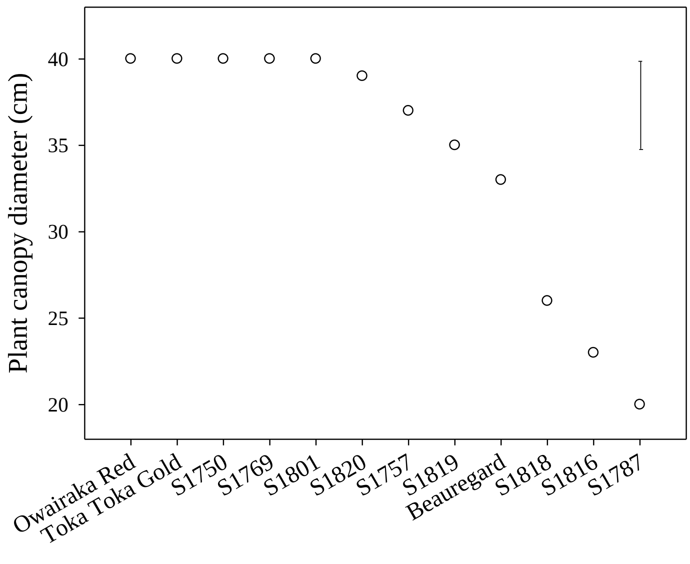

Figure 3: Average plant canopy diameter for sweetpotato (*Ipomoea batatas*) clones grown under drought conditions at Dargaville, New Zealand. The trial was established in the field on 20 November 2009; plant diameters were recorded at harvest on 12 April 2010. Full ground cover was achieved by a canopy diameter of 40 cm. The LSD (P=0.05) of 5.0 cm is indicated by a vertical bar.

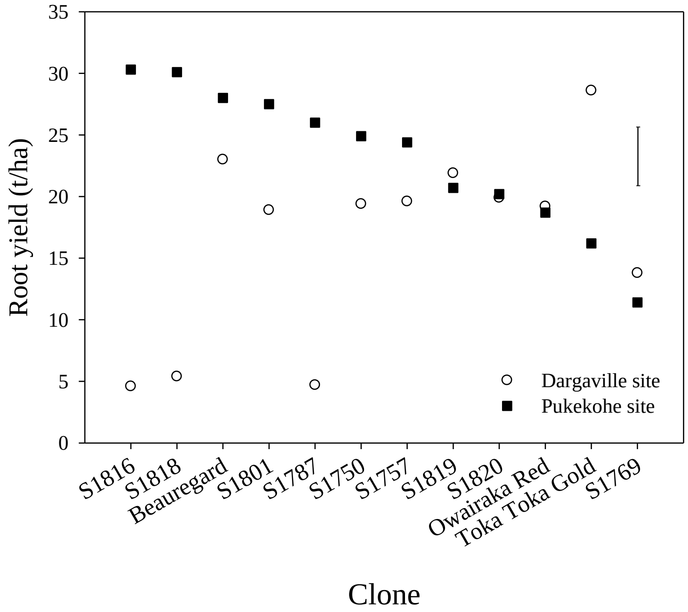

Figure 4: Storage root yields for sweetpotato (*Ipomoea batatas*) clones grown under well watered conditions at Pukekohe and water deficit conditions at Dargaville, New Zealand. An LSD (P=0.05) of 4.60 t/ha, for comparing a given clone across sites, is indicated by a vertical bar.

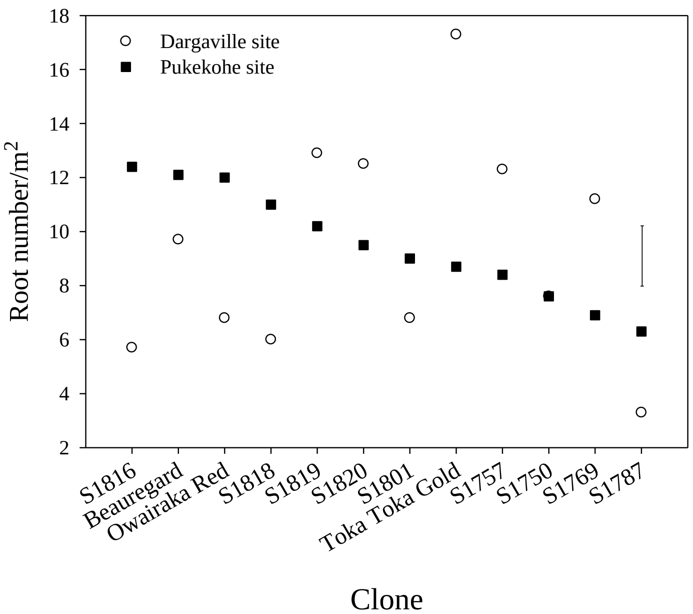

Figure 5: Storage root numbers for sweetpotato (*Ipomoea batatas*) clones grown under both well watered conditions at Pukekohe and water deficit conditions at Dargaville, New Zealand. The LSD (P=0.05) of 2.20 roots/m^2, for comparing a given clone across sites, is indicated by a vertical bar.

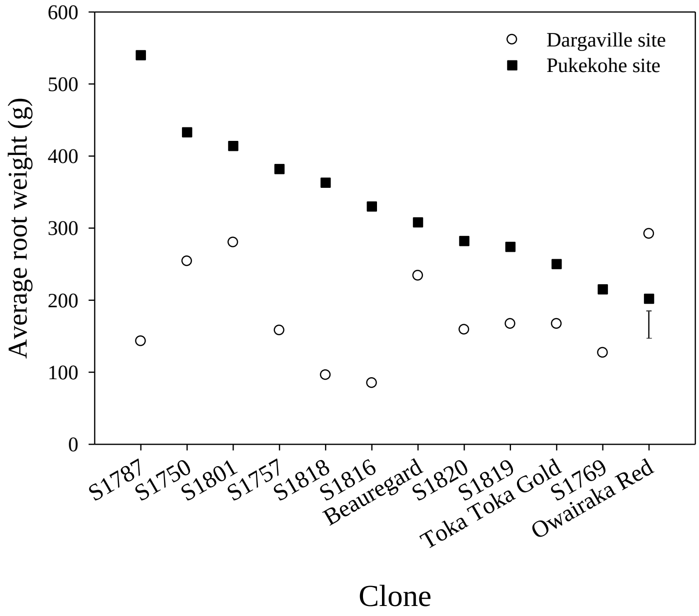

Figure 6: Average storage root weight for sweetpotato (*Ipomoea batatas*) clones grown under both well watered conditions at Pukekohe and water deficit conditions at Dargaville, New Zealand. The LSD (P=0.05) of 40.9 g, for comparing a given clone across sites, is indicated by a vertical bar.

The clones that showed no significant difference in root yield under well watered and water-deficient regimes included S1819, which has already been discussed, along with S1769, S1820 and 'Owairaka Red'. Clone S1769 had a relatively low yield at both sites (Figure 4). Clones S1769 and S1820 both had a significantly decreased average root weight at Dargaville, which was balanced by an increase in marketable root numbers ($P<0.001$). 'Owairaka Red' had the lowest average root weight at Pukekohe, but was the only cultivar that showed a relative increase in average root weight under water stress at Dargaville (Figure 6). This was balanced by a corresponding decrease in root numbers at Dargaville ($P<0.001$).

The clones S1750, S1757 and S1801 did not show a significant reduction in canopy growth, but did have a small but significant reduction in storage root yield under water deficit ($P<0.001$). The yield components for these clones show that S1750 and S1801 had no significant change in root number between sites, but did have lower average root weights at Dargaville ($P<0.001$). Clone S1757 also had a significantly lower average root weight at Dargaville, which was not compensated for by an increase in root numbers.

'Toka Toka Gold' was the only cultivar to produce a significant increase in storage root yield at Dargaville (Figure 4) relative to the Pukekohe site ($P<0.001$). The yield increase was due to a doubling of root numbers at Dargaville (Figure 5), which compensated for a reduction (33%) in average root weight (Figure 6). Given appropriately moist environmental conditions, the cultivar 'Toka Toka Gold' produces excessive numbers of roots, primarily along the vines at leaf nodes. The drought appears to have limited the number of roots formed, so that without internal competition for carbohydrates the remaining roots swelled to a size greater than the 2.5 cm diameter discard grade.

Root quality was also affected by prolonged soil water deficit, with all the clones in the Dargaville trial showing a significant increase in root dry matter content (%) relative to Pukekohe ($P<0.001$). The dry matter increase across clones ranged from 2.7 to 10.1% (data not shown). Other researchers have reported that root dry matter is particularly sensitive to water stress, and may provide a useful cultivar selection indicator for drought resistance (Ekanayake and Collins, 2004). Storage root shape was affected by drought, as roots of clones ‘Owairaka Red’, S1787, S1801, S1816 and S1818 from the Dargaville trial showed distinctive unattractive fluting along their main axis. The dry soils at Dargaville formed small coarse concretions which abraded the root periderm during the harvesting process, unlike the softer textured moist soils at Pukekohe. In general, roots from the Dargaville trial showed evidence of insect damage that was not observed from the Pukekohe site. Soil at the Dargaville trial was deeply cracked, and showed evidence of black beetle (*Heteronychus arator* Fabricius) and black field cricket (*Teleogryllus commodus* Walker) activity.

While the sweetpotato plant is robust and may be able to survive drought conditions, commercial production requires an economic yield. This study revealed a range of responses to prolonged water deficit, representing variation in the underlying physiology at an individual clone level (van Heerden and Laurie, 2008). In general drought stress causes adverse effects, but in specific circumstances can potentially enhance quality aspects such as antioxidant content (Rautenbach *et al*., 2010). Three named cultivars were included in this study, with ‘Owairaka Red’ being the most widely grown commercial cultivar in New Zealand. Drought did not cause a significant change in overall yield for ‘Owairaka Red’, but did modify the root size distribution and caused a loss of root quality. ‘Beauregard’ produced a lower but viable root yield without loss of quality. The cultivar ‘Toka Toka Gold’ had a positive response to drought, producing a higher yield of good quality roots under water stress. However, the rooting attributes that enabled this response can be problematic when water supply is not restricted. This study demonstrates the importance of selection for cultivar yield stability under different growing conditions, in order to minimise commercial risk; it also provides an indication of the probable nature and magnitude of future drought responses.

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References

Anselmo, B.A., Ganga, Z.N., Badol, E.O., Heimer, Y.M. and Nejidat, A. 1998. Screening sweetpotato for drought tolerance in the Philippine highlands and genetic diversity among selected genotypes. *Tropical Agriculture* 75: 189-196.

Bouwkamp, J.C. 1985. Production requirements. pp 9-33. *In*: Sweet potato products: A natural resource for the tropics. Ed. Bouwkamp, J.C. CRC Press, Florida.

Constantin, R.J., Hernandez, T.P. and Jones, L.G. 1974. Effects of irrigation and nitrogen fertilization on quality of sweet potato. *Journal of the American Society for Horticultural Science* 99: 308-310.

Edmond, J.B. and Ammerman, G.R. 1971. Sweetpotatoes: production, processing and marketing. AVI, Westernport, Connecticut. 334 pp.

Ehara, K. and Sekioka, H. 1962. Effect of atmospheric humidity and soil moisture on the translocation of sucrose-C^{14} in sweet potato plant. *Proceedings of the Crop Science Society, Japan* 31: 41-44.

Ekanayake, I.J. 1997. Evaluation of potato and sweetpotato genotypes for drought resistance. Section 3.5, pp 1-9. *In*: Sweetpotato germplasm management, Training manual. Ed. Huáman, Z. International Potato Center (CIP), Lima.

Ekanayake, I.J. and Collins, W. 2004. Effect of irrigation on sweet potato root carbohydrates and nitrogenous compounds. *Journal of Food, Agriculture & Environment* 2: 243-248.

Gollifer, D.E. 1980. A time of planting trial with sweet potatoes. *Tropical Agriculture* 57: 363-367.

Jones, S.T. 1961. Effect of irrigation at different levels of soil moisture on yield and evapotranspiration rate of sweet potatoes. *Proceedings of the American Society for Horticultural Science* 77: 458-462.

Kandel, D., Chiew, F. and Grayson, R. 2005. A tool for mapping and forecasting soil moisture deficit over Australia. Cooperative Research Centre for Catchment Hydrology, Technical Report 05/02, 18 pp.

Laurie, S.M., van den Berg, A.A., Magoro, M.D. and Kgonyane, M.C. 2004. Breeding of sweetpotato and evaluation of imported cultivars in South Africa. *African Crop Science Journal* 12: 189-196.

Lebot, V. 2009. Tropical root and tuber crops: cassava, sweet potato, yams and aroids. CABI, Wallingford. 413 pp.

Lewthwaite, S.L. 1998. Commercial sweetpotato production in New Zealand: foundations for the future. pp. 33-50. *In*: Proceedings of the International Workshop on Sweetpotato Production Systems toward the 21st Century. Eds LaBonte, D.R., Yamashita, M. and Mochida, H. 9-10 December, 1997, Kyushu National Agricultural Experiment Station, Japan.

Lewthwaite, S.L., Fletcher, P.J., Fletcher, J.D. and Triggs, C.M. 2011. Cultivar decline in sweetpotato (*Ipomoea batatas*). *New Zealand Plant Protection* 64: 160-167.

Lewthwaite, S.L. and Triggs, C.M. 2009. Preliminary study of the spatial distribution of sweetpotato storage roots. *Agronomy New Zealand* 39: 111-122.

Rautenbach, F., Faber, M., Laurie, S. and Laurie, R. 2010. Antioxidant capacity and antioxidant content in roots of 4 sweetpotato varieties. *Journal of Food Science* 75: 400-412.

Ravi, V. and Indira, P. 1996. Anatomical studies on tuberization in sweetpotato under water deficit stress and stress free conditions. *Journal of Root Crops* 22: 105-111.

Rolston, L.H., Clarke, C.A., Cannon, J.M., Randle, W.M., Riley, E.G., Wilson, P.W. and Robbins, M.L. 1987. 'Beauregard' sweet potato. *HortScience* 22: 1338-1339.

Togari, Y. 1950. A study on tuberous root formation in sweet potato. *Bulletin of the National Agricultural Experiment Station, Tokyo* 68: 1-96.

van Heerden, P.D.R. and Laurie, R. 2008. Effects of prolonged restriction in water supply on photosynthesis, shoot development and storage root yield in sweet potato. *Physiologia Plantarum* 134: 99-109.

Villareal, R.L., Lin, S.K. and Lai, S.H. 1979. Variations in the yielding ability of sweet potato under drought stress and minimum input conditions. *HortScience* 14: 31-32.

Williams, E.R. and John, J.A. 1989. Construction of row and column designs with contiguous replicates. *Applied Statistics* 38: 149-154.