NUTRITIONAL AND WATER PRODUCTIVITY OF SWEET POTATO

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Crop Science, School of Agricultural, Earth and Environmental Sciences, in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa. The research was financially supported by the Water Research Commission (WRC) of South Africa through WRC Project No. K5/2493//4 ‘Water use and nutritional water productivity for improved health and nutrition in poor rural households’ (WRC, 2016).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

ATModi

Signed: Professor Albert T. Modi (Supervisor)

Date: 06 December 2017

DECLARATION

I, Ladyfair Ntokozo Thobekile Dladla, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

> a) their words have been re-written but the general information attributed to them has been referenced;
>
> b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included.

Signed: Ladyfair Ntokozo Thobekile Dladla

Date: 06 December 2017

ABSTRACT

Vitamin A deficiency is a prevalent issue in many developing countries as it causes deaths among pregnant women and young children. Several sweet potato cultivars have been identified as a good source of beta-carotene, a precursor of Vitamin A. Therefore, versatile crops such as sweet potatoes have the potential to assist in addressing challenges related to food and nutrition security under conditions of water scarcity, thus addressing the water-food-nutrition-health nexus. The objective of this study was to determine nutritional water productivity (NWP) of three locally bred sweet potato cultivars (A40, A45 and 199062.1) in response to varying water regimes. The experiment was conducted under controlled environment conditions (~33/18°C day/night and 65% relative humidity). The experimental design was a split-plot with water regimes [30% and 100% crop water requirement (ETc)] as main plots and cultivars (A40, A45 and 199062.1) as sub-plots arranged in randomised complete blocks, replicated three times. Cultivars A45 and 199062.1 are orange-fleshed sweet potato varieties (OFSPs) and A40 is cream-fleshed. Yield and water productivity (WP) were determined at harvest. Thereafter, samples were analysed for nutrient (energy, protein and fat) and micro-nutrient (β-carotene, calcium, zinc and iron) content. Results of nutrient content (NC) and WP were used to estimate NWP. Yield varied with cultivar, where 199062.1 (26.4 t ha^{-1}) was the best, followed by A45 (16.7 t ha^{-1}) and A40 (14.9 t ha^{-1}), respectively. Water productivity (WP) was higher under 30% ETc compared to 100% ETc. This difference was attributed to better yield maintenance under low water availability. Consistent with results of yield, cultivars differed in WP, where 199062.1 (13.4 kg m^{-3}) was better than A45 (8.8 kg m^{-3}) and A40 (7.5 kg m^{-3}), respectively. The trend for NWP$_{(E, P, F)}$ (energy, protein and fat) was such that 30% ETc was better than 100% ETc. Cultivar differences showed a consistent trend as with WP, where 199062.1 > A45 > A40. NWP for calcium, zinc and iron mirrored this trend. However, NWP$_{\beta\text{-carotene}}$ varied significantly ($P<0.05$) between water regimes and among cultivars. Consistent with other variables, NWP$_{\beta\text{-carotene}}$ was higher at 30% ETc than 100% ETc. Cultivars A45 and 199062.1 had significantly higher NWP$_{\beta\text{-carotene}}$ than A40. This confirmed that OFSPs are more nutritious than the cream fleshed sweetpotato, and may offer greater diversity, especially in areas where nutrient deficiency is a problem in terms of food insecurity. It can be concluded that both orange and cream fleshed sweet potatoes have drought tolerance and potential to contribute to yield and nutrition across water regimes. Therefore, the use of NWP as a metric for crop performance allows for a useful indication of how a crop can contribute to food and nutrition security under water scarce conditions.

Keywords: crop water requirement, nutritional water productivity, sweet potato, water regime

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BACKGROUND AND OBJECTIVES

1.1 Introduction

The demand for water by people, industry and agriculture is higher than its availability and this has caused fresh water to become a scarce resource (Ridoutt and Pfister, 2010). Water scarcity in sub-Saharan African countries has caused many losses in the agricultural sector and resulted in higher food prices (Agili *et al.*, 2012). This increased the level of hunger or food and nutrition insecurity. Hunger is projected to get worse in sub-Saharan African countries over the next two decades (FAO, 2016). Hunger can reduce a country's economy, lead to death and it hinders mental and physical development in young children (Liu *et al.*, 2008). Therefore, the inadequate food and nutrition security remain prevalent in sub-Saharan Africa (SSA).

The UNSCN (2013) stated that "food and nutrition security exists when all people at all times have physical, social and economic access to food, which is consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life.". Food insecurity leads to malnutrition. Close to 200 million people in sub-Saharan Africa (SSA), are undernourished. Malnutrition is the cause of an estimated 54% of deaths in children (UN, 2014).

Agriculture is the primary source of livelihood for rural communities in SSA and ultimately the primary solution to ensure food and nutrition security. However, agricultural production is limited by water scarcity and recurring droughts. There is a need to identify crops that utilise less water while producing sufficient and nutritious yields. Sweet potato (*Ipomoea batatas* L.) is the fourth highest dry matter producer per hectare (Reddy, 2015). There are orange and white fleshed sweet potato varieties. The orange-fleshed sweet potatoes are a great source of beta-carotene, which is precursor of Vitamin A. The white-fleshed sweet potatoes are rich in antioxidants (Donado-Pestana *et al.*, 2012). Sweet potato (*Ipomoea batatas* L.) is considered to be a drought tolerant root crop with good nutritional value and can, therefore, be used to combat food and nutrition insecurity.

The aim of this study was to determine nutritional water productivity of selected sweet potato cultivars for improved production, nutrition and health. The null hypothesis of this study was that variation in available water during sweet potato growth will have no effect on water productivity and yield. To test the hypothesis, specific objectives were:

i. To determine water use of three sweet potato cultivars with respect to selected morphological and physiological growth patterns under controlled environment and field conditions.

ii. To determine yield parameters of three sweet potato cultivars in response to different available water regimes under controlled environment and field conditions.

iii. To determine nutritional water productivity of three sweet potato cultivars in response to different available water regimes under controlled and field conditions.

iv. To determine nutritional water productivity of three sweet potato cultivars under field conditions.

1.1 Literature review

Sweet potato (*Ipomoea batatas*) is believed to have originated in Central and South America approximately around 2000 B.C. based on the linguistic and archaeological approaches respectively (O'brien, 1972; Woolfe, 1992). Using molecular studies, Roullier *et al.* (2011) supported this evidence (Roullier *et al.*, 2011). It was then introduced to Europe by Christopher Columbus (1942) and later to China, India, Southeast Asia and Africa around the sixteenth century (Loebenstein, 2009). Sweet potato was then shipped from Mexico to the Philippines during the sixteenth century (Loebenstein, 2009). According Loebenstein (2009), Peruvian or Polynesian voyagers brought sweet potato to northern New Zealand - this is evidence by the sweet potato fossilized tubers found in that area dating back to over a thousand years ago. The misconception by most sub-Saharan African farmers is that sweet potato is indigenous to Africa. Sweet potato has been cultivated in Africa longer than the Irish potato (*Solanum tuberosum*), which was only introduced around the eighteen hundreds and the introduction of sweet potato slowly reduced the use of yam in Africa (Low *et al.*, 2009). In 1652, when Jan Van Riebeeck colonized the Cape, sweet potato was introduced to South Africa (Motsa *et al.*, 2015).

Sweet potato is a dicotyledonous plant that belongs to the order of *Solanales* under the Convolvulacea family (Bovell- Benjamin, 2007). The Convolvulaceae family, or more commonly the morning glory family, consists of members from both tropical and the temperate environments (Woolfe, 1992; Austin, 1998). However, sweet potato is found in tropical regions. The *Ipomoea* genus is one of the biggest genera under the Convolvulaceae family which are mostly found in warmer climates (Austin and Huáman, 1996). Sweet potato belongs to the *batatas* species which has both annual and perennial plants. *Ipomoea batatas* or sweet potato is an herbaceous perennial vine (Nikiema, 2017).

Huaman (1992) reported that sweet potato is a plant that can reproduce sexually and asexually. However, Belehu (2005) reported that most sweet potato cultivars are self-incompatible. The above ground parts consist of flowers, vines and leaves. The different sweet potato cultivars can flower profusely while others do not flower (Huaman, 1992). The flowers are generally bisexual but they can also be unisexual and are naturally pollinated by bees. Flower colours range from pale purple, lilac or whitish. Sweet potato flowers are funnel-shaped and are arranged in cyme.

When pollinated, the fruit formed is a called a capsule that has a spherical shape, which turns brown in colour when it reaches maturity (Huaman, 1992; Belehu, 2005). A capsule may contain one to four seeds; the seeds may be brown or black. Sweet potato seeds have a hard seed coat and they generally require scarification before germinating and can stay viable for years (Huaman, 1992). Sweet potato seeds have an epigeal germination (Belehu, 2005).

Sweet potato leaves come in different shapes and the total number of leaves per plant ranges from 60 to 300 depending on the number of branches (Somda *et al.*, 1991; Masango, 2015). The lower the planting density, the higher the leaf number per plant. Their growth habit can be very spreading, spreading, erect and semi-erect (Huaman, 1992). Sweet potato leaves are generally green but can have a purple pigmentation. Antial *et al*. (2006) and Owusu *et al*. (2008) reported that sweet potato leaves contain a high level of proteins, fat, vitamins and minerals. Leaves and vines can have high yields (Laurie et al., 2004). In most parts of Africa the leaves were generally used as animal feed (Woolfe, 1992).

The sweet potato roots system can reach a 2 m depth depending on soil conditions (Belehu, 2005; Masango, 2015). Roots developed from true seeds form a typical root system, which starts with a central axis, the radicle and then adventitious roots form which later become storage roots (Huaman, 1992; Villordon *et al.*, 2014). However, the root system of plants developed through vegetative propagation forms adventitious roots from the cutting or the storage root and then later on develops into storage roots (Laurie et al., 2004).

Research has shown that sweet potato plants have adventitious and lateral roots. The adventitious ones are divided into fibrous, pencil and storage roots (Huaman, 1992; Woolfe, 1992; Belehu, 2005; Masango, 2015). Lateral roots are divided into primary, secondary and tertiary roots. All the roots have the main functions to absorb water, nutrients and anchor the plant (Huaman, 1992; Woolfe, 1992). Fibrous roots enable sweet potato to be drought resistant, since they can reach a depth of 1 m into the soil and have a dense network of lateral roots (Belehu, 2005; Masango, 2015). Belehu (2005) reported that pencil roots develop when there are unfavourable conditions for sweet potato in the initial stages of growth. Sweet potato storage roots are also called tuberous roots, as they are modified roots (Gregory, 1965; Huaman, 1992; Li and Zhang, 2003). These are lateral, their function is to absorb and store excess carbohydrates (Ravi *et al.*, 2009). Storage roots form part of the commercial part of the plant, and depending on the cultivar they can be scattered and come in different colours from purple through white, yellow and orange (Sasikiran *et al.*, 2002; Li and Zhang, 2003). Storage roots are usually thick and fleshy (Sasikiran *et al.*, 2002).

Storage roots are a source of food for both humans and livestock (Woolfe, 1992; Thompson *et al.*, 1998; Laurie and Van Heerden, 2012). They can also be used as a source of starch and alcohol production (Yu *et al.*, 1996). Yellow and orange-fleshed storage roots have a higher carotenoid content compared to the white or cream-fleshed ones (Hagenimana *et al.*, 1998; Low *et al.*, 2007). The nutritional content of the orange-fleshed sweet potato (OFSP) is used to combat vitamin A deficiency (Laurie *et al.*, 2009; Laurie and Van Heerden, 2012; Agili *et al.*, 2012).

Sweet potato is an annual crop that is grown as a perennial crop (Nikiema, 2017). It grows better between temperatures of 12 ºC and 35 ºC (Belehu, 2005). The crop grows well in tropical and subtropical regions but has a high adaptability in a wide range of environments (Woolfe, 1992; Low *et al.*, 2007; Masango, 2015; Low *et al.*, 2017). It can be produced at different altitudes from 0 to 3000 m above sea level. Sweet potato storage roots can be negatively affected by low temperatures as well as drought during their initiation stage (Agili *et al.*, 2012). Although increasing soil moisture improves sweet potato productivity, excessive moisture during storage root initiation may cause damage and sweet potato grows better in well drained sandy loam soils (Oggema *et al.*, 2007; Motsa *et al.*, 2015). Sweet potato is considered to be a drought tolerant crop and requires an annual rainfall of 600 to 1600 mm (Sanginga and Mbabu, 2015).

1.1.2 Crop responses to water stress

Drought tolerance occurs when plants change their chemical constitution through osmotic adjustment. Tobacco uses this mechanism to maintain plant turgor and increase the shoot to root ratio. This process allows the plant to survive and avoid permanent damage during low water conditions. Plants experiencing drought stress tend to have high levels of proline, tetrahaole, abscisic acid and glycine.

Niederwieser (2004) and Nedunchezhiyan *et al.* (2012) recommended that sweet potato should be planted using mounds or ridge and furrow methods in order to improve storage root formation. The ridge and furrow method reduces soil erosion and improve drainage. Sweet potato is generally planted in four different ways; half of the cutting can be horizontally inserted into the soil, the middle part of the cutting can be inserted in the soil leaving both ends sticking out; the entire cutting covered with soil, successive planting and sprouting storage roots. Although sweet potato is generally horizontally planted, research has shown that vertical planting gives higher storage root yields. Successive planting is used when planting material is limited, then vines are harvested from planted sweet potato to fill up the field.

A closer plant spacing is recommended to improve storage root yield according to Niederwieser (2004). However, the higher the planting density of sweet potato, the lower the yield per plant (Woolfe, 1992; Belehu, 2005). Sweet potato is a crop used in rotation systems to control weeds in the field and is generally planted as a sole crop, in some instances sweet potato is intercropped (Belehu, 2005). In temperate regions it is challenging to produce sweet potato since it is very sensitive to frost, planting material is planted and covered with plastic in late winter (Woolfe, 1992; Niederwieser, 2004).

The growth and yield of sweet potato is affected by the environmental conditions and agronomic practices. A plant can undergo physiological, morphological and metabolic changes in response to water stress (Saraswati, 2007). OFSP cultivars have been reported to be more susceptible to water stress (Yanggen and Nagujja, 2006; Agili *et al.*, 2012). However, sweet potato is considered a hardy crop as the plants can survive in adverse climatic conditions using different coping mechanisms (Laurie *et al.*, 2015; Masango, 2015).

Saraswati (2007) reported that a plant experiencing water stress can have many of its normal functions impaired and thus limiting the plants growth and development. In sweet potato if this occurs during, crop establishment and storage root initiation, it can have detrimental effects on the plant (Omotobora *et al.*, 2014). Water stress causes the plant to reduce carbon fixation when the plant closes the stomata in order to limit evapotranspiration and this leads to reduced plant growth. A drought resistant crop can continue growing even during low water conditions (Belehu, 2005; Saraswati, 2007; Omotobora *et al.*, 2014).

Drought resistant plants use three physiological mechanisms, namely' drought escape, drought avoidance and drought tolerance (Saraswati, 2007; Kivuva, 2013). Drought escape occurs when the plant increases its production cycle in order to achieve early maturity. This is a common mechanism used by millet. When the maize plant experiences water stress during the development stage the plant limits growth and produces less cobs and even fewer kernels. A plant avoids drought by closing stomata, rolling leaves, having a large root system and having thick cuticles.

Sweet potato cultivars use drought avoidance by evolving the deep fibrous root system which enables the plant to extract water from deep in the soil (Huaman, 1992; Saraswati, 2007; Agili *et al.*, 2012; Andrade *et al.*, 2016). They have smaller leaves which allows sweet potato to have lower transpiration rates, enabling the plant to maintain cellular integrity during water stressed conditions (Saraswati, 2007). Sweet potato cultivars that are drought tolerant produce high cuticular wax since the leaves have a low inorganic phosphate content and a high desiccation tolerance.

Sweet potato is rich in proteins, carbohydrates, caretenoids (β-carotene), calcium, potassium, anthocynanins, ascorbic acid and antioxidants (Woolfe, 1992; Masango, 2015). OFSP that contain a high level of β-carotene are a good source of Vitamin A and its long term consumption could be a solution to Vitamin A deficiency (Rautenbach *et al.*, 2010; Burri, 2011). Minerals found in large quantities in OFSP include calcium, magnesium, potasium, then in smaller quantities are copper, manganese, zinc and iron (Masango, 2015). The green leaves of sweet potato contain high levels of essential oils, polyphenolic acid and anthocyanins (Owusu *et al.*, 2008; Burri, 2011; Yooyongwech *et al.*, 2017).

The effect of drought on sweet potato nutritional value has not been clearly demonstrated in literature. However, the nutritional value and agronomic properties of sweet potato makes it essential in developing countries to combact food and nutritional security (Laurie *et al.*, 2015; Masango, 2015). In SSA countries vitamin A deficiency (VAD) is a prevalent health problem and OFSP is valuable in addressing the problem (Woolfe, 1992; Low *et al.*, 2009; Low *et al.*, 2017).

2. NUTRITIONAL WATER PRODUCTIVITY OF SELECTED SWEET POTATO CULTIVARS UNDER CONTROLLED ENVIRONMENT CONDITIONS

2.1 Introduction

Sweet potato, the "poor man's crop", is a versatile crop (Motsa *et al*., 2015) that is adapted to a wide range of environmental conditions (Iheagwara, 2013). While it is underutilised (Chivenge et al., 2015), it remains an important crop (Iheagwara, 2013) for poor rural farmers (Agili et al. 2012), and women (Laurie et al., 2012). It is a nutritious crop with a potential to improve food and nutrition security in water scarce environments.

South Africa has seen the introduction of orange-fleshed sweet potato varieties (OFSP) which contain β-carotene, a precursor to vitamin A (Laurie 2004). Studies have linked consumption of boiled OFSP with improved vitamin A status in children (Low et al., 2007). It has also been suggested as a complementary food in infant feeding (Amagloh et al., 2011). In addition to vitamin A, sweet potatoes are nutrient dense. In addition to reasonable amounts of starch and protein, they also contain almost all the macro- and micro- nutrients, substantial quantities of vitamin C, moderate amounts of vitamin B complex (Vitamin B1, B2, B5 and B6) and folic acid, as well as satisfactory amounts of vitamin E (Walter et al., 1983; Laurie, 2004).

There is a need to promote nutrient dense crops that are adapted to water limited conditions (Mabhaudhi et al., 2016). This would improve nutrition and human health outcomes for poor rural farmers. Nutritional water productivity (NWP) (Renault and Wallender) has been proposed as an index that could be used to determine such benefits. Versatile crops such as sweet potatoes have potential to assist in addressing challenges related to food and nutrition security under conditions of water scarcity, hence addressing the water-food-nutrition-health nexus. Sweet potato growers generally depend on seasonal rainfall to sustain the crop and if there is insufficient rainfall the nutritional water productivity of the crop could be diminished. The objective of this study was to determine nutritional water productivity (NWP) of three sweet potato cultivars (A40, A45 and 199062.1) in response to varying water regimes under controlled conditions.

2.2 Materials and methods

2.2.1 Plant material

The project targeted a combination of orange fleshed and white fleshed sweet potato cultivars. Two orange fleshed (A45 and 199062.1) and one white fleshed (A40) sweet potato cultivar were used for the study. Cultivars A40 and A45 were bred by the University of KwaZulu-Natal's (UKZN) Plant Breeding Department (Dr Paul Shannahan), while cultivar 199062.1 was bred by the International Potato Centre (CIP) (Kapinga et al., 2010) and subsequently multiplied at UKZN by Dr Paul Shannahan. Therefore, all three cultivars were obtained from Dr Paul Shannahan's long-term multiplication trials at the UKZN Plant Breeding Department. Planting material was prepared by cutting approximately 30 cm vines from the tip of mother plants and then defoliated to one top fully expanded leaf to minimize photosynthetic demand during crop establishment.

2.2.2 Experimental design

A controlled environment experiment was conducted from 4 April to 14 September 2015 in a growth tunnel at the University of KwaZulu-Natal's Controlled Environment Facility (CEF) (29°37'12"S; 30°23'49"E). Three sweet potato cultivars (A40, A45, and 199062.1) were planted on built-in beds (1 m high) (Fig 2.1). The soil in the beds was taken to the KZN Department of Agriculture and Rural Development Soil Analysis Laboratory for determination of chemical and physical properties (Table 2.1).

The experimental design was a split-plot design factorial experiment consisting of two factors: water regimes as the main factor and sweet potato cultivars as the sub-factors arranged in randomized complete blocks (Fig 2.1). The experiment was replicated three times. The two water regimes were 30% and 100% of crop water requirement (ET_c). Sweet potato cuttings were planted at 60 cm between rows and 30 cm between plants.

Table 2.1: Physical and chemical characteristics of soil in the beds.

Clay	N	Organic C	pH	P	K	Ca	Mg	Zn	Mn	Cu
%			(KCl)			(mg·ℓ$^{-1}$)				
38	0.32	3.3	5.09	100	296	2413	350	23.5	44	6.4

Figure 2.1: Sweet potato cultivars (A40, A45, 19906.1) planted in a growth tunnel on raised beds under different irrigation regimes (100% and 30% ET_c).

Water was supplied three times a day (8 am, 12 noon and 4 pm) to minimize losses due to evaporation and drainage through drip irrigation. Drip irrigation was used to apply water in the beds. The system consisted of solenoid valves, a control box and online drippers. The system was set to have a maximum operating pressure of 200 kPa and an average discharge rate of 2 L hr^{-1}. Drip lines were placed according to plant spacing (0.6 m x 0.3 m).

Irrigation was scheduled based on daily crop water requirement calculated from the product of sweet potato crop factors (K_c) as published by (Allen et al., 1998) and monthly average reference evapotranspiration (ET_o) values. Reference evapotranspiration values were obtained from the UKZN Agrometeorology Discipline's automatic weather station that is located on site. Crop water requirement (ET_c) was therefore:

$ET_c = ET_o \times K_c$ **Equation 2.1**

where:

ET_c = crop water requirement (mm), ET_o = reference evapotranspiration (mm), and K_c = crop factor (Allen et al., 1998) (Table 2.2).

2.2.3 Crop management

The beds were ploughed before planting. The trials were kept weed free through routine hand weeding. Karate (30 ml/15 litres water) was sprayed eight weeks after planting and repeated two times at weekly intervals to control mealy bug.

Table 2.2: Crop water requirements of sweet potato grown under controlled environment.

$^{x}K_c$		$^{y}ET_o$	$^{z}ET_c$	Duration	Total water applied
		mm	mm	days	mm
Initial	0.50	3.00	1.50	31	46.50
Mid-season	1.15	3.00	3.45	68	234.6
Late-season	0.65	30	1.95	30	58.50
Total water applied (100% ET_c)					339.60
Total water applied (30% ET_c)					134.43

$^{x}K_c$ = crop factor based on Allen et al. (1998); $^{y}ET_o$ = reference evapotranspiration; $^{z}ET_c$ = crop water requirement

2.2.4 Data collection

2.2.4.1 Physiological measurements

Physiological measurements were done weekly before the midday irrigation event (between 11 am and midday) from establishment (five weeks after planting) to the end of the vegetative stage (13 weeks after planting). Chlorophyll content index (CCI) was measured using the SPAD-502Plus Chlorophyll Meter (Konica Minolta, USA) on the adaxial surface of fully expanded, fully exposed and actively photosynthesizing leaves. Stomatal conductance was measured using a Steady State Leaf Porometer Model SC-1 (Decagon Devices, USA) on the abaxial surface of a new fully expanded and fully exposed leaf. In order to determine plant photosynthetic efficiency, chlorophyll fluorescence (CF) was measured using a Pocket PEA-Chlorophyll Fluorescence System (Hansatech Instruments, United Kingdom). Chlorophyll fluorescence was measured on the adaxial surface of young, fully expanded and fully exposed green leaves. Before measuring CF, a sample area of the targeted leaf was covered with a lightweight leaf clip (Hansatech Instruments, United Kingdom) for 20 minutes to exclude light and allow for dark adaptation.

2.2.4.2 Yield and yield components

Sweet potato plants were harvested 159 days after planting. Measurements recorded on a plot basis included yield (fresh below ground mass), number of tubers per plant and number of marketable tubers. Marketable roots were defined as whole (undamaged) and weighed between 100 g and 1400 g and without harvest wounds, pest and disease damage (Ossom and Rhykerd, 2007). Yield was converted to kg.ha^{-1}. Percentage of marketable storage roots was computed as:

$$\frac{Number\ of\ marketable\ roots\ per\ plot}{Total\ number\ of\ roots\ per\ plot} \times 100\% \qquad \textbf{Equation 2.2}$$

2.2.4.3 Determination of water productivity

Water Productivity was calculated as

$$WP = Y_a / ET_c \qquad \textbf{Equation 2.3}$$

where WP is water productivity (kg m^{-3}), Y_a is the fresh tuber yield (kg) and ET_c is the water applied based on crop water requirement.

2.2.4.4 Determination of nutritional content

To preserve nutrients and avoid further metabolic reactions, sweet potato tubers were freeze dried using a model RV3 vacuum freeze drier (Edwards, United States of America) after yield determination. Thereafter, samples were ground using mortar and pestle and sent to the KZN Department of Agriculture and Rural Development Plant Nutrition Laboratory for analysis. The nutrients analysed on a dry matter basis included energy, fat and protein and elemental nutrients (calcium, zinc, iron, magnesium and sodium). Pigment extraction for beta-carotene was carried out according to the Association of Official Analytical Chemists (AOAC, 1980) method with minor modifications.

2.2.4.5 Determination of nutritional water productivity (NWP)

Nutritional water productivity was calculated based on the formula by Renault and Wallender (2000):

$$NWP = (Y_a/ET_c) \times NC \qquad \textbf{Equation 2.4}$$

where NWP is the nutritional water productivity (nutrition m^{-3} of water evapotranspired), Y_a is the actual harvested yield ($kg \cdot ha^{-1}$), ET_c is is the water applied based on crop water requirement ($m^3 \cdot ha^{-1}$), and NC is the nutritional content per kg of product (nutrition unit$\cdot kg^{-1}$).

2.2.5 Data analysis

Data were subjected to analysis of variance (ANOVA) using GenStat® version 18 (VSN International, UK). Least significance difference (LSD) was used to separate means at the 5% level of significance.

2.3 Results and discussion

2.3.1 Physiology

There were no significant differences ($P>0.05$) observed on the chlorophyll florescence and chlorophyll content index of crops from both water regimes. Based on results of measured physiological parameters (stomatal conductance, CF and CCI), stomatal conductance was the most sensitive parameter. Stomatal conductance varied significantly ($P<0.001$) over time (weeks after planting). The interaction between time and water treatments followed a similar trend (Fig 2.2). There were no differences ($P>0.05$) between water treatments and among cultivars with respect to stomatal conductance. This was contrary to expectation that the 30% ET_c treatment would have significantly less stomatal conductance.Motsa *et al.* (2015), working on similar cultivars under similar conditions, found lower SC at 30% ET_c relative to 100% ET_c. The lack of differences may be due to frequent wetting of the soil, even at 30% ET_c, which meant that some water was always available in the root zone. In future, less frequent irrigation would be advisable to allow for stress to develop in the soil.

2.3.2 Yield

Consistent with results of crop physiological parameters, although yield varied in response to water regimes between cultivars (Table 2.3), the differences were not statistical. Based on means, the 100% ET_c treatment yielded 6% more than the 30% ET_c treatment (Table 2.3). With respect to number of roots, plants from the 30% ET_c yielded more (12.5%) than plants from the 100% ET_c. The percentage of marketable roots, however, showed significant differences among the cultivars with 199062.1 out-yielding the other cultivars. The A45 cultivar only performed well (>50% of the cultivars were marketable) under 100% ET_c. With respect to differences between cultivars, cultivar A40 yielded less than (22%) marketable roots under both water treatments. While yield results were not significantly different, there was a 70% difference in water applied to the water treatments (Table 2.3). This led to significant differences ($P<0.05$) between the water treatments with respect to water productivity. The 30% ET_c water treatment was 135% more productive than the 100% ET_c water treatment. The results of the current study were similar to reports by Motsa *et al.* (2015) who also used similar cultivars.

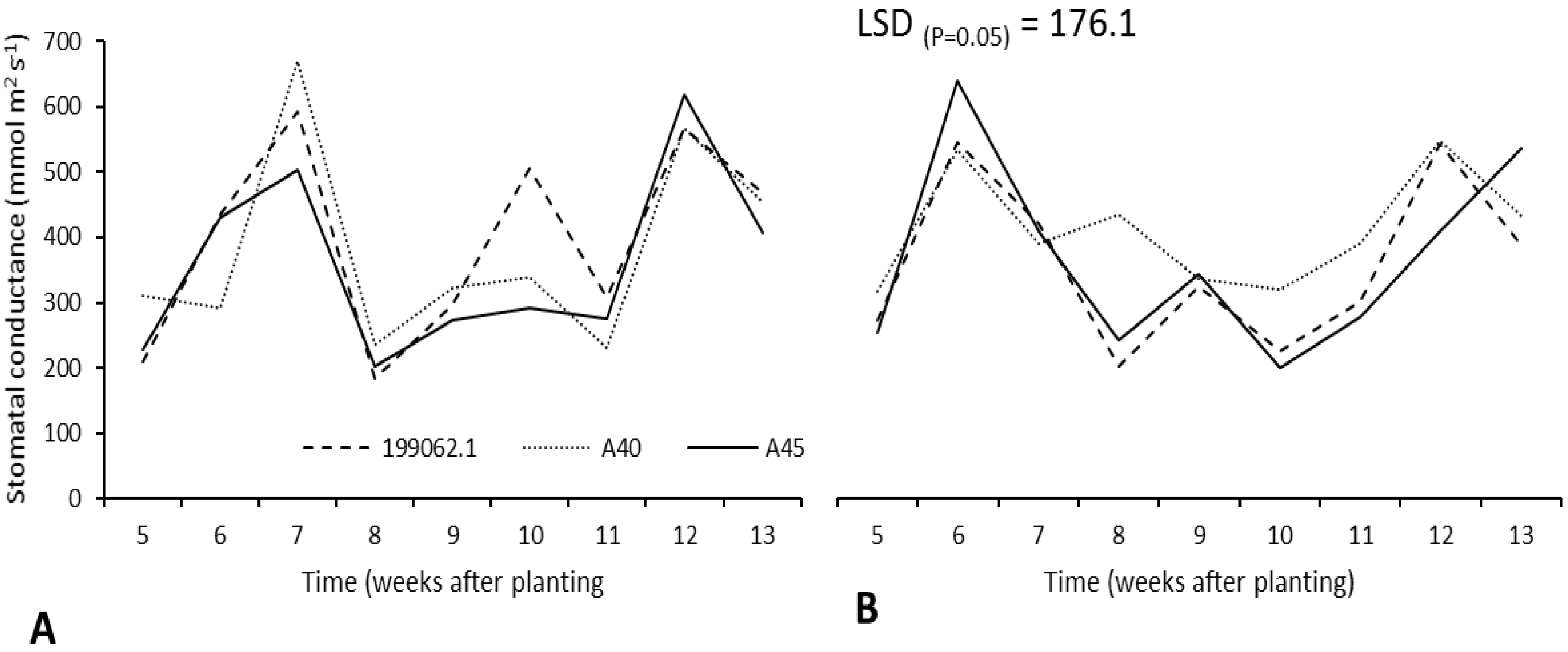

Figure 2.2: Stomatal conductance (mmol m^{-2} s^{-1}) observed weekly for three sweet potato cultivars (A40, 199062.1 and A45) under A = 30% ET_c and B = 100% ET_c water treatments.

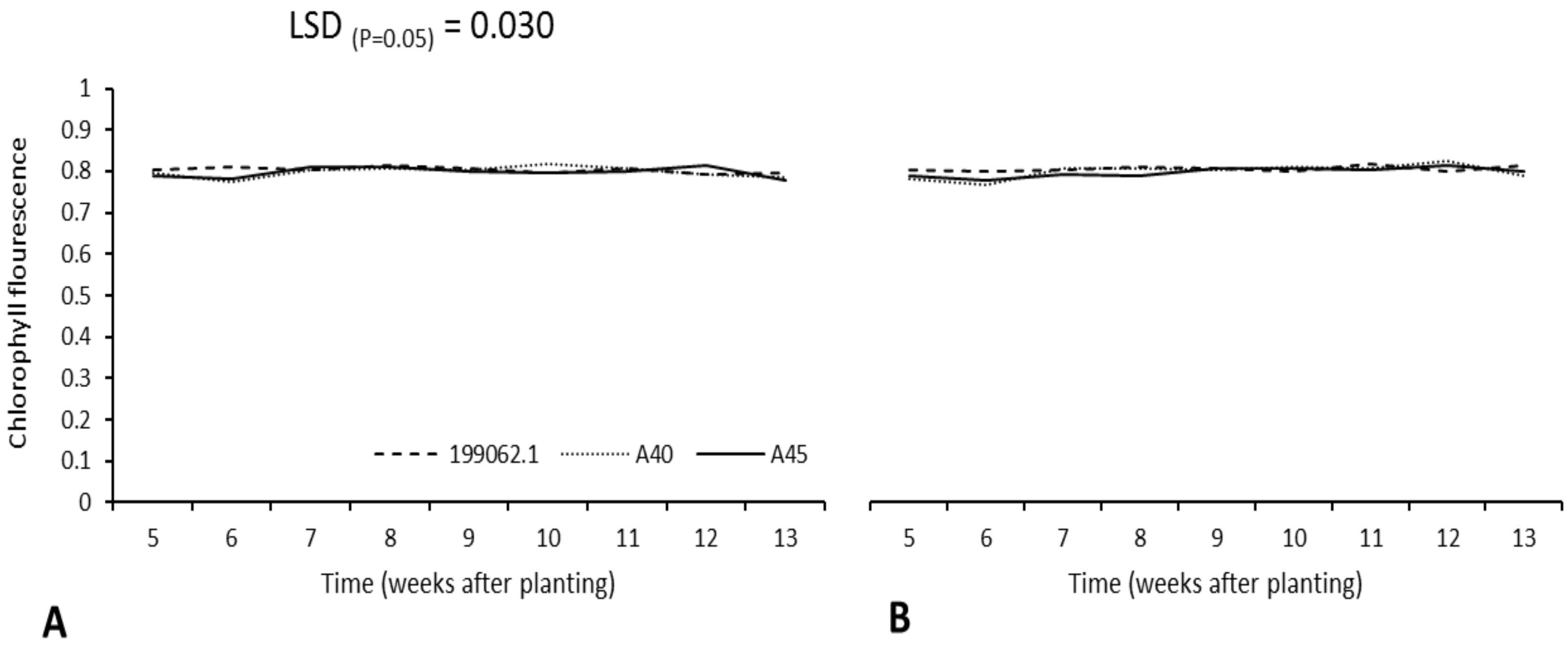

Figure 2.3: Chlorophyll fluorescence observed weekly for three sweet potato cultivars (A40, 199062.1 and A45) under A = 30% ET_c and B = 100% ET_c water treatments.

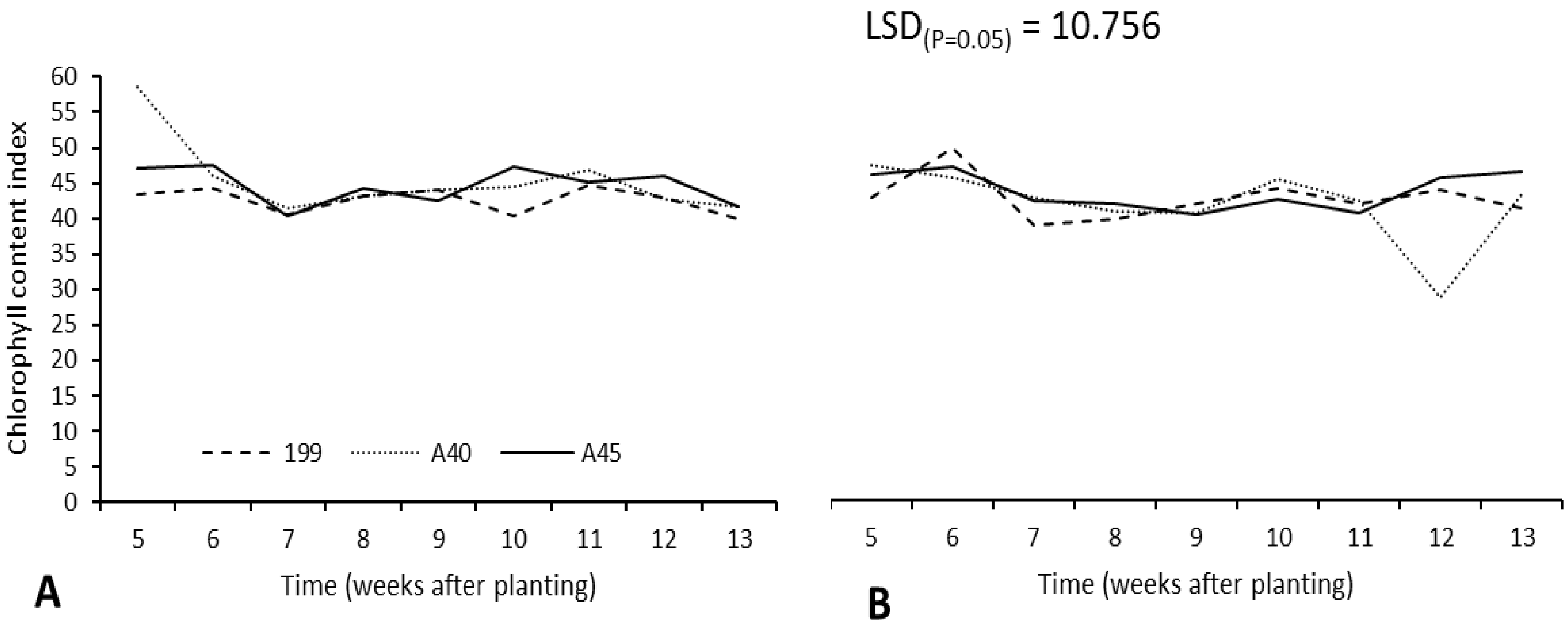

Figure 2.4: Chlorophyll fluorescence observed weekly for three sweet potato cultivars (A40, 199062.1 and A45) under A = 30% ET_c and B = 100% ET_c water treatments.

Table 2.3: Yield and yield components of three sweet potato cultivars (A40, 199062.1 and A45) under A = 30% ET_c and B = 100% ET_c water treatments.

Water treatment	Cultivar	Yield kg ha^{-1}	No. of roots plant $^{-1}$	Marketable roots (%)	WP kg m^{-3}
30% ET_c	A40	13889a	37.3a	21.7b	10.3b
	A45	17245a	43.3a	28.5b	12.8a
	199062.1	25058a	41.0a	49.3a	18.6a
	Mean	18731	40.6	33.2	13.9
100% ET_c	A40	15972a	40.3a	15.0b	4.7b
	A45	16204a	31.3a	50.6a	4.8b
	199062.1	27766a	33.7a	53.6a	8.2b
	Mean	19981	35.1	39.7	5.9
LSD $_{(P = 0.05)}$		19523.2	17.2	24.0	9.9
Fpr.	Treatment	0.810	0.263	0.448	0.011
	Cultivar	0.188	0.954	0.040	0.194
	Treatment*Cultivar	0.949	0.426	0.455	0.750

2.3.3 Nutritional composition

The A45 variety had the highest energy content (584 MJ kg^{-1}) under the 30% ET_c while the 199062.1 had the lowest energy content (471 MJ kg^{-1}) under the 30% ET_c (Table 2.4). With respect to fat content the 199062 was superior (14.1 g kg^{-1}). The same variety also produced the lowest fat content under the water stress treatment (1.4 g kg^{-1}). The highest protein content (75 g kg^{-1}) was observed in A45 under the optimum water treatment while the lowest protein content (38 g kg^{-1}) was observed in A40 under the water stress treatment. The white fleshed variety (A40) had the highest calcium and magnesium content (5.3 and 1.3 mg kg^{-1}, respectively) under both water treatments. A40 and A45 showed the highest sodium contents under the optimum water treatment (2.1 and 2.4 mg kg^{-1}). For iron and zinc it was the A40 variety that was more superior (868 and 16.8 mg kg^{-1}, respectively) compared to the other cultivars. The orange fleshed varieties (A45 and 199062) contained more beta-carotene than the white fleshed variety (A40). The 199062 variety contained twice as much beta-carotene under 30% ET_c, compared to the optimum treatment. Between the two orange-fleshed varieties, A45 had higher beta carotene compared to 199062 (Table 2.4).

Table 2.4: Nutritional value of three sweet potato cultivars (A40, 199062.1 and A45) under A = 30% ET$_c$ and B = 100% ET$_c$ water treatments.

		Energy	Fat	Protein	Calcium	Magnesium	Sodium	Zinc	Iron	Beta carotene
Water treatment	Cultivar	MJ kg^{-1}	------- g kg^{-1} --------		------------------------------- mg kg^{-1} ----------------------------------					
100% ET$_c$	A40	574.0	7.3	75.1	5.3	1.3	2.1	9.0	399.0	2.0
	A45	448.4	9.1	61.8	2.4	0.7	2.4	15.4	622.3	198.0
	199062.1	489.7	14.3	43.0	4.8	0.9	0.8	13.4	529.0	53.0
30% ET$_c$	A40	555.6	7.5	53.6	5.1	1.2	1.0	16.8	868.1	29.0
	A45	584.6	9.4	38.9	1.3	0.6	1.0	11.0	269.6	232.0
	199062.1	471.2	1.4	53.8	4.6	1.0	1.1	14.4	428.5	100.9

2.3.4 Nutritional water productivity

Nutritional water productivity for all the major nutrients (energy, fat, protein) and most of the elemental nutrients (calcium, zinc, iron, and magnesium) measured in this study varied significantly ($P<0.05$) between water treatments ($P<0.05$) (Table 2.5). The only exception was NWP_{Na} which did not show any significant differences ($P>0.05$) between water treatments (Table 2.5). Interestingly, high NWP was observed under water limited relative to optimum conditions. The highest difference (372%) was observed for $NWP_{beta\ carotene}$. With respect to NWP_{energy}, it was 149% higher under water limited relative to optimum conditions. A similar trend was also observed for $NWP_{protein}$, NWP_{fat}, NWP_{zinc}, NWP_{iron} and $NWP_{magnesium}$.

With respect to the cultivars, it was NWP_{fat}, $NWP_{calcium}$ and $NWP_{beta\ carotene}$ that showed significant differences ($P<0.05$) (Table 2.5). The highest NWP_{fat} (268 g m^{-3}) was observed for cultivar 199062.1 under the water-limited conditions, while the lowest NWP_{fat} (34 g m^{-3}) was observed for cultivar A40 under optimum conditions (Table 2.5). With respects to $NWP_{calcium}$, it was cultivar 199062.1 that was superior to all other cultivars (> 62 mg m^{-3}) under both water treatments while the inferior cultivar was A45 (11.9 mg m^{-3}) under optimum conditions (Table 2.5). For $NWP_{beta\ carotene,}$ the orange fleshed varieties (A45 and 199062) had the highest $NWP_{beta\ carotene}$ (2976 and 1881 mg m^{-3}, respectively). This was under 30% ET_c. For all the results of major and elemental nutrients, NWP results of the interaction between cultivar and water treatment was not significantly different ($P>0.05$) (Table 2.5).

The results were consistent with observations of yield, WP and nutritional content (***cf.*** Sections 2.3.2 and 2.3.3). The conclusion drawn from the results show that sweet potatoes have potential to provide nutrition even under water limited conditions.

Table 2.5: Nutritional water productivity of three sweet potato cultivars (A40, 199062.1 and A45) under A = 30% ET_c and B = 100% ET_c water treatments.

Water Treatment	Cultivar	NWP (Energy)	NWP (Protein)	NWP (Fat)	NWP (Zinc)	NWP (Iron)	NWP (Calcium)	NWP (Magnesium)	NWP (Sodium)	NWP (Beta carotene)
		MJ m^{-3}	-----------g m^{-3}-----------		-------------	-------------	-------------mg m^{-3}-------------	-------------	-------------	-------------
30% ET_c	A40	5 740.0a	555.0b	77.0b	176.0a	8 968.0a	52.7a	12.40a	10.33b	300b
	A45	7 500.0a	499.0b	121.0b	141.0a	3 464.0b	16.7b	7.70b	14.11a	2976a
	199062.1	8 783.0a	1 405.0a	268.0a	261.0a	7 978.0a	85.7a	18.64a	22.37a	1881a
	Mean	7 341.0	820.0	155.0	193.0	6 803.0	51.7	12.91	15.60	1719
100% ET_c	A40	2 700.0b	354.0b	34.0b	42.0b	1 877.0b	25.4b	5.58b	9.88b	9b
	A45	2 122.0b	295.0b	43.0b	72.0b	2 968.0b	11.9c	3.82b	11.45a	945b
	199062.1	4 004.0a	352.0b	117.0b	106.0b	4 325.0b	62.8a	7.36b	7.36b	433b
	Mean	2 942.0	879.0	65.0	73.0	3 057.0b	25.8b	5.76	9.56b	462
LSD $_{(P = 0.05)}$		5 261.0	333.0	128.5	132.3	4 409.0	36.3	9.29	11.14	1430.0
FPr. Water treatments		0.007	0.010	0.020	0.006	0.013	0.039	0.015	0.062	0.007
FPr. Cultivars		0.408	0.056	0.016	0.168	0.187	0.015	0.093	0.432	0.010
FPr. Water.Cultivar		0.757	0.075	0.422	0.596	0.149	0.346	0.454	0.134	0.192

3. NUTRITIONAL WATER PRODUCTIVITY OF SWEET POTATO UNDER FIELD CONDITIONS

3.1 Introduction

Sweet potato is considered an important root crop, in the tropical and subtropical regions of the world (Nedunchezhiyan *et al.*, 2012). It is ranked third among the root and tuber crops after cassava and yam in the sub-Saharan African (SSA) region (Masango, 2015). In Africa, it is considered a food security crop that can produce high yields with low agricultural input (Low *et al.*, 2009; Motsa *et al.*, 2015). Sweet potato is one of the most efficient crops that can provide a good source of vitamins and minerals (Masango, 2015) and its leaves can be used as animal feed. This makes sweet potato an ideal crop to ensure food and nutrition security (Andrade *et al.*, 2016).

In South Africa (SA), sweet potato is largely produced by resource-poor farmers and the main production areas are found in the Western cape, Limpopo, Mpumalanga and KwaZulu-Natal provinces (KZN) (Naidoo *et al.*, 2016). According to Camp (1999), the KZN province has a variation of soils as well as climates and is situated on the Eastern coast of SA, with summer rainfalls ranging between 600 and 2 000 mm/annum. The KZN midlands can have very cold winters, hot summers and tends to be drier compared to areas located by the coast. Sweet potato is considered a hardy crop that can grow in a wide range of environments (Khan and Doty, 2009; Kyamanywa *et al.*, 2011). However, some sweet potato cultivars have been reported to be susceptible to drought while others tend to perform better in one part of S.A and on the other hand perform worse in another in terms of agronomy (Agili *et al.*, 2012; Adebola *et al.*, 2013; Motsa *et al.*, 2015). This means a combination of agronomic practices as well as environmental conditions can limit sweet potato yields. There are a few studies showing which cultivars are most suitable for the different environments in KZN. However, a recent study showed which cultivars of both white and orange fleshed sweet potato (OFSP) were most suited for which environments in KZN (Laurie *et al.*, 2015).

Camp (1999) and Domola (2006) reported that in KZN sweet potato was the second most important crop after maize and the most important root crop. Its cultivation was mainly through vegetative propagation and the cultivars that were shared were only white fleshed sweet potato (WFSP). According to Motsa *et al.* (2015), the uptake of OFSP cultivars has not been widespread compared to the white fleshed sweet potato (WFSP) cultivars in KZN.

Studies have shown that in S.A children between the ages of 1 and 5 years old, as well as women in their reproductive age suffer from Vitamin A deficiency (Van Jaarsveld *et al.*, 2005; Naidoo *et al.*, 2016; Palmer *et al.*, 2017). The OFSP has been identified as a promising source of ß-carotene, the vitamin A precursor (Hagenimana *et al.*, 1998). This means OFSP cultivars are the solution to the water-food-nutrition-health nexus (Mabhaudhi *et al.*, 2016). Initially there were not enough OFSP cultivars that contained all the desired traits, i.e. good taste, good yields and an adequate carotenoid content (Laurie *et al.*, 2009). Therefore, the aim of this study was to evaluate the crop growth, physiology, yield and nutritional water productivity of different sweet potato cultivars grown under different agro-ecological locations of KZN.

3.2 Materials and methods

3.2.1 Plant material

Sweet potato cuttings were obtained from a subtropical nursery at the University of KwaZulu-Natal (UKZN). The cuttings were of three sweet potato cultivars (A40, A45 and 199062.1) and these were originally sourced from the UKZN’s Plant Breeding Department. The 199062.1 cultivar was, multiplied by UKZN during the 2011/12 planting season and was originally obtained from the International Potato Centre (CIP). The A40 and A45 cultivars were bred locally at UKZN. The A40 cultivar was a white-fleshed cultivar and A45 and 199062.1 cultivars were orange-fleshed. Planting vines of 30 cm were cut from the tip of the mother plant vines. Only two leaves were left on each of the cuttings before planting.

3.2.2 Description of experimental sites

The study was carried out on two different locations (Umbumbulu and Fountain Hill Estate (FHE)) of KwaZulu-Natal, South Africa. The locations selected have two distinct bio-resource groups (Table 4.1). A bio-resource group has specific vegetation that is influenced by climate, altitude and soil (Camp, 1999).

Table 3.1: Site description for Umbumbulu (Umb) and Fountain Hill Estate (FHE).

Site	Bio-resource group	Geog. location	Alt.	Ann. Rain.	Av. min. temp.	Av. max. temperature	Frost	Soil type	Clay content	Effect. rooting depth	FC	PWP	Sat.	Prev. crop
			(m)	(mm)	(°C)					(m)	(%)			
Umb.	Moist coast hinterland and ngongoni veld	29°98’S 30°70’E	632	1200	13	27	Light	Hutton	>60 %	50	45,1	34,5	51	Fallow
FHE	Moist coast hinterland mistbelt	29.447°S 30.546°E	940	905	17	29	Light	Sandy	20	80	30	20	45	Fallow

3.2.3 Experimental design

Field trials were conducted at two locations (Umbumbulu and FHE) during the summer season 2016/17. The summer planting season was November for both locations and the experiments were planted in a way that data collection for both areas coincided. The first planting in November 2017 FHE was not successful as plants did not establish; the trial was then re-established in January 2017.

At each location, there was an experiment evaluating the effects of planting methods (Peak and Flat ridge type) on three sweet potato cultivars (A40, A45 and 199062.1). The experimental design was a randomized complete block design (RCBD) and replicated three times. The total plot area was 51.52 m^2; the plant population was kept at 55 556 plants/ha with a spacing of 0.6 m and 0.3 m (inter-row and intra-row spacing, respectively). The experiments were rainfed and the experimental designs as well as layouts were consistent for both locations.

3.2.4 Agronomic practices

Sweet potato cuttings with at least three vine nodes were planted on two ridges. There were two ridge types, peak (0.5 m high and 0.5 m wide) and flat (0.25 m high and 0.5 m wide). The ridges were prepared by hand after a tractor was used for land preparation. At Umbumbulu, local farmers assisted with land preparation. The fields were weeded before crop establishment, and once more before the crops reached full ground cover.

3.2.5 Data collection

3.2.5.1 Climate data

At Umbumbulu and FHE the daily weather data were obtained from an automatic weather station (AWS) that was about 10 km radius from the experimental sites. The collected data were obtained from the South African Sugar Association (SASA). The daily meteorological data considered included minimum (T_{min}) and maximum (T_{max}) air temperature (°C), rainfall and reference evapotranspiration (mm).

3.2.5.2 Soil water content

The soil water content was obtained using gravimetric sampling. Briefly, soil samples were taken between the two experimental rows of each plot at a depth of 30 cm and placed in zip-lock bags to seal off moisture loss. Thereafter, samples were weighed to obtain wet mass. Soil samples were then dried at 105°C for 72 hours. Thereafter, gravimetric water content was calculated as follows:

$$(\boldsymbol{\theta_g}) = (\frac{(\boldsymbol{\theta wet - \theta dry})}{\boldsymbol{\theta dry}}) \times \mathbf{100}\ \% \qquad \text{Equation 3.1}$$

where:

Θ_g = Gravimetric moisture content (%),

Θ_{Wet} = wet soil (g) and

Θ_{Dry} = dry soil (g).

Gravimetric water content was then converted to volumetric water content via the following equation:

$$(\boldsymbol{\theta_v}) = \boldsymbol{\theta_g} \times \left(\frac{\boldsymbol{\rho_{soil}}}{\boldsymbol{\rho_{water}}}\right) \qquad \text{Equation 3.2}$$

where:

Θ_v = Volumetric moisture content (%),

Θ_g = Gravimetric moisture content (%),

P_{soil} = the bulk density of that given soil (g. cm^{-3}) and

P_{water} = water density (g. cm^{-3}).

Crop water use was then determined as follows (Allen *et al.*, 1998):

$$\boldsymbol{ET_a = P \pm \Delta SWC} \qquad \text{Equation 3.3}$$

where:

ET_a = actual evapotranspiration (mm),

P = Precipitation (mm) and

ΔSWC = changes in soil water content (mm).

3.2.5.3 Plant growth and physiology

The crop was allowed to establish in both locations before data collection commenced. Plant growth and physiology data were determined by measuring leaf number, vine number length of the longest vine, stomatal conductance (SC) and chlorophyll content index (CCI). A steady-state leaf porometer (Model SC-1, Decagon Devices, USA) was used to measure the SC. Using the SPAD-502Plus, the CCI was measured. Data were collected on a weekly basis.

3.2.5.4 Yield and yield components

The sweet potato was then harvested after 20 weeks after planting leaving a few plants on the field and then sequential harvesting was done every two weeks for three times. The fresh mass measurements recorded included whole plant, above and below ground biomass. Then the harvest index (HI), length, and circumference of the tubers were determined for marketable tubers. Marketable tubers were tubers that weighed between 0.1 – 1.4 kg, did not have disease or pest damage and they were whole (Njoku *et al.*, 2010). The yield was recorded in tonnes per hectare (t ha^{-1}). A sample of the harvested tubers was then freeze-dried for nutritional analysis.

3.2.5.5 Water use efficiency and Water productivity

The sweet potato's water use efficiency and productivity was then determined using equation 4.4 and 4.5, respectively as defined by (Mabhaudhi *et al.*, 2016).

$$\boldsymbol{WUE = \frac{Y_a}{ET_a}} \qquad \text{Equation 3.3}$$

Where:

WUE = is the water use efficiency (Kg ha^{-1} mm^{-1}),

Y_a = is the actual harvested yield (Kg ha^{-1}) and

ET_a = is the actual evapotranspiration (mm).

$$\boldsymbol{WP = \frac{Y_a}{ET_a}} \qquad \text{Equation 3.4}$$

Where:

WP = is the water productivity (Kg m^{-3}),

Y_a = is the actual harvested yield (Kg ha^{-1}) and

Et_a = is the actual evapotranspiration (m^3 ha^{-1}).

3.2.5.6 Nutritional content

The harvested tubers were washed with distilled water to remove dirt and possible impurities. On a sterilized surface they were cut into smaller pieces and then placed in a - 60 °C freezer for 24 hours. The samples were freeze-dried using a model RV3 vacuum freeze drier (Edwards, United States of America) and then ground using a blender. Thereafter, the samples were kept in a freezer set to -15 ℃ and the nutritional content was analysed at KZN Department of Agriculture and Rural Development Plant Nutrition Laboratory. The analysed nutrients were fats, crude protein, calcium (Ca), zinc (Zn), copper (Cu) and iron (Fe).

3.2.5.7 Nutritional water productivity

The NWP was obtained after harvest using equation 3.6 as defined by (Renault and Wallender, 2000).

$$\boldsymbol{NWP = \frac{Ya}{ETa}NC} \qquad \text{Equation 3.5}$$

Where:

NWP = is the nutritional water productivity (nutrition unit/m^3 of water),

Y_a = the actual harvested yield (Kg ha^{-1}),

ET_a = is the actual evapotranspiration (m^3 ha^{-1}) and

NC = is the nutrition content per kg of product (nutrition unit/kg).

3.*2.6 Data analysis*

At FHE, the initial planting was not successful due to lack of, or very low, rainfall. Hence there was a huge difference between the planting dates between the two experimental sites. Therefore, the results for plant growth and physiology of the two sites were analysed separately. The data were statistically analysed using the analysis of variance (ANOVA) in GenStat version 18 (VSN International, Hemel Hempstead, UK,) at a 5% level of significance. Least significant differences (LSD) were used to separate the means.

3.3 Results and discussion

3.3.1 Weather data

The daily data were generally consistent in both locations (Figure 3.1). At Umbumbulu, there were higher rainfall levels with the maximum rainfall being 126.7 mm, a minimum rainfall of 0 mm and a total of 866.78 mm. The minimum and maxim temperatures were 29.9 °C and 49.6 °C, respectively. At FHE the highest rainfall recorded was 29.4 mm, the lowest was 0 mm and the total rainfall was 521.3 mm. The minim and maximum temperatures were 19.2 °C and 37.5 °C, respectively. Umbumbulu had the highest rainfall and temperature recorded compared to FHE.

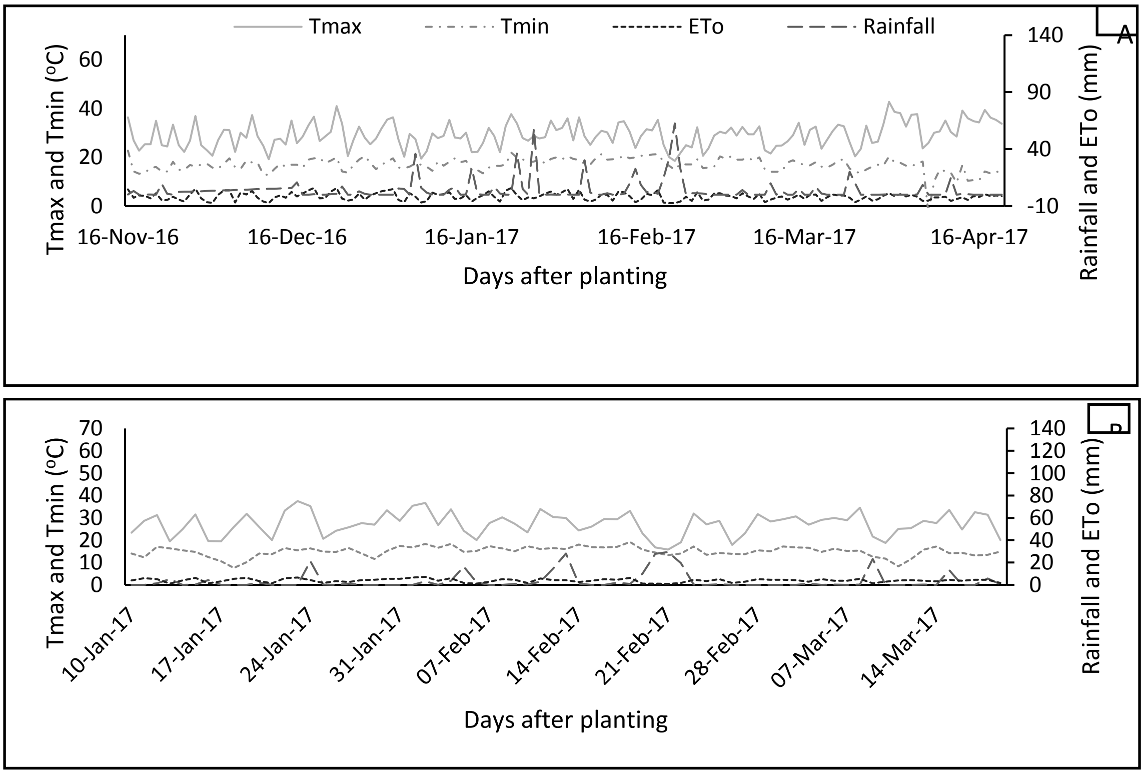

Figure 3.1*:* Daily temperature (minimum and maximum), reference evapotranspiration and rainfall for two different locations (A: Umbumbulu and B: FHE).

3.3.2 Plant growth

Location had a great influence on the leaf number of different cultivars (Figure 3.2; A & B). At Umbumbulu there was a highly significant ($P \leq 0.001$) difference between the leaf numbers of different cultivars. There were significant ($P = 0.004$) differences between cultivars on different ridge types (Figure 3.2; AP & AF). At FHE, there were significant ($P = 0.003$) differences between cultivars, but no significant differences between cultivars grown on the two different systems (Figure 3.2). There were also significant ($P = 0.012$) differences between cultivars: 199062.1 had the highest leaf number throughout the season and in both locations followed by A45 and A40. At both locations cultivar A45 and A40 were not significantly different but A45 had a higher leaf number than A40.

At Umbumbulu (Figure 3.3; AP & AF), there were no significant ($P = 0.018$) differences between cultivars grown on different ridge types with respect to vine number. Cultivar 199062.1 had the highest number of vines followed by A45. However, there was no significant differences between cultivars. The interaction between cultivar and ridge type showed significant ($P = 0.04$) differences with respect to the vine number at FHE (Figure 3.3; BP & BF). Cultivar 199062.1 had the highest number of vines followed by A40.

There were no significant differences with respect to the length of the longest vine of the sweet potato at Umbumbulu (Figure 3.4; AP & AF). Although there were no significant differences, cultivar A40 and A45 had the highest vine length while 199062.1 had the shortest vine length. At FHE, there were highly significant ($P \leq 0.001$) differences with respect to the longest vines of crops grown on different ridge types (Figure 3.4; BP & BF). Cultivar A40 had the longest vine followed by A45; cultivar 199062.1 had a significantly shorter vine.

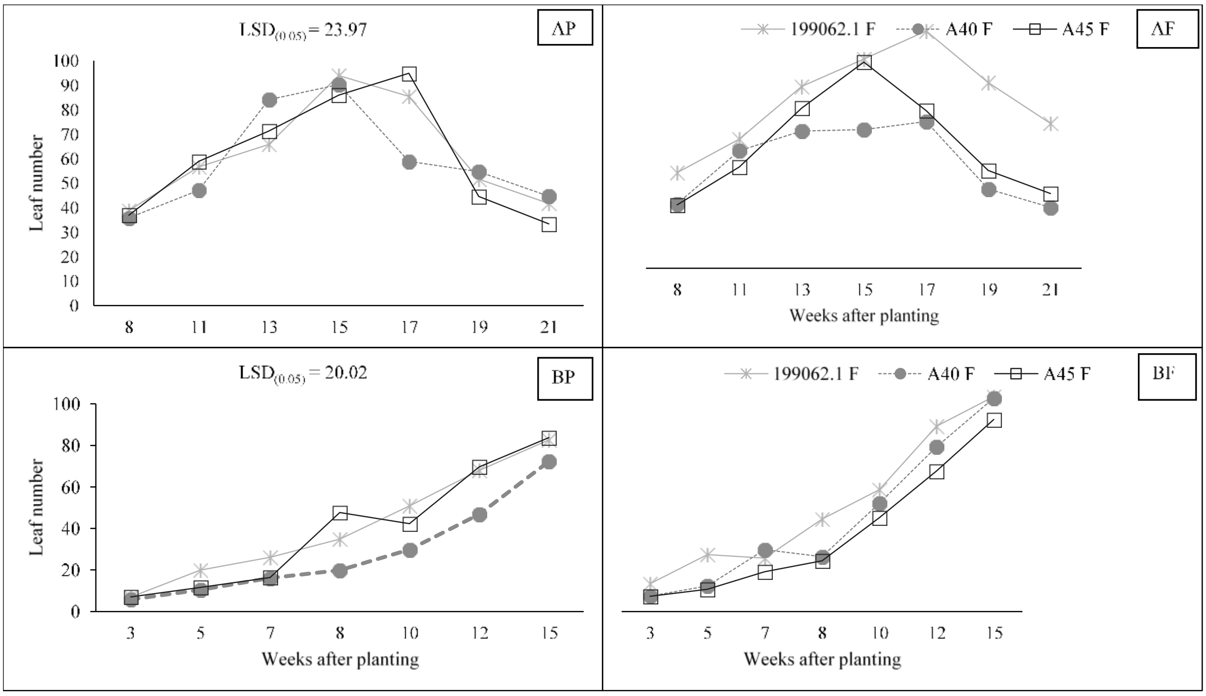

Figure 3.2: Leaf number of three sweet potato cultivars grown in two different locations (A: Umbumbulu and B: FHE) under two different ridge types (P: Peak and F: Flat).

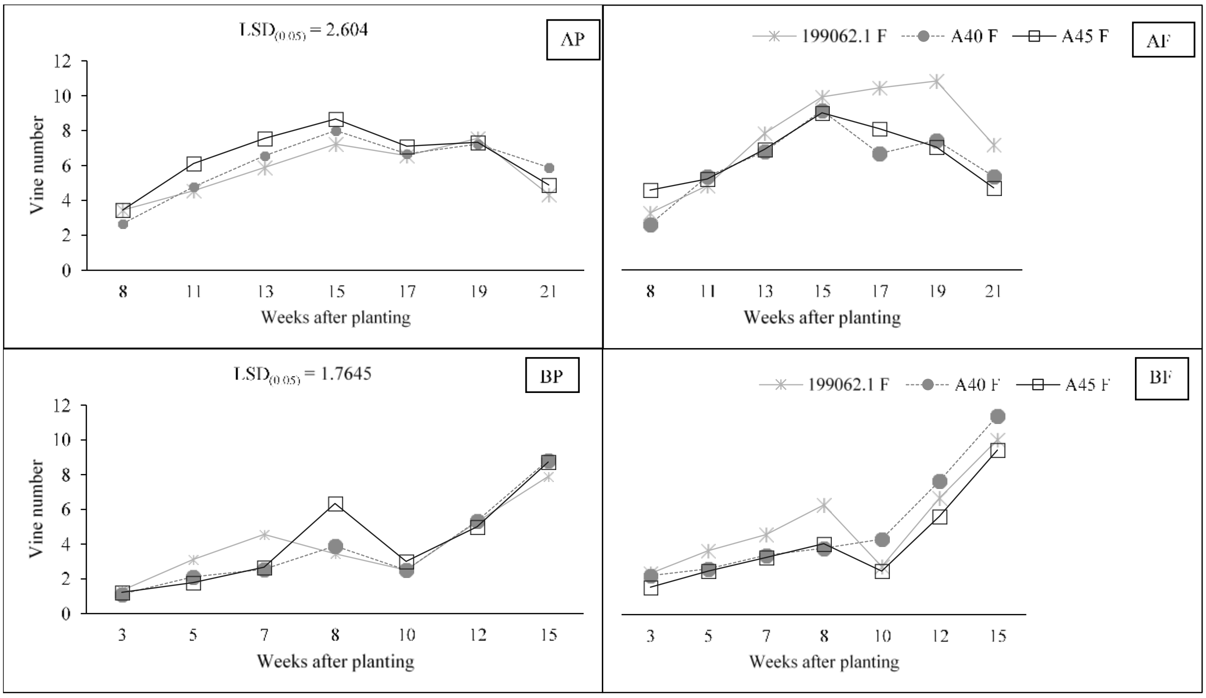

Figure 3.3: Vine number of three sweet potato cultivars grown in two different locations (A: Umbumbulu and B: FHE) under two different ridge types (P: Peak and F: Flat).

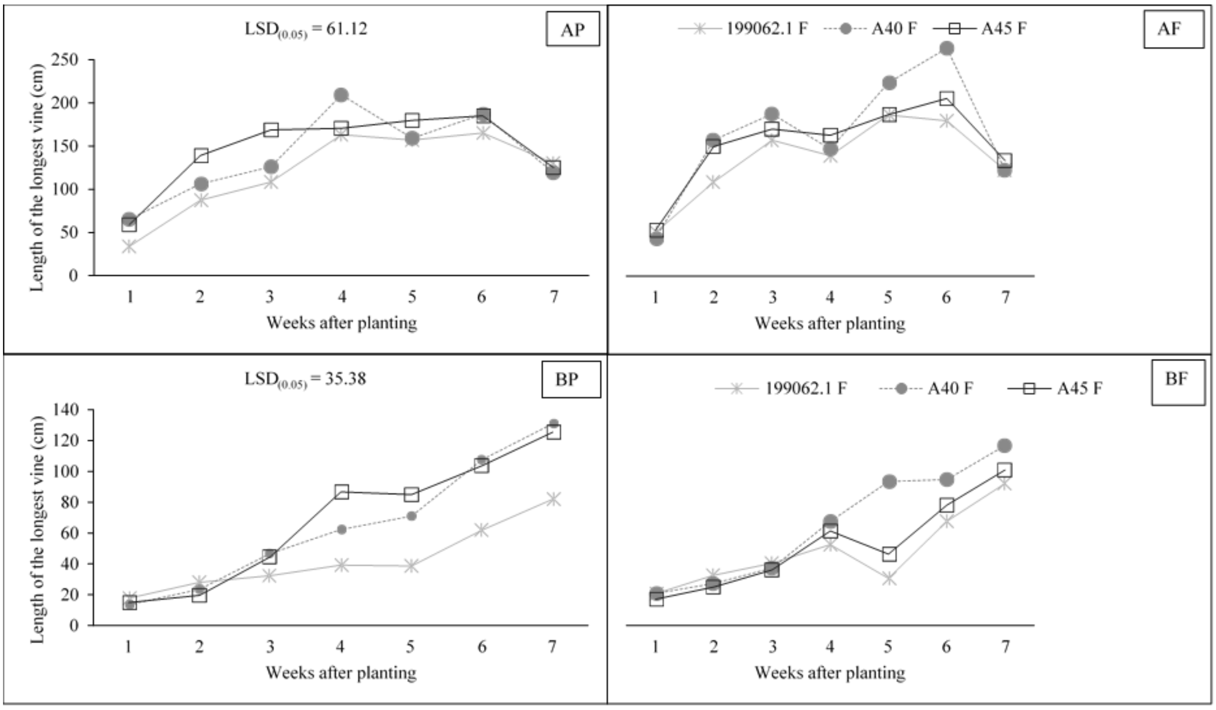

Figure 3.4: The length of the longest vine of three sweet potato cultivars grown in two different locations (A: Umbumbulu and B: FHE) under two different ridge types (P: Peak and F: Flat).

3.3.2 Plant physiology

The chlorophyll content index of the sweet potato grown at Umbumbulu showed no significant differences (Figure 3.5; AP & AF), although cv. 199062.1 had the highest CCI. However, cv. A40 and A45 did not vary significantly much from each other. At FHE, there was a significant ($P \leq 0.001$) difference between cultivars with respect to the chlorophyll content index (Figure 3.5; BP & BF). Cultivar 199062.1 had the highest CCI followed by A45. The three cultivars had no similarities.

There was a highly significant ($P \leq 0.001$) difference with respect to stomatal conductance of cultivars grown on different ridge types at Umbumbulu (Figure 3.6; AP & AF). Cultivar A40 followed by 199062.1 under the peak ridge type had the highest stomatal conductance. At FHE there were significant ($P = 0.029$) differences with respect to the stomatal conductance of cultivars grown on different ridge types (Figure 3.6; BP & BF). Cultivar A45 had the highest stomatal conductance followed by cultivar A40.

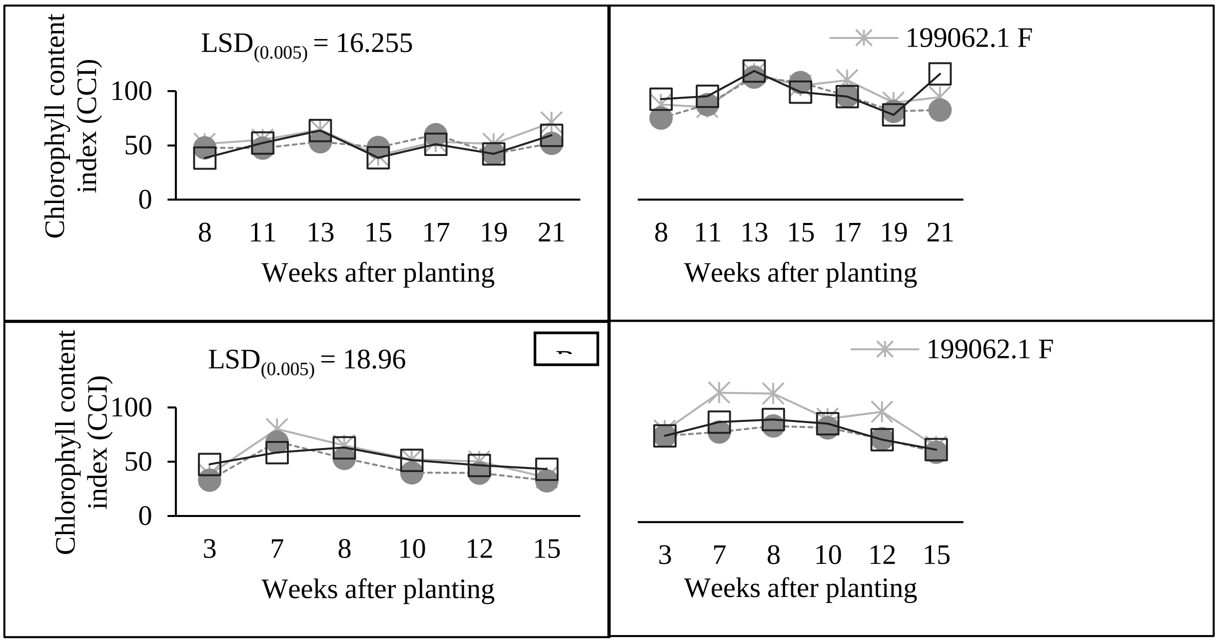

Figure 3.5: Chlorophyll content index (CCI) of three sweet potato cultivars grown at two different locations (A: Umbumbulu and B: FHE) under two different ridge types (P: Peak and F: Flat).

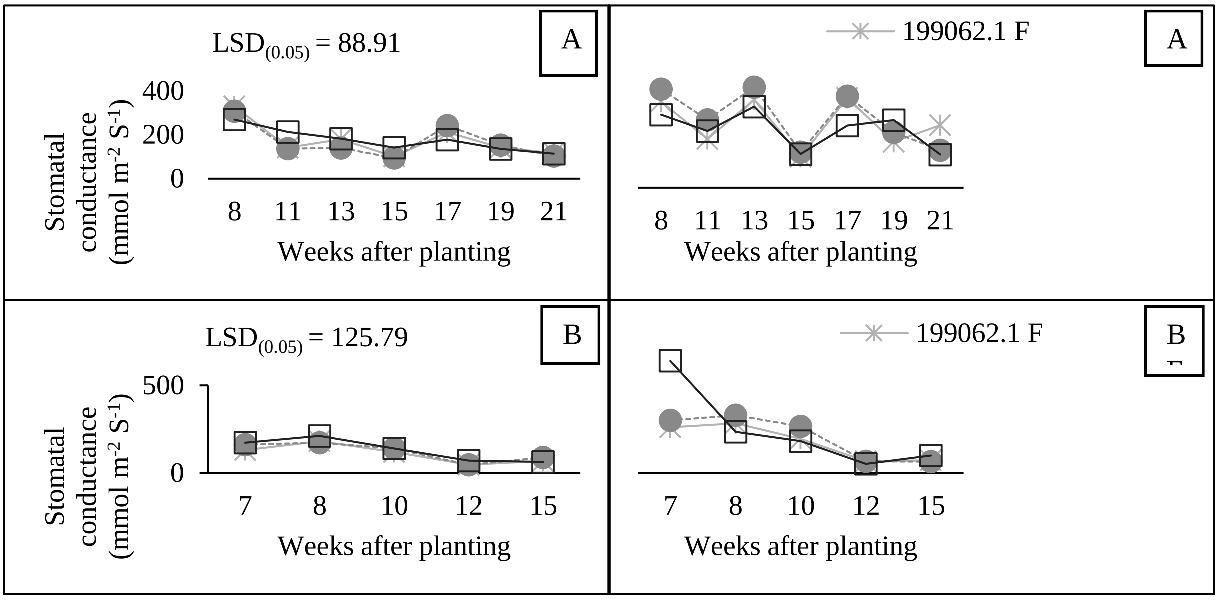

Figure 3.6: Stomatal conductance (mmol m^{-2} s^{-1}) of three sweet potato cultivars grown at two different locations (A: Umbumbulu and B: FHE) under two different ridge types (P: Peak and F: Flat).

3.3.4 Yield and yield components

Planting systems did not have a significant effect on the yield components (Table 3.2). The combination of planting system and sequential harvesting did affect crop yield (Table 3.3). On average across sites, ridging produced about 15% more yield than flat planting (Table 3.3). The differences can be attributed to differences in water use efficiency, which was better at Umbumbulu compared to FHE.

Table 3.2: Yield components of cultivars grown in two different locations of KwaZulu-Natal, South Africa under different ridge types (P: Peak and F: Flat).

Cultivars	**Umbumbulu**					**Fountain Hill Estate**				
	Biomass ($t.ha^{-1}$)	Yield ($t.ha^{-1}$)	Root length (cm)	Root circumference (cm)	HI* (%)	Biomass ($t.ha^{-1}$)	Yield ($t.ha^{-1}$)	Root length (cm)	Root circumference (cm)	HI* (%)
A40	104.62a	51.39a	19.46a	19.08a	0.48b	71.40a	11.33a	16.53a	11.50a	0.55a
A45	71.35a	36.11a	14.88a	20.23a	0.47b	21.01a	21.77a	17.20a	17.23b	0.58a
199062.1	67.15a	43.90a	13.11a	21.31a	1.88a	20.35a	14.45a	16.00a	14.15ab	0.68a
Location mean	**81.04a**	**43.98a**	**18.82a**	**20.21a**	**0.95a**	**37.59a**	**15.85a**	**16.58a**	**14.29ab**	**0.603a**
LSD$_{(p=0.5)}$ Cultivars	89.2	44.09	7.32	6.33	2.4	80.31	10.75	2.31	4.18	0.28
LSD$_{(p=0.5)}$ Ridge type	72.83	36	5.97	5.17	1.96	65.57	8.78	1.88	3.41	0.23
LSD$_{(p=0.5)}$ Cultivar*ridge type	126.15	62.36	10.35	8.96	3.39	113.57	15.21	3.26	5.9	0.39

*HI= Harvest index. Values in the same column sharing the same letter are not significantly different at LSD (p=0.05).

Table 3.3: Yield, water use, and WUE of cultivars grown in two different locations of KwaZulu-Natal, South Africa. Planting system (System: P = ridge and P =flat); Harvest (Sequential harvest).

			Umbumbulu			**Fountain Hill Estate**		
System	Cultivar	Harvest	Yield t. ha^{-1}	Water used or ETa mm	WUE kg ha^{-1}mm^{-1}	Yield t.ha^{-1}	Water used or ETa (mm)	WUE kg ha^{-1}mm^{-1}
P	A45	1	39.9	808.8	49.4	17.1	3927.3	43.5
P	199062.1	1	75.3	798.0	94.3	10.2	3794.2	26.8
P	A40	1	133.9	782.8	171.0	18.6	3842.2	48.4
P	A45	2	62.5	808.8	77.3	36.6	3927.3	93.2
P	A40	2	31.0	782.8	39.7	12.8	3842.2	33.3
P	199062.1	2	43.5	798.0	54.5	20.9	3794.2	55.1
P	A40	3	15.6	782.8	19.9	4.3	3842.2	11.2
P	A45	3	5.7	808.8	7.0	19.7	3927.3	50.2
P	199062.1	3	29.2	798.0	36.6	13.8	3794.2	36.2
F	A45	1	31.0	865.1	35.8	22.3	3410.8	65.4
F	199062.1	1	21.9	859.7	25.4	9.5	3792.4	25.1
F	A40	1	37.7	905.9	41.6	6.1	3661.0	16.7
F	A45	2	20.8	865.1	24.1	8.9	3410.8	26.1
F	A40	2	28.9	905.9	31.9	17.6	3661.0	48.0
F	199062.1	2	67.2	859.7	78.2	27.7	3792.4	73.0
F	A40	3	61.3	905.9	67.6	8.6	3661.0	23.5
F	A45	3	56.7	865.1	65.6	26.0	3410.8	76.4
F	199062.1	3	26.3	859.7	30.6	4.7	3792.4	12.3

Although there were significant cultivar differences with respect to tuber nutrient content, the trends varied (Table 3.4). However, on average across sites and cultivars, both water productivity and nutritional water productivity benefitted slightly from ridging (Table 3.4; 3.5).

Table 3. 4: Nutrient content, water productivity and nutritional water productivity for three sweet potato cultivars grown on two planting systems (a ridge – P and a pit – F) in Umbumbulu.

Planting system	CV	Sequential harvest	WP kg ha^{-1} m^{-3}	**Nutrient content**						**NWP**					
				Fat g/kg	Crude Protein g/kg	Ca mg/kg	Zn mg/kg	Cu mg/kg	Fe mg/kg	Fat g/kg	Crude Protein g/kg	Ca mg/kg	Zn mg/kg	Cu mg/kg or ppm	Fe mg/kg
P	A45	1	5	11	37.1	1.2	8.6	6.0	45	55	183.4	6.1	42.5	29.6	224
P	199062.1	1	9	10	38.7	0.9	9.9	6.8	53	95	365.0	8.1	93.3	63.9	507
P	A40	1	17	5.4	28.0	1.1	11.4	7.7	182	93	478.1	19.2	196	131.9	312
P	A45	2	8	5.9	26.3	1.5	9.4	2.6	38	46	202.9	11.4	72.8	20.1	300
P	A40	2	4	16	43.1	1.0	9.8	5.6	35	65	170.8	3.8	38.8	22.3	139
P	199062.1	2	5	14	34.4	1.0	10.2	3.1	59	78	187.5	5.5	55.7	16.8	321
P	A40	3	2	7.2	24.4	0.8	8.1	2.6	43	14	48.5	1.6	16.1	5.1	85
P	A45	3	1	20	46.2	1.1	10.9	5.1	50	14	32.5	0.7	7.7	3.6	35
P	199062.1	3	4	6.8	44.9	1.0	9.7	4.5	61	25	164.4	3.8	35.4	16.6	224
F	A45	1	4	18	56.2	0.4	9.3	7.7	44	66	201.2	1.5	33.3	27.7	157
F	199062.1	1	3	13	29.3	0.7	6.9	6.1	36	34	74.6	1.7	17.5	15.6	92
F	A40	1	4	7.7	23.1	1.2	7.8	6.1	50	32	96.0	4.9	32.6	25.5	208
F	A45	2	2	17	36.1	1.2	8.3	4.0	25	41	86.9	2.9	19.9	9.6	59
F	A40	2	3	6.3	32.3	1.2	7.9	3.9	62	20	103.1	4.0	25.2	12.3	197
F	199062.1	2	8	13	38.1	2.4	10.1	3.5	75	103	298.2	18.9	79.0	27.7	586
F	A40	3	7	6.8	31.1	1.1	8.2	2.3	56	46	210.1	7.5	55.4	15.8	377
F	A45	3	7	28	29.9	1.2	7.4	3.4	63	186	196.4	7.6	48.4	22.3	411
F	199062.1	3	3	36	43.4	0.5	9.8	5.6	54	110	133.0	1.6	30.1	17.3	164

Table 3.5: Nutritional composition of three sweet potato cultivars (A40, A45 and 199062.1) grown on using two methods a ridge (P) and a pit (F) at Fountain Hill Estate.

				Nutrient content						NWP					
Planting system	Culti var	Sequential harvest	WP Kg ha-1 m-3	Fat g/kg	Crude Protein g/kg	Ca mg/kg	Zn mg/kg	Cu mg/kg or ppm	Fe mg/kg	Fat g/kg	Crude Protein g/kg	Ca mg/kg	Zn mg/kg	Cu mg/kg	Fe mg/kg
P	A45	1	4	11.2	71.3	0.7	13.4	7.5	25.6	48.7	310.3	3.2	58.1	32.6	111
P	199062.1	1	3	15.8	58.7	1.0	10.5	10.1	23.4	42.3	157.6	2.8	28.3	27.1	63
P	A40	1	5	10.0	66.2	1.3	9.8	5.7	15.7	48.3	320.7	6.5	47.3	27.5	76
P	A45	2	9	16.4	49.1	0.8	11.2	6.9	13.3	153.2	457.8	7.1	104.1	64.0	124
P	A40	2	3	7.6	76.7	1.0	9.8	6.4	37.9	25.3	255.1	3.2	32.5	21.4	126
P	199062.1	2	6	17.1	47.0	1.0	11.4	6.5	21.8	94.0	258.7	5.4	62.8	35.8	120
P	A40	3	1	7.5	56.9	1.3	10.6	4.6	25.1	8.4	63.8	1.4	11.9	5.2	28
P	A45	3	5	13.3	52.8	0.6	11.9	7.1	21.7	67.0	264.9	2.9	59.8	35.5	109
P	199062.1	3	4	13.7	64.4	1.0	11.5	6.7	29.3	49.6	233.5	3.5	41.7	24.3	106
F	A45	1	7	15.1	59.3	1.1	10.1	8.8	22.2	98.7	387.5	7.0	65.8	57.2	145
F	199062.1	1	3	14.3	49.4	0.7	8.8	6.8	23.2	35.8	123.9	1.9	22.1	17.1	58
F	A40	1	2	8.8	40.4	1.1	8.1	4.1	17.6	14.7	67.5	1.8	13.5	6.8	29
F	A45	2	3	12.0	58.6	0.5	14.1	6.0	18.1	31.2	152.6	1.4	36.8	15.6	47
F	A40	2	5	7.0	43.7	1.4	10.3	4.5	16.1	33.6	209.9	6.5	49.4	21.7	78
F	199062.1	2	7	11.4	54.7	0.9	12.6	6.0	15.9	83.1	399.4	6.2	92.0	43.9	116
F	A40	3	2	7.9	46.6	1.2	12.1	4.1	18.9	18.6	109.6	2.9	28.4	9.6	44
F	A45	3	8	17.2	67.8	1.9	17.6	5.7	21.9	131.2	517.4	14.5	134.5	43.6	168
F	199062.1	3	1	14.3	50.1	0.7	10.1	6.3	19.6	17.6	61.5	0.9	12.4	7.8	24

4. CONCLUSIONS

Sweet potatoes are nutritious and offer greater diversity for poor rural farmers practising agriculture under water limited conditions. The orange fleshed sweet potatoes had higher beta carotene and can be promoted to alleviate Vitamin A deficiency. The fact that NWP was higher under water limited, relative to optimum conditions, supports the argument that sweet potatoes have potential to contribute to human nutrition in water scarce areas. The use of NWP as a metric allows for an analysis of how agriculture can contribute to food and nutrition security under water scarce conditions. Future studies will determine water use and NWP of sweet potatoes under field conditions and varying agro-ecologies. At Umbumbulu there were higher rainfall and temperatures compared to FHE. There was rainfall at Umbumbulu almost every month, and there was a variation with respect to the amount of rainfall throughout the season. The rainfall of FHE was low, occurring at even lower levels in the initial stages of plant development. The temperature variation was minimal throughout the growing season at both sites. The different climatic conditions had a significant effect on plant growth. The leaf number, number of vines and vine length of the crops grown at Umbumbulu was initially higher than those from FHE. However, at FHE these growth parameters were negatively affected by the low rainfall during crop establishment. Although sweet potato is a drought tolerant crop, water scarcity in the initial stages of development can limit the crop’s full production potential. Sweet potato is generally produced on ridges. Studies have shown that ridges improve plant establishment by retaining soil moisture longer than a flat surface. At FHE, this phenomenon was more expressed as the cultivars grown on the different ridge types showed a significant difference with respect to all the growth parameters. The crops grown on the peaks generally performed better than those grown on the flats. This may be as a result of the low levels of rainfall at FHE during the initial growth stages and therefore the peak was able to retain higher moisture levels for crop development.

REFERENCES

Adebola, P., Shegro, A., Laurie, S., Zulu, L. and Pillay, M. 2013. Genotype x environment interaction and yield stability estimate of some sweet potato [Ipomoea batatas (L.) Lam] breeding lines in South Africa. Journal of Plant Breeding and Crop Science 5: 182-186.

Agili, S., Nyende, B., Ngamau, K. and Masinde, P. 2012. Selection, yield evaluation, drought tolerance indices of orange-flesh sweet potato (Ipomoea batatas Lam) hybrid clone. Journal of Nutrition & Food Sciences 2012.

Agili, S., Nyende, B., Ngamau, K. and Masinde, P. 2012. Selection, yield evaluation, drought tolerance indices of orange-flesh sweet potato (Ipomoea batatas Lam) hybrid clone.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome 300: D05109.

Andrade, M.I., Naico, A., Ricardo, J., Eyzaguirre, R., Makunde, G.S., Ortiz, R. and Grüneberg, W.J. 2016. Genotype× environment interaction and selection for drought adaptation in sweetpotato (Ipomoea batatas [L.] Lam.) in Mozambique. Euphytica 209: 261-280.

Austin, D.F. 1998. Convolvulaceae morning glory family. Journal of the Arizona-Nevada Academy of Science: 61-83.

Austin, D.F. and Huáman, Z. 1996. A synopsis of Ipomoea (Convolvulaceae) in the Americas. Taxon: 3-38.

Belehu, T. 2005. Agronomical and physiological factors affecting growth, development and yield of sweet potato in Ethiopia.

Bovell-Benjamin, A.C. 2007. Sweet potato: a review of its past, present, and future role in human nutrition. Advances in food and nutrition research 52: 1-59.

Burri, B.J. 2011. Evaluating sweet potato as an intervention food to prevent vitamin A deficiency. Comprehensive Reviews in Food Science and Food Safety 10: 118-130.

Camp, K.G.T. 1999. A bioresource classification for KwaZulu-Natal, South Africa.

Domola, M.J. 2006. Survey and characterisation of sweet potato viruses in South Africa.

Donado-Pestana, C.M., Salgado, J.M., De Oliveira Rios, A., Dos Santos, P.R. and Jablonski, A. 2012. Stability of carotenoids, total phenolics and in vitro antioxidant capacity in the thermal processing of orange-fleshed sweet potato (Ipomoea batatas Lam.) cultivars grown in Brazil. Plant foods for human nutrition 67: 262-270.

Gan, Y., Siddique, K.H., Turner, N.C., Li, X.-G., Niu, J.-Y., Yang, C., Liu, L. and Chai, Q. 2013. Ridge-furrow mulching systems—an innovative technique for boosting crop productivity in semiarid rain-fed environments. Advances in agronomy 118: 429-476.

Gregory, L. 1965. Physiology of tuberization in plants.(Tubers and tuberous roots.). Differenzierung und Entwicklung/Differentiation and Development. Springer. p. 1328-1354.

Hagenimana, V., Carey, E., Gichuki, S., Oyunga, M. and Imungi, J. 1998. Carotenoid contents in fresh, dried and processed sweetpotato products. Ecology of Food and Nutrition 37: 455-473.

Huaman, Z. 1992. Systematic botany and morphology of the sweetpotato plant. Boletin de Informacion Tecnica (Peru).

Khan, Z. and Doty, S.L. 2009. Characterization of bacterial endophytes of sweet potato plants. Plant and soil 322: 197-207.

Kivuva, B.M. 2013. Breeding sweetpotato (Ipomoea batatas [L.] Lam.) for drought tolerance in Kenya. University of KwaZulu-Natal, Pietermaritzburg.

Kyamanywa, S., Kashaija, I.N., Getu, E., Amata, R., Senkesha, N. and Kullaya, A. 2011. Enhancing food security through improved seed systems of appropriate varieties of cassava, potato and sweetpotato resilient to climate change in Eastern Africa.

Laurie, S., Faber, M., Adebola, P. and Belete, A. 2015. Biofortification of sweet potato for food and nutrition security in South Africa. Food Research International 76: 962-970.

Laurie, S., Van Den Berg, A., Tjale, S., Mulandana, N. and Mtileni, M. 2009. Initiation and first results of a biofortification program for sweet potato in South Africa. Journal of Crop Improvement 23: 235-251.

Laurie, S. and Van Heerden, S. 2012. Consumer acceptability of four products made from beta-carotene-rich sweet potato. African journal of food science 6: 96-103.

Laurie, S.M., Tjale, S.S., Van Den Berg, A.A., Mtileni, M.M. and Labuschagne, M.T. 2015. Agronomic performance of new cream to yellow-orange sweetpotato cultivars in diverse environments across South Africa. South African Journal of Plant and Soil 32: 147-155.

Li, X.-Q. and Zhang, D. 2003. Gene expression activity and pathway selection for sucrose metabolism in developing storage root of sweet potato. Plant and cell physiology 44: 630-636.

Li, X., Su, D. and Yuan, Q. 2007. Ridge-furrow planting of alfalfa (Medicago sativa L.) for improved rainwater harvest in rainfed semiarid areas in Northwest China. Soil and Tillage Research 93: 117-125.

Liu, J., Fritz, S., Van Wesenbeeck, C., Fuchs, M., You, L., Obersteiner, M. and Yang, H. 2008. A spatially explicit assessment of current and future hotspots of hunger in sub-Saharan Africa in the context of global change. Global and Planetary Change 64: 222-235.

Loebenstein, G. 2009. Origin, Distribution and Economic Importance. In: Loebenstein, G. and Thottappilly, G., editors, The Sweetpotato. Springer Netherlands, Dordrecht. p. 9-12.

Low, J., Ball, A., Magezi, S., Njoku, J., Mwanga, R., Andrade, M., Tomlins, K., Dove, R. and Van Mourik, T. 2017. Sweet potato development and delivery in sub-Saharan Africa. African Journal of Food, Agriculture, Nutrition and Development 17: 11955-11972.

Low, J., Lynam, J., Lemaga, B., Crissman, C., Barker, I., Thiele, G., Namanda, S., Wheatley, C. and Andrade, M. 2009. Sweetpotato in sub-Saharan Africa. The sweetpotato: 359-390.

Low, J., Lynam, J., Lemaga, B., Crissman, C., Barker, I., Thiele, G., Namanda, S., Wheatley, C. and Andrade, M. 2009. Sweetpotato in sub-Saharan Africa. In: Loebenstein, G. and Thottappilly, G., editors, The Sweetpotato. Springer Netherlands, Dordrecht. p. 359-390.

Low, J.W., Arimond, M., Osman, N., Cunguara, B., Zano, F. and Tschirley, D. 2007. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. The Journal of nutrition 137: 1320-1327.

Mabhaudhi, T., Chibarabada, T. and Modi, A. 2016. Water-food-nutrition-health nexus: Linking water to improving food, nutrition and health in sub-Saharan Africa. International journal of environmental research and public health 13: 107.

Masango, S. 2015. Water use efficiency of orange-fleshed sweetpotato (Ipomoea batatas L. Lam.).

Motsa, N.M., Modi, A.T. and Mabhaudhi, T. 2015. Sweet potato (Ipomoea batatas L.) as a drought tolerant and food security crop. South African Journal of Science 111: 1-8.

Motsa, N.M., Modi, A.T. and Mabhaudhi, T. 2015. Sweet potato response to low-input agriculture and varying environments of KwaZulu-Natal, South Africa: implications for food security strategies. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science 65: 329-340.

Naidoo, S., Laurie, S., Odeny, D., Vorster, B., Mphela, W., Greyling, M. and Crampton, B. 2016. Genetic analysis of yield and flesh colour in sweetpotato. African Crop Science Journal 24: 61-73.

Nedunchezhiyan, M., Byju, G. and Jata, S.K. 2012. Sweet potato agronomy. Fruit Veg. Cereal Sci. Biotech 6: 1-10.

Niederwieser, J. 2004. Guide to sweet potato production in South Africa.

Nikiema, J. 2017. Exploitation of heterosis in sweetpotato (Ipomoea batatas L.(Lam)) via progeny testing and use of molecular markers.

Njoku, J., Muoneke, C. and Okocha, P. 2010. Effect of propagule size and storage period on establishment and yield of sweetpotato in a tropical ultisol. Journal of Sustainable Agriculture and the Environment 12: 43-56.

O'brien, P.J. 1972. The sweet potato: its origin and dispersal. American anthropologist: 342-365.

Oggema, J., Kinyua, M., Ouma, J. and Owuoche, J. 2007. Agronomic performance of locally adapted sweet potato (Ipomoea batatas (L) Lam.) cultivars derived from tissue culture regenerated plants. African Journal of Biotechnology 6.

Omotobora, B.O., Adebola, P.O., Modise, D.M., Laurie, S.M. and Gerrano, A.S. 2014. Greenhouse and Field Evaluation of Selected Sweetpotato (Ipomoea batatas (L.) LAM) Accessions for Drought Tolerance in South Africa. American Journal of Plant Sciences 5: 3328.

Owusu, D., Ellis, W.O. and Oduro, I. 2008. Nutritional potential of two leafy vegetables: Moringa oleifera and Ipomoea batatas leaves.

Palmer, A.C., Darnton-Hill, I. and West Jr, K.P. 2017. Vitamin A Deficiency. Nutrition and Health in a Developing World. Springer. p. 181-234.

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.

Ravi, V., Naskar, S., Makeshkumar, T., Babu, B. and Krishnan, B.P. 2009. Molecular physiology of storage root formation and development in sweet potato (Ipomoea batatas (L.) Lam.). J Root Crops 35: 1-27.

Reddy, P.P. 2015. Sweet Potato: Ipomoea batatas. Plant Protection in Tropical Root and Tuber Crops. Springer. p. 83-141.

Renault, D. and Wallender, W. 2000. Nutritional water productivity and diets. Agricultural water management 45: 275-296.

Ridoutt, B.G. and Pfister, S. 2010. A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Global Environmental Change 20: 113-120. doi:http://dx.doi.org/10.1016/j.gloenvcha.2009.08.003.

Roullier, C., Rossel, G., Tay, D., Mckey, D. and Lebot, V. 2011. Combining chloroplast and nuclear microsatellites to investigate origin and dispersal of New World sweet potato landraces. Molecular ecology 20: 3963-3977.

2015. Root and tuber crops (Cassava, yam, potato and sweet potato). Proceedings of the An Action Plan for African Agricultural Transformation Conference, Dakar, Senegal.

Saraswati, P. 2007. Physiological and growth responses of selected sweet potato (Ipomoea batatas (L.) Lam.) cultivars to water stress. James Cook University.

Sasikiran, K., Rekha, M. and Padmaja, G. 2002. Proteinase and alpha-amylase inhibitors of sweet potato: changes during growth phase, sprouting, and wound induced alterations. Botanical Bulletin of Academia Sinica 43.

Somda, Z.C., Mahomed, M. and Kays, S. 1991. Analysis of leaf shedding and dry matter recycling in sweetpotato. Journal of plant nutrition 14: 1201-1212.

1998. Sweetpotato and cassava in the Kwazulu Natal Province of South Africa: a baseline study. Proceedings of scientific workshop of SARRNET.

Van Jaarsveld, P.J., Faber, M., Tanumihardjo, S.A., Nestel, P., Lombard, C.J. and Benadé, A.J.S. 2005. β-Carotene–rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. The American journal of clinical nutrition 81: 1080-1087.

Villordon, A.Q., Ginzberg, I. and Firon, N. 2014. Root architecture and root and tuber crop productivity. Trends in plant science 19: 419-425.

Woolfe, J.A. 1992. Sweet potato: an untapped food resourceCambridge University Press.

Yanggen, D. and Nagujja, S. 2006. The use of orange-fleshed sweetpotato to combat vitamin A deficiency in Uganda.: A study of varietal preferences, extension strategies and post-harvest utilizationInternational Potato Center.

Yooyongwech, S., Samphumphung, T., Tisaram, R., Theerawitaya, C. and Cha-Um, S. 2017. Physiological, Morphological Changes and Storage Root Yield of Sweetpotato [Ipomoea batatas (L.) Lam.] under PEG-Induced Water Stress. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 45.

Yu, B., Zhang, F., Zheng, Y. and Wang, P. 1996. Alcohol fermentation from the mash of dried sweet potato with its dregs using immobilised yeast. Process biochemistry 31: 1-6.