EFFECT OF PLANTING DEPTH AND CUTTING ORIENTATION ON GROWTH AND YIELD OF SWEET POTATO (***IPOMOEA BATATAS L. (LAM)*** CULTIVARS FOR SMALL SCALE PRODUCTION IN VERULAM

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ABBREVIATIONS

%	Percentage
°C	Degrees Celsius
ABM	Above ground biomass
Acid sat.	Acid saturation
ANOVA	Analysis of variance
APan	Evaporation measurement
ARC	Agricultural Research Council
ARC-VOP	Agricultural Research Council - Vegetable and Ornamental Plants
C	Carbon
Ca	Calcium
CIP	International potato Centre
Cm	Centimetre
cmol	Centimole
Cu	Copper
DAFF	National Department of Agriculture, Forest and Fisheries
DARD	Department of Agriculture and Rural Development Kwa Zulu-Natal
E	East
ERD	Effective Root Depth
Exch.acid	Exchange acidity
FAOSTAT	Food and Agriculture Organisation of United Nations Statistics database
Fe	Iron
G	Grams
GENSTAT	General Statistics
g/mol	grams per mole

g/ml	gram per millilitre
HI	harvest index
HSD	Tukey's Honestly Significant Difference
KCl	Potassium Chloride
K	Potassium
kg/ha	Kilograms per hectare
Km	Kilometres
KZN	KwaZulu-Natal
KZN-BRU	KwaZulu-Natal Bio resource Unit Programme
L	Litre
LAN	Lime Ammonium Nitrate
$LSD_{0,05}$	Least significant difference at 5 % confidence level
M	Metres
m^2	Square metres
Mg	Magnesium
Mm	Millimetres
Mn	Manganese
MY	Marketable Yield
NMY	Non-Marketable Yield
N	Nitrogen
Ns	Not significant
Org.	Organic content
OFSP	Orange Fleshed Sweet potato
P	Phosphorus
pH	Measure of acidity /alkalinity

RCBD	Randomised complete block design
SASRI	South African Sugarcane Research Institute
SSA	Sub Saharan Africa
t ha^{-1}	Tons per hectare
UKZN	University of KwaZulu- Natal
VAD	Vitamin A deficiency
WAP	Weeks after planting
Zn	Zinc

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To almighty God in heaven. Thank you,

DECLARATION

I, Ntombifuthi Zanele Queen Pakkies, declare that this dissertation is the product of my own work and effort. I have, to the best of my knowledge and belief, acknowledged all sources of information in line with normal academic conventions.

The work presented in this dissertation was my own and has never been submitted for a degree at this or any other university.

Signature: …… Date: .....

ABSTRACT

Sweet potato (Ipomoea batatas L. (Lam) is an important root crop for small scale farmers in the KwaZulu-Natal province of South Africa. However, low storage root yields in small scale farming are attributed to a number of factors including poor selection of cultivars and possibly unsuitable cultivation practices. Therefore, two experiments were conducted over two growth seasons (2014/2015 and 2015/2016) to test the effect of sweet potato cultivar, orientation of cuttings at planting and planting depth of cuttings in the Verulam area of northern KwaZulu-Natal province. Both experiments were conducted in the field under rain fed conditions and both were laid out in a randomized complete block design (RCBD) with four replications per treatment. Experiment 1 tested four cultivars (Monate, Ndou, 199062.1 and Blesbok) in either horizontal or vertical orientation of cuttings at planting. In Experiment 2, cuttings of one cultivar (Bophelo) were planted at 5 different depths (5 cm, 10 cm, 15 cm, 20 cm and 25 cm) either horizontally or vertically. Vine lengths were measured at 3, 6, 9 and 12 weeks after planting on five randomly selected plants per plot. Aboveground biomass (ABM) yield, marketable yield (MY), non-marketable yield (NMY), storage root yield according to four size classes, total storage root yield and harvest index (HI) were determined at harvesting. Of the four cultivars tested in Experiment 1, cultivar 199062.1 scored the highest values for most parameters measured in season I, including MY, extra-large tubers (451 – 1000 g) and total storage root yield (significant, $p<0.05$). Cultivar Ndou scored the lowest values for all yield-related parameters measured in season I, but had the longest (significant $p<0.05$, at 12 weeks after planting) vines in season II. In season II, most differences among cultivars were not significant. For both experiments, there was generally a trend for plants grown from horizontally orientated cuttings to show

higher values for most parameters measured than for plants grown from vertically orientated cuttings with significant ($p<0.05$) differences for total storage root yield and HI in season I. Planting cuttings to different depths did not have significant effect on any of the parameters measured, except for vine length at 12 weeks after planting for season II, where cuttings planted to a depth of 25 cm produced significantly ($p<0.05$) longer vines compared with other planting depths. However, it was observed that planting cuttings to a depth of 10 cm had a tendency to result in higher values for most parameters measured and 20 cm the lowest. The data collected in this study was preliminary and the experiments will have to be repeated before recommendations can be made to farmers with regards to the best cultivar, cutting orientation at planting and planting depth to use by small scale farmers at Verulam.

CHAPTER 1

INTRODUCTION

1.1 General introduction

The sweet potato (*Ipomoea batatas L.(Lam)* is an important root crop in most tropical, sub-tropical and temperate regions of the world, and is a major staple food in African countries (Sharma and Dayal 1990; Nedunchezhiyau et al. 2012). It is estimated that the sweet potato is ranked as the fifth most important food crop on a fresh weight basis in developing countries after cassava, rice, wheat and maize (Scott and Maldonado 1998). It is an important source of carbohydrates, vitamins A and C, fibre, iron, potassium, and protein (Woolfe 1992), and is used for both human and animal consumption.

The crop has been widely cultivated throughout the KwaZulu-Natal (KZN) province of South Africa for many years on both commercial and subsistence level (Naicker 2014). Production of sweet potatoes in KZN is more concentrated in the small-scale farming sector and, is considered as a means to improve food security among the poor communities in rural areas (Motsa 2014). The sweet potato yield is affected by various cultivation practices, including cutting orientation at planting, the type of cultivar planted, and depth of planting (Wilson and Lowe 1973; Lowe and Wilson 1975; Nedunchezhiyau et al. 2012).

Using stem (vine) cuttings is the preferred method for sweet potato propagation (Belehu, 2003). Many different researchers have conducted research on different

planting methods for sweet potato cuttings. These include cuttings orientated horizontally, vertically, or at an angle at planting. However, the results obtained by these studies are often contradictory (for example, Onwueme 1999; Dhliwayo and Chiunzi 2004; Nedunchezhiyau et al. 2012). Likewise, research on the effect of different planting depths on cuttings has also yielded contradictory results (for example Ravindran and Mohankumar 1985; Hall 1986; Bautista and Vega 1991). Various sweet potato cultivars are currently available in South Africa, all of which differ in taste, yield, and their adaptation to environmental conditions. Identifying suitable cultivars for a particular region and market is important in improving yield and profitability.

1.2 Background

In KwaZulu-Natal, sweet potatoes provide an important source of carbohydrates, particularly in the low-income rural communities, and is therefore one of the most important staple crops (Van der Mescht et al. 1997). Most small scale farmers produce sweet potatoes because they provide an opportunity to improve the economic status and food and nutritional security of resource-poor farmers. In general, the crop is planted using vine cuttings. Vine cuttings provide better planting material than sprouts from storage roots because plants can be grown from vine cuttings sourced in areas free from soil-borne diseases (Belehu 2003).

The discipline of plant breeding in the University of KwaZulu-Natal (UKZN), in conjunction with the Horticultural Science section at Cedara, have been developing and releasing new locally produced and adaptive cultivars to farmers (Naicker

2014). Other research centres such as Centre for Potato Improvement (CIP), based in Lima (Peru) and the Agricultural Research Council (ARC) of South Africa, have also released some sweet potato cultivars which are orange-fleshed and are used in Sub-Saharan African (SSA) countries to combat the deficiency of vitamin A (VAD) and to improve food security and malnutrition in rural communities (Laurie at al. 2003).

Small-scale sweet potato producers in rural KZN continue to utilise traditional methods of planting (i.e. using hand hoes and flat planting), use planting material with old landraces and share vines amongst themselves within the communities (Motsa 2014). This current study was conducted on a farm in Verulam, north of Durban, KZN. The designated area is located outside Verulam, where both small scale and commercial farming is practiced. The research simulated the existing sweet potato cultivation practices of farmers in Verulam in order to improve their planting methods and consequently yield.

1.3 Justification

Sweet potato as a crop has a vital contribution in terms of its staple and nutritional value, and it is, therefore, imperative that more rigorous research is conducted in order to improve sweet potato production. Sweet potato production is affected by agronomical practices like planting orientation, depth at which cuttings are planted, as well as cultivar selection (Low et al. 2009; Lebot 2009; Niederwieser 2004). Small-scale farmers in KZN are not familiar with the effects of these factors on storage root yield.

To date, there are limited studies that have been conducted in Verulam to evaluate the effect of using different agronomical practices on sweet potato production. The specificity of the research in the Verulam area will provide an added benefit, as the crop has a particular significance to the area in terms of both economic and nutritional factors. Conducting the proposed study could not only fulfil the academic requirement, but will also produce information that will be helpful to small scale farmers.

The outcomes and the recommendations will add critical information to that currently available on sweet potato production in KZN. This will also ensure that quality information relating to optimum production methods can be generated and made available to farmers through participation. In this way, research can contribute to increased productivity. Furthermore, recommendations made based on the findings and outcomes of this study can be used by the Department of Agriculture and Rural Development (DARD) to make informed decisions on the support mechanism required by small farmers in the Verulam area.

1.4 Problem statement

Sweet potato is an important crop for small scale farmers in the Verulam area. It has potential to contribute as a source of income, as well as a source of healthy nutrition in rural communities. However, the effects of production practices such as cutting orientation and depth of planting, as well as cultivar have not been evaluated in the Verulam area. However, farmers were observed to be using

various planting orientations and planting depths yet there was no rationale for these planting practices. This study aimed to determine how these factors affected sweet potato production in the Verulam area.

1.5 Research objectives

The main objective of this study was to investigate the effect of planting depth and orientation of cuttings at planting of different sweet potato cultivars on their growth and yield under dry land conditions in the Verulam area. The specific objectives were:

i) To evaluate the effect of planting orientation on growth and yield of sweet potato.
ii) To evaluate effect of planting depths on the growth and yield of sweet potato.
iii) To test a number of sweet potato cultivars for their suitability for cultivation in the Verulam area.

1.6 Research hypotheses

Research hypotheses were:

i) Planting orientation affects sweet potato growths and yield.
ii) Different planting depths affect sweet potato growth and yield.
iii) Different sweet potato cultivars differ from each other in terms of growth and yield in the Verulam area

CHAPTER 2

LITERATURE REVIEW

2.1 Sweet potato classification, origin and distribution

Sweet potato (*Ipomoea batatas L. (Lam*) is an herbaceous perennial crop, but is grown as an annual root crop (Yen 1976; Norman et al. 1984; Huamán 1992). Its taxonomy was described by various authors under different hypotheses. Sweet potato was originally described by Linnaeus in 1753 as *Convolvulus batata*, however, the name was changed to *Ipomoea batatas* L. (Lam) in 1791 after Lamarck classified this species under the genus *Ipomoea* based on the stigma shape and the surface of pollen grain (Huamán 1992). Later Van Oorstroom and Hoogland (1954) and Yen (1974) described it as a hexaploid, but this has been debatable as to whether this is as a result of hybridization between the wild species followed by allohexaploid or whether the species is an autohexaploid derived directly from *I. trifida* as is maintained by Nishiyama (1971). The genus *Ipomoea* belongs to the family Convolvulaceae (Huamán 1992; Francesco 2005) (Table 1.1).

Table 1.1: Sweet potato systematic classification

Classification of sweet potato	
Family	Convolvulaceae
Tribe	Ipomoeae
Genus	Ipomoea
Sub-genus	Eriospermum
Section	Eriospermum
Series	Batatas
Species name	*Ipomoea batatas L.(Lam)*

Sweet potato is native to Latin or Tropical America (Nishiyama 1971; Martin and Jones 1972). Within the Series Batatas, 13 wild species were considered to be

related to the sweet potato and their distribution was within America only (Austin 1978; 1979). Prehistorically, the cultivated species of *Ipomoea batatas* that included plants with varying morphologies were selected and cultivated in Latin America and distributed throughout the tropical countries including China, India and also on the African continent (Huamán 1992).

The distribution of the sweet potato to Polynesia around 700 $_{AD}$ was believed to have occurred through the Polynesians who had travelled to South America and spread it across Polynesia, Hawaii and New Zealand (Yen 1974). Bulmer (1965) and Yen (1974) reported that among the 3 lines (i.e*. Kumara*, *Camote* and *Batatas* lines) that reached the Pacific only the *Batatas line* was distributed to the African continent though the exact arrival is unknown (Low et al. 2009). In South Africa, the *Batatas* line arrived in the 16th century with the Portuguese explorers (Woolfe 1992; Laurie and Niederwieser 2004) when Jan Van Riebeeck colonised Cape Town (Bester and Louw (1992; Laurie and Niederwieser 2004).

2.1.1 Sweet potato morphology

2.1.2 Flowers

Sweet potato flowers grow either in clusters or solitarily in the axils of the leaves (Francesco 2005; Huamán 1992). They are bisexual, and the calyx and corolla contain the stamens and the pistil. Each flower consists of five sepals, five stamens, two carpels and a superior ovary. The ovary consists of two carpels and one locule (Onwueme 1978). The stamens vary in height with respect to the length of the style. The filament is white and hairy. The anther is also white, and contains pollen grains (Belehu 2003).

The ability of the sweet potato to flower under normal conditions in the field differs between cultivars. Colours of the flower bud, pedicel and peduncle vary from green to completely purple (Francesco 2005). Each flower opens during the day and stays fresh for a few hours and wilts in the afternoon. The length for which the flower stays open is determined by weather conditions. If it is cold or cool, the flower stays open for longer (Onwueme 1978).

2.1.3 Fruit and seeds

The sweet potato fruit is a capsule with a spherical shape with a terminal tip (Huamán 1992). Fruits can be smooth or hairy. Seed shapes vary, ranging between rounded, irregular, and slightly angular. The sweet potato seeds are hard and water impermeable, with a size of approximately 3 mm, and mature 30-60 days after anthesis (Huamán 1992).

Onwueme (1978) indicated that growing sweet potato using seeds is possible but has great complications due to its complex quantitative inheritance. Most sweet potato cultivars are self-incompatible but can only grow by scarification through mechanical abrasion or with chemical treatment (Huamán 1999). Chemical treatment may involve treating seeds for about 45 minutes with sulphuric acid (Onwueme 1978). The scarified seeds can germinate within two days of treatment. The plants which are produced from seeds are highly heterozygous and differ genetically from the mother plant. Germination will occur in the epigeal pattern, since the cotyledons will be carried above the soil level. The cotyledons expand, form chlorophyll and later photosynthesise (Onwueme 1978).

2.1.4 Leaves

Leaves are arranged on the stem in a two to five phyllotaxis pattern but vary from cultivar to cultivar. Sweet potato leaves can be rounded, reniform (kidney shaped), cordate (heart-shaped), triangular, hastate, (trilobular and spear-shaped with two basal divergent leaves), lobed, and almost divided (Francesco 2005). Their colour can range from yellowish green to green with purple pigmentation in the lamina. Some cultivars may show purple colour at the early growth stage and change to green at maturity (Huamán 1992).

The petiole of the leaves retains the ability of the leaves to grow either curved or twisted so as to expose the lamina to light. The petiole is thickened at its junction with the stem, and it forms two nectaries at the junction. Sweet potato leaves have stomata on both abaxial and adaxial sides of the leaves. The stomata density varies among cultivars. The high-yielding cultivars tend to have a greater number of stomata on the abaxial surface and less stomata on the adaxial surface than the low yielding cultivars (Onwueme 1978).

The total number of leaves per plant varies from one cultivar to another. The number of leaves ranges from thirty to six hundred. The petiole length also varies widely with genotypes and may range from 9-33 cm. If fertiliser and irrigation application is increased, the number of leaves per plant also increases (Indira and Kabeerathumma 1990; Nair and Nair 1995).

2.1.5 Stems

Sweet potato stems have cylindrical creeping or branching, gnarled stems known as vines (Francesco 2005). Depending on the cultivar, the stem may have different colours, usually either purple or green. The stem growth habit can be erect, semi-erect, or spread on the ground, depending on the cultivar (Huamán 1999). The sweet potato stem length depends on the cultivar, growth pattern, and water availability in the soil. The erect cultivars may grow up to 1 m high and the spreading cultivars can reach up to 8 m long. Stems have nodes and internodes which vary from short to long depending on the stem diameter. They can be thin or very thick (Chua and Kays 1982).

2.1.6 Roots

The sweet potato's entire root system develops from the adventitious roots formed at the slips' nodes and from the cut end of the vine or slip. Adventitious roots develop from adventitious buds or nodes (root primodia) of the underground portion of the sweet potato mother stem cutting that was used as a planting material (Firon et al. 2009). However, the spreading cultivars produce storage roots at some of the nodes that come into contact with the soil (Francesco 2005). Initially, the adventitious roots develop two days after planting, and some of these roots subsequently undergo developmental changes in their growth pattern and develop into storage roots. The number of roots that will become storage roots is determined in the first two weeks after planting (Graves 2013). Villordon et al. (2009) also indicated that the initial stages of adventitious roots' development are important in determining the root sets in sweet potatoes.

When the conditions are conducive, the adventitious roots become storage roots, but if not, adventitious roots become fibrous roots (Du Plooy 1989; Graves 2013). The development of storage roots is initiated between 35 to 60 days after planting, and the weight increases linearly until harvesting (Firon et al. 2009). Adventitious roots undergo an anomalous cambium growth that forms a successful transition into storage roots. This eventually determines yield, but it differs from one cultivar to another (Wilson and Lowe 1973). The number of storage roots is also determined by a number of aspects, such as cutting size, planting depth, soil moisture, and fertiliser application, and pest and disease control. (Villordon et al. 2009).

The formation of storage roots can be in clusters (open or closed clusters) around the stem, and it is determined by the length of root stalk. If the root stalk is long, the cluster will be open, and when the root stalk is short or absent, the cluster will be open (Huamán 1992). The storage roots of the sweet potato have different sizes, shapes, and skin and flesh colours (Villordon et al. 2009). The shape and the size of the sweet potato storage roots vary depending on the cultivar and abiotic and biotic factors. Storage roots can manifest different skin and flesh colour. Sweet potato flesh may also vary in texture, moisture content, and quality (Huamán 1992). The storage roots are an important part of sweet potato production as they have the main function of storage of carbohydrates (Graves 2013).

The storage root yield is dependent on the production of assimilates through a source- sink mechanism (Keutgen et al. 2001). According to Ravi and Saravanan

(2012) yield is not only controlled by source potential but also by sink capacity. Assimilates are accumulated in the predominant sink from the source during storage root formation however, the source itself can be a sink during vegetative crop growth (Vimala et al. 2011a). During the storage root development, the photosynthetic rate and leaf area become the potential source whereas the storage roots and roots' mass weights are the sink capacity (Wilson and Low 1973).

According to Huett and O'Neill (1976) storage root yield is determined by total dry matter partitioning and the efficiency of dry matter allocation to storage roots. These vary widely among the sweet potato cultivars due to cultivar genetic makeup (Ravi and Saravanan (2012) hence there are high, medium or low yielders. Fibrous roots do not have the carbohydrate storage function, but serve to anchor the plant and provide extensive access to soil moisture and mineral reserves. These are formed from five days after planting to twenty-five days after planting of the initial stage and later develop and constitute to the formation of the storage roots (Firon et al. 2009).

Pencil roots in the sweet potato are well-defined adventitious roots emerging from the subterranean node of the cutting. Pencil roots are between 5 and 15 mm in diameter and develop mainly from young, thick adventitious roots when conditions are mostly not conducive for the development of storage roots. Lignification results in the formation of uniform thickening of the whole root (Wilson and Lowe 1973; Belehu and Hammes (2004). Pencil roots have limited carbohydrate storing capacity, because the stele is partially lignified, allowing the secondary lateral thickening (Wilson and Lowe 1973).

2.2 Sweet potato cultivation practices in small holder production

2.2.1 Climatic requirements

2.2.1.1 Rainfall

According to Smith (2006), KZN has a summer rainfall that ranges from 600 mm - 2000 mm per annum. Since sweet potato is a subtropical crop which requires high rainfall, it is generally well adapted to conditions in KZN (Motsa 2014). Although sweet potatoes can survive dry conditions, irrigation may be necessary to achieve higher root yields (DAFF 2011). Laurie and Niederwieser (2004a) reported that a well distributed rainfall of 1000 - 2000 mm per annum is sufficient for cultivation of sweet potatoes. A decrease in storage roots' yield due to water shortages when plants are at bulking stage has been reported by Mohankumar (2000), but Martin (1988) pointed out that heavy rainfall encourages vegetative growth.

2.2.1.2 Temperature

Although sweet potato is a subtropical crop, it can adapt well to temperate climates provided the average temperature does not drop below 20 ºC (Van den Berg and Laurie 2004). Generally, optimum plant establishment and growth can be achieved when temperatures are between 21 ºC and 29 ºC (DAFF 2011; Nedunchezhiyan et al. 2012). Nonetheless, the crop can tolerate high temperatures of up to 35 ºC, but temperatures below 15 ºC retard growth (Laurie and Niederwieser 2004). According to Ramirez (1992), high storage root yield may be achieved when temperatures during the day are between 25 ºC to 30 ºC and at night are between 15 ºC to 20 ºC, while Lebot (2009) reported high storage root weights when plants are grown over a constant soil temperature of 30 ºC combined with 25 ºC at night. Very low

temperatures result in complete vine damage (Mukhopadhyay et al. 2011). According to DAFF (2011) soil temperature influences the formation and development of storage roots.

2.2.1.3 Photoperiod and light intensity

A combination of optimum photoperiod and light intensity plays an important role in plant growth and storage root yield (Nedunchezhiyan et al. 2012). Storage root development and limited vegetative growth is favoured under short days and optimum temperature (Youg 1962). Sufficient light is necessary for plants to grow and plants planted under shade may produce less storage roots (Nedunchezhiyan et al. 2010). Carvalho et al. (2010) indicated that subjecting plants to longer photoperiod conditions resulted in an increased red colour appearance on the leaves compared to those kept under short days which had yellow leaves.

2.2.2 Soil requirements

2.2.2.1 Soil physical properties

Soil structure and texture influence plant growth, storage root development, storage root appearance and quality (Van den Berg and Laurie 2004), however, sweet potatoes can be grown in a wide range of soils usually with low crop production inputs (Ramirez 1992; Laurie 2004). Sandy loam and clayey-loam soils produce good quality sweet potatoes with good physical appearance and size (Laurie 2004), but Hartemink (2003) concluded that sandy loam soils resulted in poor storage root production when nitrogen (N) fertiliser application was delayed. Light loamy soils usually result in roots with better shapes than those grown in heavy clayed soils,

which result in rough, irregular roots. Coarse, deep sandy soils are generally low in fertility, prone to moisture stress and require supplementary irrigation and fertiliser in order to produce a good quality crop (Ramirez 1992). Heavy clayed soils should be avoided as they restrict storage root development due to inadequate supply of oxygen at root level (Lebot 2009). Heavy clay also has poor aeration and creates difficulty in lifting during harvesting (Mukhopadhay et al. 2011). For optimum root yields the soil must be friable, have good internal and superficial drainage and with a rooting depth of more than 25 cm (Ramirez 1992).

2.2.2.2 Soil moisture

Soil moisture has a significant influence on sweet potato establishment, vegetative growth and storage root formation (Lebot 2009). A massive decrease in stem length in sweet potato cultivars deprived of soil water was reported by Van Heerden and Laurie (2008). Plants use a stomatal closure mechanism to avert drought (Lawlor 2002). Although stomatal closure by plants prevents water loss, it also discontinues the photosynthesis process leading to a decrease in the biomass (Chaves et al. 2002, Blum 2009). Too dry soil conditions may result in poor development of storage roots due to an increase in shoot to root dry matter ratio (Ramirez 1992). Sweet potato cultivars respond differently to soil moisture stress due to genetic variations that exist within cultivars (Lebot 2009). High moisture levels in high clayed soils cause high vegetative growth, with little tuberization occurring resulting in a decrease in yield (Chua and Kays 1981; Biswal 2008).

2.2.2.3 Soil pH

For optimal growth sweet potatoes require soil pH between 5.5 and 6.0 (Ramirez 1992; DAFF 2011). However, the crop may also do well at a pH level of 7.0 (Roberts et al. 2014). Soil acidity may be corrected by application of agricultural lime. In order to ensure that soils are properly limed or fertilised a representative soil sample should be collected from the field whenever little is known about that particular field (DAFF 2011).

2.2.2.4 Soil preparation

To ensure optimal storage root and good quality storage root production, the soil must be prepared accordingly. Prior to planting, the soil needs to be pulverized to create a fine and even seedbed and to ensure that the soil layers do not a form a crust that will restrict water and moisture retention (Van den Berg and Laurie 2004). The soil should be ploughed to a depth of 250 mm – 300 mm to ensure optimum root formation. Ridge height and base width will depend on the type of irrigation, implements and tractor wheel to be used (DAFF 2011).

Soil type, structure and management tend to have an effect on the storage root yield and appearance and therefore affect the soil preparation required (Van den Berg and Laurie 2004). In the small scale production sector, due to the shortage of implements, farmers normally use the same implements (plough and ridge) from one area field to another field and that creates problems in terms of weeds transfer. The lack of crop rotation increases disease infection from volunteer plants of the previous cultivations (Smith 2006). According to Van den Berg and Laurie (2004)

fertiliser and lime should form part of soil preparation and should be applied and incorporated into the soil 3-6 days prior to planting in order to improve yields.

2.2.3 Planting material and methods

Sweet potatoes are propagated vegetatively from root sprouts or vine cuttings (DAFF 2011). Propagation using vine cuttings is commonly preferred because vine cuttings are convenient to handle during planting and produce higher root yield compared to sprouts (Beyene et al. 2015). However, a previous study revealed that a major challenge with the use of cut vines is the presence of viral diseases inherited from the previous generations of the sweet potato plant (Ogero et al. 2012). To avoid viral disease spread, ARC-VOP make use of planting material from virus-index nuclear plants to establish mother plants and sell clean planting material to specialised vine growers in all provinces in South Africa (Laurie et al. 2015b).

The best vine cuttings are derived from the apical part of the vine stem as they were reported to produce higher storage root yield (Choudhury et al. 1986). When there are shortages, proper selection of cuttings is often neglected and the middle and basal part of the vine stem may be used (Alcoy et al. 1993). The part where the vine cutting was obtained has a strong influence on growth and yield of the sweet potato plant (Choudhury et al.1986).

2.2.4 Cutting length

Literature revealed that there are conflicting results regarding the optimum length of vine cuttings to be used at planting to achieve higher yields. According to Belehu (2003), the length of the cutting or the number of nodes per vine cutting varies from farmer to farmer depending on location. Onwueme (1978) recommended a 30 cm long vine cutting and that high storage root yield increases as the length of vine cutting increased while shorter cuttings establish slower and resulted in poor yields. Ravindran and Mohankumar (1982) and Bautista and Vega (1991) concluded that 20 cm to 40 cm long vine cuttings should be used to obtain higher yields. Hall (1986) found that 40 cm to 45 cm vine cuttings are associated with high marketable yields, but Belehu (2003) reported no significant differences in total marketable yields when using 20 cm to 30 cm cuttings. In KZN small scale farmers use 30 cm to 40 cm long cuttings with at least 5 - 8 nodes and 2 leaves at the tip of the cutting (Van den Berg and Laurie 2004; DAFF 2011).

2.2.5 Planting method

Sweet potato cuttings are commonly planted using the mounds method, ridge and furrow method or bed/flat method (Low et al. 2009). The land is ploughed and harrowed to a depth of about 20 cm to pulverize the soil (DAFF 2011). Planting on the ridge or mounds permits sufficient drainage, enhances root growth and bulking and facilitates harvesting (Lebot 2009). The mounds planting method traditionally used in Uganda with mounds 100 cm wide and 60 cm tall and in eastern Nigeria mounds may reach the height of up to 1 m with 6-10 vine cuttings planted per mound (Belehu 2003). However, the number of plants planted per hole differs from farmer to farmer depending on the traditional knowledge (Low et al. 2009).

The ridge method is commonly used in South Africa by small scale sweet potato producing farmers (Smith 2006). The cutting is inserted in the tapered triangular hole on the ridge at the depth of 10 - 12 cm depth with 2 leaves exposed above ground (Van den Berg and Laurie 2004), but the disadvantage of this method is the washing away of top soil from the ridge during heavy rains thereby exposing storage roots to excess heat (Onwueme 1978). According to the furrow method, cuttings are planted on flat beds and covered with soil (Lebot 2009).

2.2.6 Depth to which the vine cutting is inserted at planting

Graves (2013) stated that planting depth directly affects yield in sweet potato production. He concluded that planting vines at a depth of 50 cm increases yield in comparison to planting at a depth of 5 cm. Firstly, this phenomenon is due to the fact that deeper planting allows more nodes to be inserted underground, and it thus increases the potential number of storage roots that can be produced from each plant. Secondly, it also provides the vines with a more stable environment with regards to soil temperature and volumetric water content. In comparison, the vines nearer to the soil surface (in shallow conditions) may be highly variable while the deeper planting conditions may be less variable. Thirdly, it also provides the necessary conditions for proper root formation to extract water and nutrients from the soil. Shallow planting depths can have a negative impact on the storage root formation, thus affecting yield (Parwada et al. 2011; Meyers 2013).

Parwada et al. (2011) support Graves (2013) by pointing out that many farmers believe that higher yields in sweet potato production are associated with deep

planting at 50 cm. Gommez (1999) recommends deeper planting or high ridges for maximum yields, as it also prevents waterlogging. Contrary to that, Dhliwayo and Chiunzi (2004) stated that medium planting at 30 cm high ridges are easy to make and may produce good yield as long as the soil is fertile. Van den Berg and Laurie (2004) reported that more storage roots develop from nodes closer to the surface than those in deeper depths.

Generally, sweet potato storage roots initiate from the nodes buried in the soil (Chen et al. 1982). Ravindran and Mohankumar (1985) described planting depth as the number of nodes inserted in the soil at planting, which will later determine initial formation of roots. Initial root formation in sweet potato production is of the utmost importance for optimum yield. It is also evident that the number of nodes plays a significant role in the total marketable root weight on vertical orientation because of differences in the number of nodes inserted in the soil (Wilson 1982).

Meyers (2013) reported that burying more nodes in the ground increases the potential number of storage roots that can be produced from each plant. However, Chen et al. (1982) and Hall (1986; 1987) showed contradicting results. Their results revealed that by increasing the length of the cutting and reducing the number of nodes buried to less than five in the horizontal orientation at planting, yield is increased in some cultivars. Coleman et al. (2005) also concluded that reducing the number of nodes buried to less than three on vertical orientation and planted at a deeper depth increased storage root weight and reduced root yield.

2.2.7 Effect of cutting orientation at planting

Orientation of a cutting at planting in sweet potato production is directly linked to vine length and root orientation, and consequently, root yield (Parwada et al. 2011). Cutting orientation at planting has contributed to yield instability at the small-scale farming level of sweet potato production (Chagonda et al. 2014). However, Van den Berg and Laurie (2004) indicated that the orientation of cuttings at planting has no effect on the number of storage roots. The orientation of cuttings at planting determines the direction of the adventitious roots during root formation (Parwada et al. 2011).

Several studies have been conducted on the effect of orientation of cuttings at planting on the yield in different agro-ecological zones, with varying results (Belehu 2003). Bose et al. (2003); Parwada et al. (2011) and Chagonda et al. (2014) concluded that horizontal orientation resulted in higher yield when compared to vertical orientation. This is, firstly, due to the lateral growth of horizontal roots and a larger area from which to extract water. Secondly, the vine orientation of subterranean nodes which are arranged linearly provides ample space for root storage development. Thirdly, it encourages the formation of storage roots at the end of horizontal vine cutting. They further explain that horizontally-planted cuttings on low ridges are recommended for higher yield. This is in agreement with the results obtained by Allison and Chen (1980), Chen and Allison (1982), Dhliwayo and Chiunzi (2004), Coleman et al. (2005) and Pandey (2007). Chagonda et al. (2014) also pointed out that there is clear improvement in marketable yield when a horizontal planting technique is used compared to a vertical planting technique. This is due to less crowding around the nodes, particularly in hard-setting soils.

However, while a horizontal, flat plan showed promising results as a means of improving yield, the quality of storage roots is compromised as the roots may be exposed to excess heat. This introduces the perspective of quality into discussion in that, although yield can be increased by utilising horizontal orientation, it may result in the quality of storage roots being reduced (Chagonda et al. 2014). However, contradictory studies showing higher yields when cuttings are horizontally orientated, Hall (1986) and Onwueme (1999) concluded that some cultivars yielded higher on vertical orientation than horizontally orientated cuttings. Malcolm (1982) and Laurie (2004) reported no significant differences in yield between plants grown from vertically and horizontally planted cuttings. According to Laurie and Niederwieser (2004a) the orientation of cuttings at planting has no effect on the number of thick roots formed. Burying cuttings vertically in deeper planting depth would result in formation of small size storage roots due to the slow rate of root development (Laurie and Niederwieser 2004)

It was observed that in Kwa-Zulu-Natal, small-scale farmers produce sweet potato using both planting methods, i.e. horizontal orientation and vertical orientation without an angle (Smith 2006). Traditionally, most small-scale farmers prefer to use vine cuttings planted on ridges made with hand hoes or a ridger (Smith 2006). Depending on a farmer's preference and traditional knowledge, cuttings may be planted either vertically at an angle, burying 2/3 of the cutting in the soil, or horizontally with both sides exposed and the middle portion buried in the soil (Ramirez 1992; DAFF 2011; Beyene et al. 2015). However small scale famers in KZN plant sweet potatoes using raised ridges which are about 30 cm high and 40

cm wide at the base (Smith 2006). According to DAFF (2011), cuttings should be planted on top of the ridge vertically at 45º angle with 3-4 nodes buried into the soil.

2.2.8 Planting date and growth period

Determining the suitable planting date in sweet potato production is of utmost importance due to the fact that incorrect planting dates may result in remarkable yield reduction due to climate changes (Lebot 2009) Planting time is mainly affected by climate variability and soil type, market price (Van den Berg and Laurie 2004) and to a lesser extent the availability of planting material. In sub-tropical areas annual planting may be possible as temperatures do not drop below 20 ºC and are frost free (DAFF 2011).

Generally, the sweet potato growth period is 4 - 5 months (Van den Berg and Laurie 2004), however in areas where there are frost occurrences the crop may require up to 6 months. Huett and O'Neil (1976) stated that the crop growth period varies between 12 – 35 weeks with as long as 50 weeks in some cultivars (Huett and O'Neill 1976). Cultivars reach their maximum storage root yield in 12 - 22 weeks after planting (Huett 1976; Nair and Nair 1985; Lebot 2009).

Cooler environments delay the crop from reaching maturity due to slow storage root development (DAFF 2011). Nair (2000) reported that sweet potatoes planted in cool North India become ready for harvesting in 5 - 6 months while those planted in warmer South India reach maturity within 4 months. Harvesting storage roots too early will reduce yield while leaving them for extended periods would result in

unpalatable storage roots and be subjected to weevil attack (Belehu 2003). Maturity of the crop could be indicated by yellowing of leaves or by cutting the storage root. Immature roots readily become dark greenish in colour around the cut strip whereas the mature ones would dry clear and do not turn dark (Woolfe 1992).

Most areas in KZN fall under sub-tropical climate especially those along the coastal areas and sweet potatoes may be planted as a perennial crop (DAFF 2011). However, there are other parts of KZN (Natal midlands areas) where perennial planting is not possible due to frost occurrence during winter months. In frost free areas planting commences from January to March, while in heavy frost occurring areas planting may be delayed to start in mid-November to December (DAFF 2011). In KZN, rainfall and temperature variations are major determinants of planting date (Smith 2006). Motsa (2014) also emphasised that variation in climatic conditions affects the planting date in KZN.

2.2.9 Plant spacing and population

The achievement of high storage root yields in sweet potato production is attributed to best plant establishment per unit area in the field (Singh and Singh 2002). This can be achieved by ensuring the use of correct plant spacing at planting. According to DAFF (2011), plants should be planted and separated by 30 cm intervals from each other with inter row spacing ranging from 1 – 1.5 m. This planting technique will ensure optimum plant population and proper utilization of soil moisture and nutrients by plants (DAFF 2011).

With sweet potato plants, population may vary from 30 000 to 60 000 plants ha^{-1} depending on the market, soil fertility and cultivar (Van den Berg and Laurie 2004). Singh and Singh (2002) reported that yield per plant decreases as plant population per unit area increases. To produce large storage roots, planting densities of 33 000 plants per hectare should be used and if medium storage roots (200 g - 400 g) are targeted, planting densities of 40 000 to 45 000 plants per hectare should be used (Low et al. 2009). Increasing the plant population to 60 000 per hectare will result in small storage root formation (Van den Berg and Laurie 2004). High plant densities increase the amount of dry matter translocation to vegetative growth rather than to storage roots, thus reducing total storage roots yield and root size (Samuel et al. 2004). This is unlike in soybean plants for example, that grows quicker and produce higher yields even when they are closely spaced (Berga and Caeser 1990).

According to Sultana and Siddique (1991) an increase in plant spacing resulted in a reduction in total storage root yield and increase in storage root weight due to larger available soil spaces around the cutting. Studies conducted by Saha and Bahargava (1982); Amato et al. (1992) and Loss et al. (1998) on the effect of high planting densities on growth have reported that an increase in planting densities in sweet potato resulted in a lower number of branches and shortened plant heights due to high competition of the available natural resources such as light and water.

2.2.10 Fertilisation

Generally, sweet potatoes are produced under minimal inputs or infertile soils (Lebot 2009). However, sweet potatoes remove recognisable quantities of plant nutrients hence, an additional amount of fertilisers or organic manures may be recommended at planting in order to maintain soil productivity (Nedunchezhiyan et al. 2012; Roberts at al. 2014). Marginal soils allow the crop to readily produce adventitious roots and settle to develop and expand (Mukhtar et al. 2010), while heavily nitrogen (N) fertilised soils tend to depress storage root production (Nair 2000). This is due to the fact that sweet potato roots are capable of fixing atmospheric nitrogen through symbiotic non-nodulating bacteria in the soil (Hartemink 2003). Nonetheless, high yield may be obtained under soils with balanced soil nutrients therefore soil sampling may be recommended (Lebot 2009).

Small scale farmers often do not use fertilisers when planting sweet potatoes in most developing countries (Belehu 2003). This is due to the fact that fertiliser application encourages weeds to grow faster thus competing with crops and demanding frequent weeding which is time consuming, costly and laborious (Laurie et al. 2015c). Secondly, small scale farmers find it difficult to cover the costs of fertiliser due to the crop sale prices being relatively low (Belehu 2003). In addition, it has been reported that though inorganic fertilisers increase yield, sensory evaluation indicated that taste may be compromised (Ossom et al. 2011).

Generally, sweet potatoes react well to organic matured kraal manure that is applied at a rate of 48 kg ha^{-1}. It can be broadcasted and incorporated prior to

planting however over-application may result in prolonged growth at an expense of storage root growth (Laurie 2004).

Inorganic fertilisers are applied according to what the crop removes from the soil (DAFF 2011). For example, the estimated crop removal in kilograms per hectare (kg ha^{-1}) is about 100 kg nitrogen (N), 90 kg phosphorus (P) and 200 kg potassium (K) (DAFF 2011). All the phosphorus (P) fertilisers may be applied as a basal with half the amount of nitrogen (N) and potassium (K) required at planting. The remaining half of nitrogen and potassium may be applied as a side dressing divided into two growth stages, which is at 4-6 weeks after planting and again at 10-12 weeks after planting (DAFF 2011).

2.2.10.1 Nitrogen

Nitrogen-based fertilisers are associated with high storage root yield (George and Mitra 2001; Satapathy et al. 2005), however high application of N may increase vine growth and depress storage root development (Hartemink 2003). Allemann (2004) indicated that excess application of nitrogen creates undesirable competition in photosynthates between the shoot and the storage roots resulting in storage root yield reduction. A moderate dosage of 50 - 75 kg N ha^{-1} is adequate for optimum storage root production (Nair et al. 1996; Biswal 2008).

Apart from improving storage root yield, nitrogen application may also influence storage root quality characters however; root quality may be improved by using organic sources of nitrogen (Nedunchezhiyan and Ray 2010).

2.2.10.2 Phosphorus

Generally, sweet potato response to phosphorus (P) is low (Nedunchezhiyan et al. 2012). Roberts et al. (2014) reported a significant response of sweet potato to a very low level of applied P of 15 kg ha^{-1} using cultivar 199062.1 and A40 in Dundee, South Africa, while Mohanty et al. (2005); Akinrinde (2006) and Sebastiani et al. (2006) recommended 25- 50 kg P ha^{-1} for optimum yield in various locations in India.

2.2.10.3 Potassium

Like most crops, potassium (K) requirement is higher relative to nitrogen (N) (Belehu 2003) and this is due to the fact that potassium (K) is a key element in the synthesis and translocation of carbohydrates from the shoots to the roots (Byju and Nedunchezhiyan 2004). Biswal (2008) reported that starch and protein content increase with an increase in application of K levels.

Various researchers reported different responses of sweet potatoes to K application in different locations, for example a moderate dose of 75-100 kg K ha^{-1} was reported in India (Nair et al. 1996) while a high dose of 300 kg K ha^{-1} was reported from China (George et al. 2002). Roberts et al. (2014) reported that potassium (K) in KZN may vary from low to high depending on the amount of rainfall occurrence according to the KZN Bio-Resource Group. Most of KZN soils in the Northern part of KZN contain sufficient amounts of K levels that are enough for optimum crop

production. However, if 40 t ha^{-1} yield is targeted, a dose of 200 kg ha^{-1} would be recommended.

2.2.11 Weeding

Sweet potato requires minimum field management (Onwueme 1978) with an exception of weed control (Laurie et al. 2015c). The unfavourable rainy conditions after planting cause weeds to grow faster, competing with the crops, making weed control difficult (Laurie et al. 2015c). Small scale farmers normally use hand hoes or hand picking to remove weeds from a sweet potato field (Onwueme 1999). This manual method is time consuming and requires labour. Depending on the extent of the production lands and the number of people in the household willing to participate during weeding, it may take several weeks to complete (Laurie et al. 2015c).

Weeds have been reported to cause major yield reduction in small scale farming (Harrison and Jackson 2011; Laurie et al. 2015c) with a yield reduction of 20 - 80% reported by Nedunchezhiyan (1996). According to Laurie et al. (2015c), small scale farmers do not have an effective method to control weeds. The mechanical, chemical and biological weed control methods effective and suitable for commercial production are normally difficult to use by small scale farmers (Belehu 2003). The disadvantages of the methods typically used in commercial farming are that they are highly expensive (due to mechanization and chemical costs) and labour intensive (Laurie et al. 2015c).

Alternatively, small scale farmers could use cropping systems (intercropping, crop rotation or relay cropping) and other agronomic practices (mulching, manipulation of plant densities) as weed control measures. Laurie et al. (2015c) reported that newspaper mulch and narrow spacing resulted in high marketable yield and could be used as an effective method for weed control in South Africa. The polythene film mulching method has been reported to produce good quality storage roots and is recommended for small scale farmers in Korea (Jeong 2000). Yamakawa et al. (1997) recommended black plastic film as mulch for small scale farmers in Japan.

In some instances, small scale farmers may use sweet potatoes as an intercrop or rotation crop to suppress weed encroachment (Onwueme 1978). Sweet potato has been reported to eliminate weeds well when it is intercropped with maize or planted after rice (Ravindran et al. 2010). This is due to the fact that sweet potato vines have an ability to grow vigorously and aggressively creating a strong competition for light and water (Ravindran et al. 2010). Harris (1958) showed that sweet potato could be used to control nutsedge grass (Cyperus *rotundus*) in the field.

2.2.12 Harvesting and yield

In sweet potato production harvesting period is determined by variety and environmental factors (Laurie 2004). Sweet potato cultivars differ with growing periods thus reaching maturity at different times (Nair 2000; Laurie 2004). In the small scale sector where production is mainly under rain fed conditions, harvesting is normally delayed when rainfall is delayed. Harvesting in the small scale sector can be done manually using a hand hoe or fork for storage roots and a knife for

vine harvesting (Ramirez 1992). In other countries like Cuba, farmers have been reported to use a mould board plough to uproot and expose the storage roots on the surface and then hand pick them (Ramirez 1992).

Yield in sweet potatoes is represented by the organs harvested that include vines and storage roots (Bhagsari and Ashley 1990). Storage root yield varies with cultivar choice, planting dates, soil conditions and fertility, virus infection and irrigation (Nair 2000; Van den Berg and Laurie 2004). In the small scale farming sector, yield reduction has been reported by many authors in developing countries (Ebregt et al. 2007; Lebot 2009; Laurie et al. 2012). The decline has been mainly due to poor adoption of suitable agronomic practices and the use of poor planting material and to a lesser extent by genetic and environmental factors (Lebot 2009). However, there have been many attempts by breeders and researchers in addressing the major challenges in the small scale farming sector in order to improve yield (Laurie at al. 2004; 2013; 2015a; 2017).

Globally, the average sweet potato yield has been reported to be 13.15 t ha^{-1} with Latin America as the highest producer (Tavva and Nedunchezhiyan 2012). Production on the African continent has shown an annual growth increase of 3.4% (from 1961 - 2010) due to the important role of the sweet potato in the alleviation of Vitamin A deficiency and the average yield has been reported to be 4.4 t ha^{-1} with Nigeria currently being the highest producer on the continent (Tavva and Nedunchezhiyan 2012). In South Africa, yield has been reported to be between 5 -

10 t ha^{-1} in the small scale sector under rain fed conditions (Laurie and Magoro 2008).

Storage root yield can be classified as marketable and non-marketable yield depending on the storage root size, physical appearance, insect and pest infection (Woolfe 1992; Laurie 2004). Storage roots weighing from 100 g – 1200 g are regarded as marketable yield and below 100 g, cracked, rotten, damaged by rodents, insects, animals and harvesting tools or implements, have rough skins, thick veins and sprouting, are classified as non-marketable yield (Laurie 2004; DAFF 2011).

2.3 Importance of the sweet potato

The sweet potato is a storage root crop plant whose large, starchy, sweet-tasting storage roots are important for nutrition in both humans and livestock (Onwueme 1978; Belehu and Hammes 2004; Loebenstein 2009). It ranks second to the potato as both an important root crop and for its economic importance. It is the seventh most important food crop worldwide in terms of production (Woolfe 1992). In Africa, it is an important crop for human consumption and as a cheap source of animal feed. Although the leaves are also edible, the starchy storage roots are by far the most important product. It produces more biomass and nutrient per hectare than any other food crop in the world (Loebenstein 2009).

Due to its high levels of vitamins A and C, iron (Fe), potassium (K), and fibre, and as an excellent precursor of beta carotene, it has been ranked as one of the

healthiest vegetables (Smith et al. 1987; Woolfe 1992). The roots are most frequently boiled, fried or baked in countries like Taiwan, Japan, South America and Sub-Saharan African countries (Smith et al. 1987). The orange-fleshed sweet potato is of exceptional importance in South Africa because Vitamin A deficiency (VAD) is a national public health problem in rural communities, as it is worldwide in developing countries (Laurie 2004). Globally, 127 million children under six years of age are estimated to be affected by VAD (Woolfe 1992). In South Africa, 64% of 1 - 9-year-olds have low vitamin A status and have an intake of less than half the required daily intake for several nutrients (Laurie 2004). In addition, 27% of women at reproductive age have low vitamin A status (Woolfe 1992). The purple-fleshed sweet potato, which contains anthocyanins, primarily peonidins and cyanidins, has important antioxidant and anti-inflammatory properties (Loebenstein 2009).

Sweet potatoes offer the highest solar fixation capacity per unit area of any crop that can be grown in a temperate climate (Woolfe 1992). In addition to being used as a food crop, it can also be used to develop a bio-based source of ethanol production that can be used either separately or as a blend. Sweet potato is also known for its high-grade starch which is suitable for pharmaceutical industries. It can also be used for the production of alcohol or wine. During World War II, sweet potato storage roots were used to produce pharmaceutical products (Yoshimoto et al. 1998). Other industrial uses include the production of starch and industrial alcohol. The accumulated starch and carbohydrates in the storage roots can be digested and converted into ethanol gas and used for energy (Smith et al. 1987).

2.4 Global, national and regional sweet potato production

Currently, the Asian continent produces the bulk of the world sweet potato crop (FAOSTAT 2009). China ranks highest and contributes about 100 million tons to the total world production. Vietnam ranks as the second largest producer, and its production is linked to animal production and the remainder for human consumption (Tavva and Nedunchezhiyan 2012). Sub–Saharan African countries produce more than 7 million tons which is about 13.98% of the world's production annually (Tavva and Nedunchezhiyan 2012). The sweet potato is the seventh largest plant food crop due to its distinct advantages including adaptability to different environmental conditions and nutritional high value (Ray and Ravi 2005; FAOSTAT 2009).

In South Africa, the sweet potato is considered to be a vegetable (Low et al. 2007). Its production represents less than two per cent of the total vegetable production of South Africa. Limpopo, Mpumalanga, KwaZulu-Natal, and the Western Cape are the major sweet potato production areas in South Africa (Laurie 2004). Production occurs at both the commercial and subsistence level. The average commercial sweet potato yield in the highly mechanized sector under irrigation is 50 t ha^{-1} compared to 5 - 10 t ha^{-1} in small-scale farming (Laurie 2004). Sweet potatoes are a popular household food security and traditional crop in rural communities (Low et al. 2007).

In the small-scale sector, the sweet potato is grown by women in small plots in the backyard gardens (Laurie 2004; Niederwieser 2004; Andrade et al. 2009). The most common cultivars of sweet potato produced in commercial production are orange or

copper skinned cultivars with orange flesh, which include Beauregard and Jewel, and white/cream skinned cultivars with white/cream flesh. Cultivar Blesbok is mostly preferred by both commercial and subsistence farmers because it has proven to produce better than cultivars Beauregard and Jewel. It has a good storage life and a relatively short growing period (Laurie 2004). Cultivar Koedoe is also popular with subsistence farmers because of its taste. The cultivars mentioned are also preferred due to their local market demand and also for their adaptation to most soil types (Niederwieser 2004).

Sweet potato production in KwaZulu-Natal occurs at both the small-scale and commercial level. Sweet potatoes are considered as one of the means of improving food security in the rural areas. Production in the small-scale growing sector has declined remarkably over the years, hence the sweet potato in the small-scale sector is known as a poor man's crop, and particularly a women's crop. Therefore, investing in sweet potato production in terms of research has a great potential for improving income and household nutrition and health (Laurie 2004). The decrease in production has been caused by various factors or challenges, ranging from issues of access to finance, use of old landraces, lack of disease-free planting material, pests and diseases, lack of knowledge of good agronomic practices and lack of interest, and lack of cultivars which are more adaptable to the environmental conditions (Laurie and Van den Berg 2002). Whatever the reasons for the decline, it has had a negative impact on the sustainability of the small-scale farmers in sweet potato production in rural areas (Motsa 2014).

Production in the commercial sector has also been unstable in KZN. During the period between 2006 and 2015, the Ethekwini, Ugu and iLembe Districts were the major exporting districts in KwaZulu–Natal (DAFF 2016). In 2008, the Ethekwini (Durban) district was the highest producer, with a total yield of 1 337 26 tons per annum and, as a result, sweet potato export was increased. From 2012 to 2014, sweet potato production in the commercial level has been declining, and as a result, exportation of sweet potato from KZN has ceased and now imports sweet potatoes (DAFF 2016). However, in 2015 sweet potato imports decreased in KZN due to increased production from the EThekwini district (DAFF 2016).

However, the Agricultural Research Council (ARC) has been continuously releasing and introducing new cultivars with an improved genetic makeup to improve yield and has also initiated nurseries in some areas of KwaZulu-Natal to address the above-mentioned issues within the small-scale sector. New nurseries, where new cultivars are multiplied, have been established in the north of KwaZulu-Natal in the Makhathini Flats, Hluhluwe, Ulundi, and Ndwedwe areas. Furthermore, diversified research based on newly released cultivars is continuously conducted by the ARC in other rural areas of KwaZulu-Natal, such as Nongoma and Vulindlela to evaluate the new cultivars' adaptability and yield (Laurie et al. 2015b). The new cultivars have shown that they better address the issue of yield in both small scale and commercial sectors (Laurie and Van den Berg 2002).

Commercial and small scale farmers use the adaptation of a cultivar as a selection trait. The genetic variation among the cultivars determines its adaptability to the

specific area for that particular cultivar. Various new cultivars have been introduced to areas of KwaZulu-Natal, but some cultivars could not adapt to the environmental conditions. Research by Laurie et al. (2015c; 2017) showed that cultivar Ndou, Monate, Blesbok, and 199062.1 were selected for adaptation to the environmental conditions in KZN. The newly released cultivars had been chosen to be distributed to farmers in KZN to address the issue of food insecurity among the resource-poor farmers (Laurie et al. 2015c; 2017). Nonetheless, these new cultivars were introduced by the ARC to small-scale farmers, but they have not been tested in the Verulam area.

CHAPTER 3

EFFECT OF CUTTING ORIENTATION ON GROWTH AND YIELD OF DIFFERENT SWEET POTATO CULTIVARS AT VERULAM, KWAZULU-NATAL

Abstract

A study was conducted to test the effect of 4 sweet potato cultivars (Ndou, Blesbok, Monate and 199062.1) and 2 cutting orientations at planting (horizontal and vertical) on the growth and yield of sweet potato in the Verulam area of northern KwaZulu-Natal, South Africa. The current experiment was laid out in randomized complete block design (RCDB) with 4 replications per treatment over two seasons (2014/2015 and 2015/2016) under rain-fed conditions. Vine length was measured for 5 randomly selected plants per plot at 3, 6, 9 and 12 weeks after planting. At each harvesting event, storage root yield and its components and harvest index (HI) were determined. Cultivars 199062.1 and Blesbok had the highest total storage root, marketable, large storage root size (451 – 1000 g) and ABM yield in season I

and II. Ndou generally had the lowest yield across both seasons, but the longest (significant, p<0.05) vines in season II. Horizontal planting of cuttings yielded significantly (p<0.05) higher than vertical planting in season I in terms of total storage root yield, yet vine lengths were significantly (p<0.05) longer for plants of vertically orientated cuttings in season II.

3.1 Introduction

Sweet potato (*Ipomoea batatas L. (Lam)* is an important food security crop and a popular crop among smallholder farmers in South Africa, especially in KwaZulu-Natal (KZN). It is considered a traditional crop (Laurie and Van Heerden 2012), which was introduced to South Africa in 1952 and has since become indigenised (Schippers 2006). Sweet potato, however, is still being regarded as an underutilised crop in South Africa. Nonetheless, orange fleshed sweet potato (OFSP) is gradually gaining attention, locally and in other developing countries, because of its potential in reducing vitamin A deficiency (VAD) (Laurie and Van Heerden 2012; Agbemafle et al. 2014). Resource poor farmers often regard sweet potato as a hardy, well adapted, multipurpose crop requiring low inputs and also as an energy-rich crop with high nutritional value (Faber et al. 2008). Therefore, sweet potato, particularly orange-fleshed sweet potato (OFSP) has potential to reduce food insecurity and VAD (Wariboko and Ogidi 2014; Birol et al. 2015).

In recognition of the great potential of the sweet potato crop in KZN, an intensified research effort has been made to enhance its production. Since 1959, the Vegetable and Ornamental Plants of the Agricultural Research Council (ARC-VOP) has been releasing improved sweet potato cultivars. To date, approximately 25 cultivars have been released with seven of these currently used in production (Laurie et al. 2013). Of these cultivars, Ndou, Monate and Blesbok were found to be well adapted to the environmental conditions in KZN (Laurie et al. 2015c) as well as cultivar 19962.1 (Laurie et al. 2017). These cultivars are currently disseminated and promoted throughout KZN to small scale famers for production. However, these cultivars were not tested specifically in the Verulam area which is situated north of Durban (eThekwini).

As for any other crop, sweet potato yield is expected to be different among cultivars (Firon et al. 2009; Yuhaya et al. 2015). Yield and yield contributing components are important selection parameters that can serve as indicators of adaptability of the sweet potato and besides, yield is an important agronomic index that shows the adaptability of the cultivar to its growing environment (Bezawit et al. 2015). In addition to cultivar, cutting orientation at planting has also been reported to affect sweet potato yield. Some studies have concluded that horizontal orientation of the cuttings at planting increased yield, relative to vertical orientation (Bose et al. 2003; Parwada et al. 2011; Chagonda et al. 2014). Chagonda et al. (2014), however, pointed out that the quality of the storage roots may be compromised in horizontal orientation. In contrast, Onwuene (1999) showed that some cultivars yielded higher on vertically orientated than horizontally orientated cuttings, while Markos and Loha

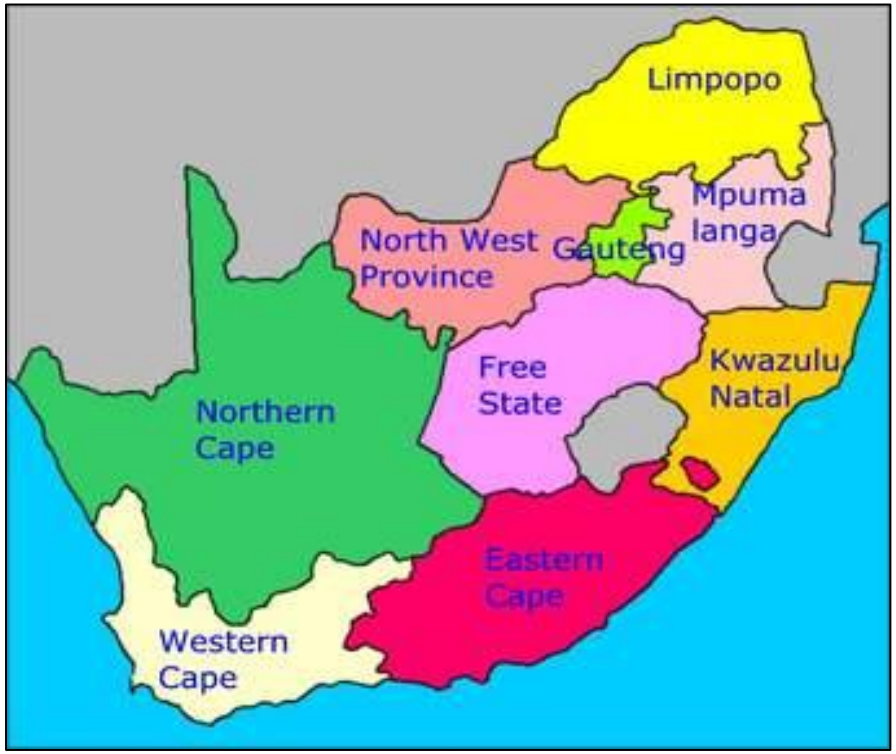
(2016) reported no significant differences in yield between vertically and horizontally planted cuttings.

In Verulam, it was observed that farmers practice both horizontal and vertical orientation of cuttings at planting, yet they could not provide a rationale for the orientation they used. Therefore, a field trial was conducted in Verulam to (i) evaluate the yield performance of different sweet potato cultivars using two planting orientations and (ii) to determine whether there was an interaction between cultivar and planting orientation for sweet potato with respect to growth and yield.

3.2 Materials and Methods

3.2.1 Study site

The field experiment was conducted in the Verulam farming area, situated on the north coast of KwaZulu-Natal. Verulam is located 30 km north of Durban at 29° 37' 45"S and 31°02' 26.5"E (Figure 3.1). Altitude varies from 3 to 661 meters above sea level. Temperature ranges from a minimum of 15 °C to a maximum of 25 °C, with no frost occurrences. The annual rainfall ranges between 850 – 950 mm. The soils are a mix of clay and loam soils, with an effective root depth (ERD) of more than 800 mm. The site is gently sloping with well-drained soil (KZN-BRU 2008). A composite soil sample was collected from the experimental site before the experiment started and analysed for its soil fertility status (Table 3.1). Total rainfall received during the corresponding seasons was obtained from SASRI weatherweb station at South African Sugar Research Institute (SASRI) near Verulam (Table 3.2).



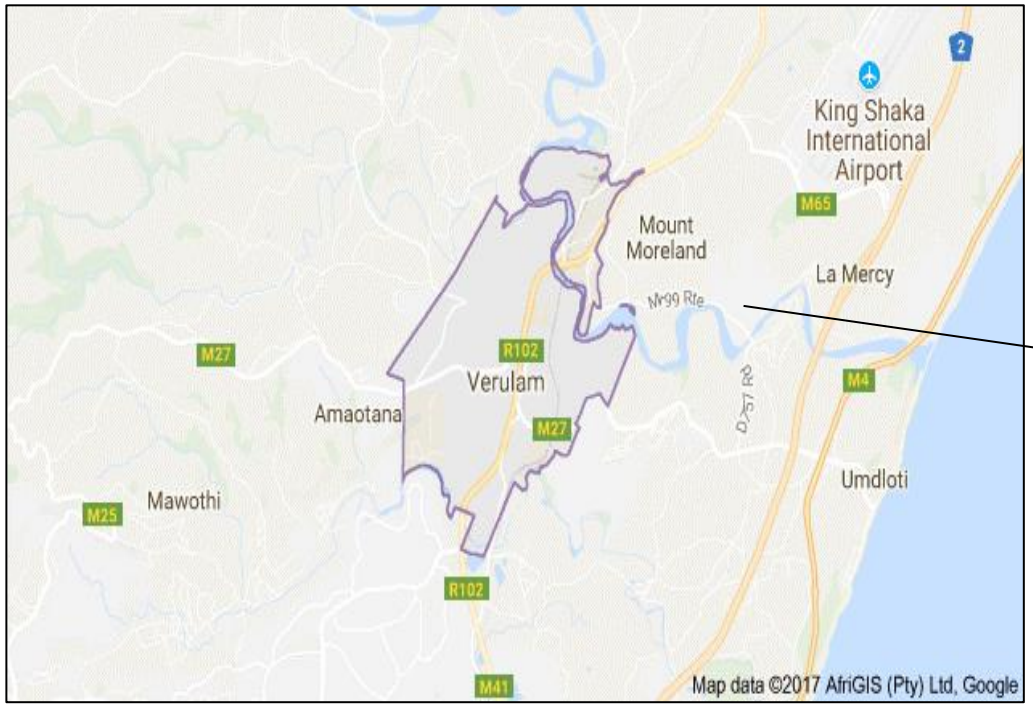


Figure 3.1: Location of the study area (source: www.googlemaps.co.za)

Table 3.1: Physio-chemical properties of the soil sample taken at experimental site in Verulam

Sample Density g/ m L	P mg/L	K mg/L	Ca mg/L	Mg mg/L	Exch*. Acidity cmol/L	Total cations cmol/L	Acid* sat. %	pH (KCl)	Zn mg/L	Mn mg/L	Cu mg/L	Org. C %	N %	Clay %
1.12	181	270	1353	371	0.11	2.81	1	5.83	2.1	12	2.2	< 0.5	0.30	21

*Exch.acidity= Exchange acidity; *Acid sat. = Acid saturation

Table 3.2: Mean and total rainfall and mean temperature during the two planting seasons at Verulam

Season I	**Months**	**Rainfall**	**Min. Temp**	**Max. Temp**
		mm	°C	°C
2014/15	November	59.5	17.4	25.1
	December	79.5	19.4	27.4
	January	99.1	20.3	28.3
	February	116.3	19.2	27.6
	March	82.5	19.2	28.2
	April	30.7	16.2	25.9
	Total	**467.60**	-	-
	Mean	**77.93**	**18.62**	**27.08**
Season II	**Months**	**Rainfall**	**Min. Temp**	**Max. Temp**
		mm	°C	°C
2015/16	December	132.0	20.1	26.0
	January	111.5	20.3	27.9
	February	63.7	20.0	28.4
	March	103.6	19.5	28.7
	April	23.5	17.5	28.2
	Total	**434.3**	-	-
	Mean	**86.86**	**19.48**	**27.84**

Source: South African Sugar Research Institute (SASRI) weatherweb station.

3.2.2 Experimental design and treatments

There were two factors tested in this experiment, that is, cultivar and cutting orientation at planting. Four cultivars were planted in one of two cutting orientations resulting in 8 treatments. The experiment was arranged in a randomised complete block design (RCBD) with four replications of each treatment. The sweet potato cultivars were Ndou, Blesbok, Monate and 199062.1. Cutting orientation at planting was either horizontal or vertical.

Each experimental plot was 4 m x 5 m in size with 5 plant rows in each plot and the rows were 1 m apart. Intra-row spacing was 30 cm giving 17 plants per row and 80 plants per plot. Three inner rows in each plot were harvested discarding two rows as border rows. Each of the three inner rows had 0.5 m discarded at either end resulting in a net plot size of 12 m^2.

3.2.3 Plant material

The plant material (vines) used for the experiment was sourced from a virus-indexed scheme at ARC-VOP at Roodeplaat, Pretoria. Cultivars used for planting included orange fleshed (199062.1), dark and white cream fleshed (Blesbok, Monate and Ndou) sweet potatoes (Table 3.3).

Table 3.3: Description of some of the characteristics of the cultivars used in the study

Cultivar Name	Origin	Skin colour	Flesh colour	Shape	Days to Maturity
Ndou	ARC-Roodeplaat:	Cream	Dark cream sometimes slight orange	Heavy elliptic to long elliptic	4-5 months
Blesbok	1989-ARC-Roodeplaat	Purple	Cream	Cylindrical to long elliptic	4 -5 Months
Monate	ARC-Roodeplaat:	Cream, purple tip	Cream	Round elliptic to long elliptic	4-5 months
199062.1	International Potato Centre (CIP)	Cream, slight orange	Yellow orange	Heavy oblong – Long elliptic	4-5months

Source: Niederwieser (2004)

3.2.4 Crop management

The field was ploughed and disked before planting in order to improve water infiltration and root penetration and ridges 30 cm high and 40 cm wide at base were created. Horizontally planted vines were established by creating a shallow furrow using hand hoes. Vine cuttings were then placed 15 cm below the surface from the top of the ridge with one half (15 cm) of vine protruding from the side of the ridge. The pathway between ridges was wide enough to allow vines from adjacent ridges to protrude without hindering movement between the ridges. For vertical orientation one half (15 cm) of a cutting was placed in the soil with one half protruding at the top of the ridge.

Each cutting consisted of an apical and middle stem portion which had nodes. Cutting establishment was satisfactory such that all plots had the same number of plants. Fertilizer was applied based on the recommendation of Mason et al. (2011) for sweet potato in accordance with the soil fertility status.

According to this recommendation, only nitrogen application was required. Nitrogen (as limestone ammonium nitrate) was applied in two split applications of 50 kg/ha each by hand top dressing at 6 weeks after planting (WAP) and 10 WAP. The experiment was conducted over two seasons with the same fertiliser application rate and method. Planting for the first season (season I) was done on 10 November 2014 and harvesting on 30 April 2015 (5 months and three weeks after planting). For the second season (season II), planting was done on 05 December 2015 and harvesting on 15 April 2016 (4 months and 1 week after planting). Harvesting was done earlier (after 4 months) in season II than in season I, because wild animals started to destroy the crop. However, only the border rows were affected and no

damage was done to the net plots. The experiment was conducted in the open field to simulate typical farmers' practices. The experiment was supplied with supplementary water through sprinkler irrigation after planting to support plant establishment and thereafter plants were grown under rain-fed conditions. Weeding was done biweekly from planting until harvesting.

3.2.5 Data collection and analysis

The length of the longest vine of 5 randomly selected plants per plot were measured using a tape measure at 3, 6, 9 and 12 weeks after planting. At harvesting, storage root yield and aboveground biomass (ABM) were determined from the net plot by weighing their fresh mass. In addition to total root yield, storage roots were categorized as marketable storage root yield (from 100 to 1200 g) (MY) and non-marketable storage root yield (<100 g and >1200 g) (NMY) according to (Van den Berg et al. 2004). Non-marketable yield included storage roots that were damaged or diseased.

Storage roots were also separated according to four yield mass classes including <100 g (small), 101 to 250 g (medium), 251 to 450 g (large) and 451 to 1000 g (extra-large). The storage root mass categories used here were selected based on the observation that farmers in the Verulam area use these sizes when sorting storage roots before selling them. Because the NMY was very similar to the small storage root size class (<100 g), only the NMY was shown and discussed. The total storage root yield and its components harvested from the net plot were extrapolated to t ha^{-1}. Data on harvest index (HI) (ratio of fresh mass of storage roots to aboveground biomass) were also calculated and analysed. Data were subjected to

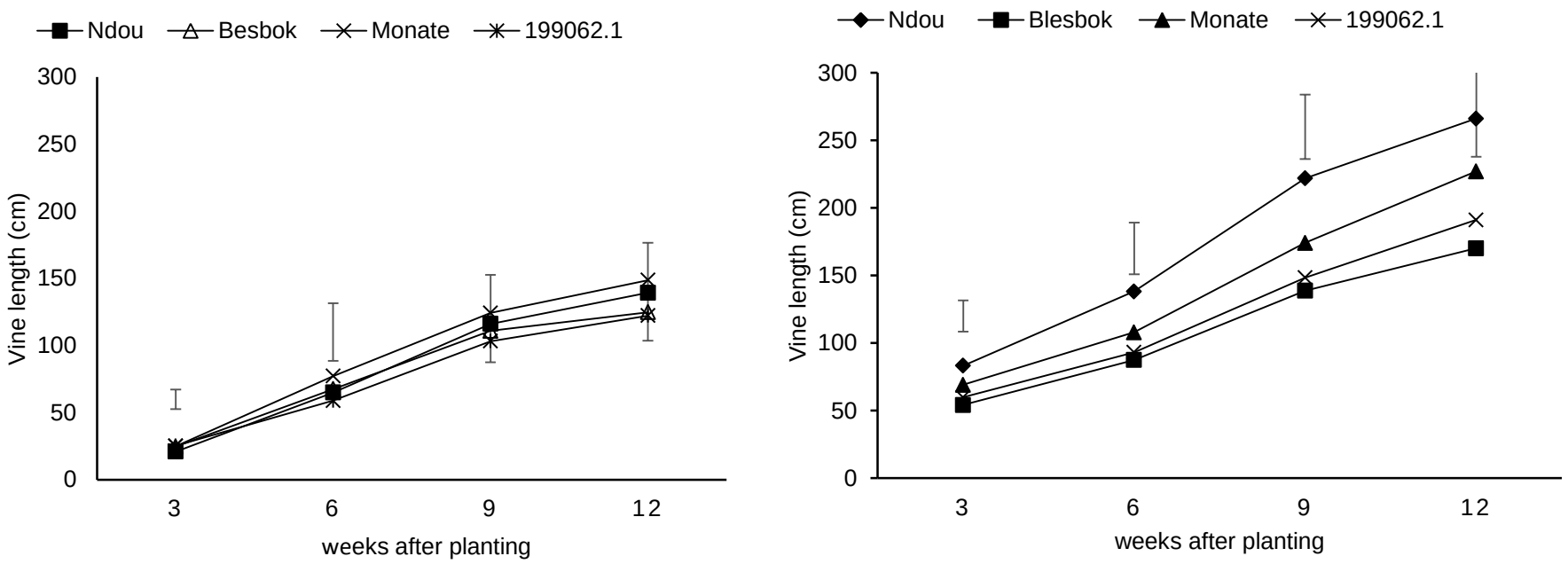
analysis of variance (ANOVA) using Gen Stat 16 software (VSN International 2016) to test for significant treatment effects and where appropriate, the means were separated using Tukey's Honestly Significant Difference (HSD) at 5% significance level.

3.3 Results

There were no significant interactions for cultivar and cutting orientation at planting for any of the parameters measured in this study.

3.3.1 Effect of cultivar on vine length

Vine length increased over time for both season I and II (Figure 3.2). The vine lengths for the evaluated sweet potato cultivars did not differ significantly in season I. Cultivar Monate recorded the longest vine length in season I, followed by cultivar Ndou while the shortest vine lengths were recorded for cultivars Blesbok and 199062.1. In season II, cultivars performed significantly ($p<0.05$) different with regards to vine length, but showed a different trend compared to season I. In season II, cultivar Ndou consistently recorded the longest vine length, followed by cultivars, Monate, 199062.1 and lastly Blesbok. In season I, the vine lengths at the end for measuring period varied from 122 cm to148 cm and in season II from 171 cm to 266 cm.



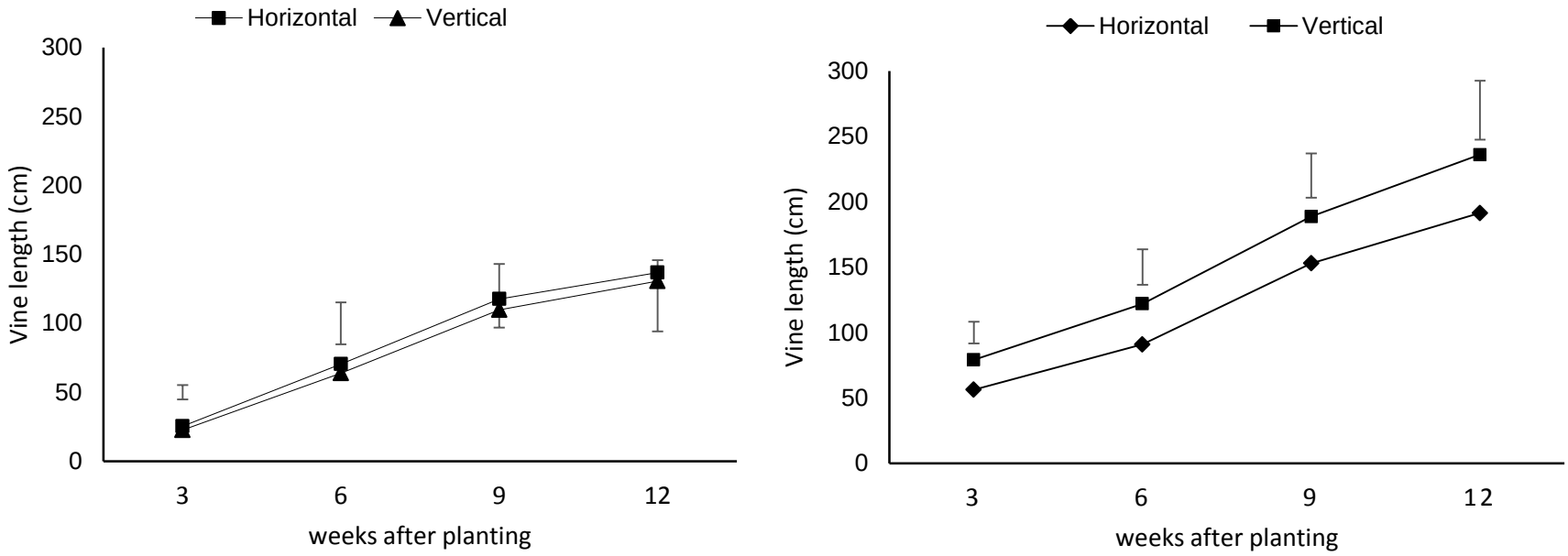
Season I (2014/2015) Season II (2015/2016)

Figure 3.2: Effect of cultivar on vine length of different sweet potato cultivars under dry land conditions over a 12 weeks' period for season I and II. Vertical bars show Lsd at $p<0.05$.

3.3.2 Effect of cutting orientation at planting on vine length

In season I, orientation of cuttings showed no significant effect on vine length of the tested cultivars. However, between the two planting methods used at planting, horizontal orientation of cuttings resulted in consistently longer vine lengths compared to vertical orientation - but only in season I (Figure 3.2). Horizontally planted cuttings produced vines of 137 cm when measured at the end of measuring period, while vertically orientated cuttings produced vines of 130 cm.

For season II a significant ($p<0.05$) effect of cutting orientation on vine length was observed at 3, 6 and 9 WAP (Figure 3.3) with vertically orientated cuttings resulting in longer vines than horizontally orientated cuttings. At 12 WAP the trend was the same, but the difference in vine length was not significant. The vine length at 12 WAP for vertically planted cuttings was 236 cm and horizontally orientated cuttings produced 191 cm.



Season I (2014/2015) Season II (2014/2015)

Figure 3.3: Effect of cutting orientation at planting on vine length of different sweet potato cultivars over a 12-week period for season I and II. Vertical bars show Lsd for $p<0.05$.

3.3.3 Effect of cultivar and cutting orientation at planting on aboveground fresh biomass (ABM)

Cultivar 199062.1 produced a significantly ($p<0.05$) higher (15.2 t ha^{-1}) ABM than cultivar Monate (10.9 t ha^{-1}) in season I, but cultivar Ndou (11.5 t ha^{-1}) and Blesbok (12.8 t ha^{-1}) were not significantly different from each other (Table 3.4). In season II cultivar 199062.1 again had the highest ABM compared to other cultivars, but the differences were not significant. Orientation of the cutting as planting did not have a significant effect on the ABM for either planting season. The ABM for season I for plants grown from horizontally and vertically orientated cuttings for season I was 11.8 and 13.9 t ha^{-1}, respectively, and for season II 17.8 and 17.5 t ha^{-1}, respectively.

3.3.4 Effect of cultivar on storage root yield and harvest index

The marketable storage root yield (MY) differed significantly ($p<0.02$) among cultivars in season I (Table 3.4). The highest MY was produced by cultivar Blesbok (24.0 t ha^{-1}) and 199062.1 (23.7 t ha^{-1}) followed by cultivar Monate (21.3 t ha^{-1}) and lowest was recorded for cultivar Ndou (15.8 t ha^{-1}) (Table 3.4). Cultivar Monate had the highest non-marketable yield (NMY) of 2.2 t ha^{-1} in season I, with cultivar Ndou producing the lowest NMY of 1.6 t ha^{-1}. Other differences in NMY among cultivars were not significant.

In season II the differences in MY and NMY among cultivars were not significant. However, cultivar 199062.1 recorded the highest MY of 7.7 t ha $^{-1}$ while cultivar Ndou had the lowest MY of 4.9 t ha^{-1}. The NMY varied from 1.0 t ha^{-1} (for cultivar 199062.1) to 2.09 t ha^{-1} (for cultivar Blesbok).

Significant ($p<0.05$) differences were observed for the 451 – 1000 g size class in season I, with cultivar Blesbok having a higher storage roots mass than all the other cultivars (13.4 t ha^{-1}), followed by cultivar 199062.1 (11.4 t ha^{-1}) and cultivar Ndou the lowest yield of 7.9 t ha $^{-1}$(Table 3.4). In season II cultivar 199062.1 had a significantly ($p<0.05$) higher yield (3.1 t ha^{-1}) in the 451 – 1000 g size class than all the other cultivars. For the remaining cultivars in this size class in season II the yield varied from 0.9 t ha^{-1} (for cultivar Ndou) to 1.3 t ha^{-1} (for cultivar Blesbok). Differences in root tuber yield in the <100 g, 101 – 250 g and 251 – 1000 g size classes were not significant in season I or II.

In season I, the tested cultivars differed significantly ($p<0.05$) in total storage root yield (Table 3.4). Cultivar 199062.1 was significantly higher (24.8 t ha^{-1}), than Ndou (18.1 t ha^{-1}) and Monate (20.0 t ha^{-1}). In season II, differences in total storage roots yield were not significant, but Ndou again scored the lowest yield (6.6 t ha^{-1}) of all cultivars. There was a decrease in the total storage root yield from season I to season II. For example, in season I the mean total storage roots was 21.1 t ha^{-1}, while in season II it was 7.8 t ha^{-1}. There was also a shift from larger to smaller storage roots size from season I to II for all cultivars (Figure 3.4 and Table 3.4). For example, in season I the small storage roots size (<100 g) accounted for between 5% to 10% of the total storage root mass, while in the second season it increased to between 10% and 30%. (Figure 3.4).

Harvest index (HI) was significantly ($p<0.05$) higher in cultivars Monate (68%) and Blesbok (66%) than in cultivar Ndou (60%) in season I, but differences in HI between 199062.1 and the other cultivars were not significant (Table 3.4). In season II,

differences in HI among cultivars were not significant and ranged from 35% for cultivar Blesbok to 26% for cultivar Monate.

3.3.5 Effect of cutting orientation at planting on storage root yield and harvest index

The two planting orientations (horizontal and vertical orientation) resulted in significant differences ($p<0.05$) in total storage roots yield and marketable yield for planting season I (Table 3.4). Horizontal planting orientation resulted in plants producing higher total storage roots yield (22.7 t ha^{-1}) compared to vertical planting orientation (19.6 t ha^{-1}). For the various storage root size classes, MY and NMY differences among plants grown from horizontally and vertically orientated cuttings were not significant, but were consistently higher for horizontal orientation. Harvest index was significantly ($p<0.05$) higher for horizontal orientation (68%) than for vertical orientation (62%) in season I. Orientation of the cuttings at planting did not have a significant effect on the total storage roots and its components in season II. The HI for both orientations was 29% in season II.

Table 3.4: Effect of cultivar and orientation on aboveground biomass yield (ABM), storage root yield and its attributes and harvest index (HI) of sweet potato at Verulam during season I and II.

	Season I								Season II							
	ABM[2]	MY[3] (101 g – 1000 g)	NMY[4] (<100 g)	101-250 g	251-450 g	451-1000 g	Total yield	HI[5]	ABM[2]	MY[3] (101 g – 1000 g)	NMY[4] (<100 g)	101-250 g	251-450 g	451-1000 g	Total yield	HI[5]
	----------t ha^{-1}----------							%	----------t ha^{-1}----------							%
Cultivar																
Ndou	11.53^{ab}	15.84^{a}	1.63	2.84	5.09	7.91^{a}	18.08^{a}	60.30^{a}	15.94	4.91	1.67	2.09	1.62	1.20^{ab}	6.60	26.20
Blesbok	12.75^{ab}	23.99^{b}	2.24	3.83	6.73	13.42^{b}	21.49^{ab}	66.70^{b}	20.40	6.81	2.09	3.28	2.23	1.30^{ab}	8.91	35.20
Monate	10.85^{a}	21.25^{ab}	2.28	4.19	6.39	10.67^{ab}	20.05^{a}	68.70^{b}	18.49	5.18	1.93	2.51	1.75	0.92^{a}	7.11	26.10
199062.1	15.23^{b}	23.70^{ab}	1.92	4.08	8.21	11.41^{ab}	24.80^{b}	63.20^{ab}	15.71	7.74	1.03	1.74	3.00	3.00^{b}	8.77	29.00
Mean	12.58	21.20		-	-	10.85	21.10	65.00	-	-	-	-	-	1.61	-	-
Significance	p<0.05	p<0.01	ns[1]	ns[1]	ns[1]	p<0.05	p<0.05	p<0.05	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	p<0.05	ns[1]	ns[1]
Lsd	3.03	5.34	-	-	-	3.30	3.79	6.12	-	-	-	-	-	1.39	-	-
Orientation																
Horizontal	11.80	22.82	2.05	4.13	7.14	11.55	22.65^{a}	68.00^{a}	17.82	6.37	1.57	2.81	1.71	1.85	7.94	29.00
Vertical	13.38	19.57	1.98	3.34	6.07	10.16	19.56^{b}	62.00^{b}	17.45	5.95	1.79	2.01	2.59	1.35	7.74	29.00
Mean	-	-	-	-	-	-	21.11	64.00	-	-	-	-	-	-	-	-
Significance	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	p<0.05	p<0.01	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]
Lsd		-	-	-	-	-	2.70	4.33	-		-	-	-	-	-	-

[1]ns = not significant; [2]ABM = aboveground biomass yield; [3]MY = marketable storage root yield; [4]NMY = non-marketable storage root yield; [5] HI = harvest index. Values in the same columns sharing same letters are not significantly different at 5% level of significance .

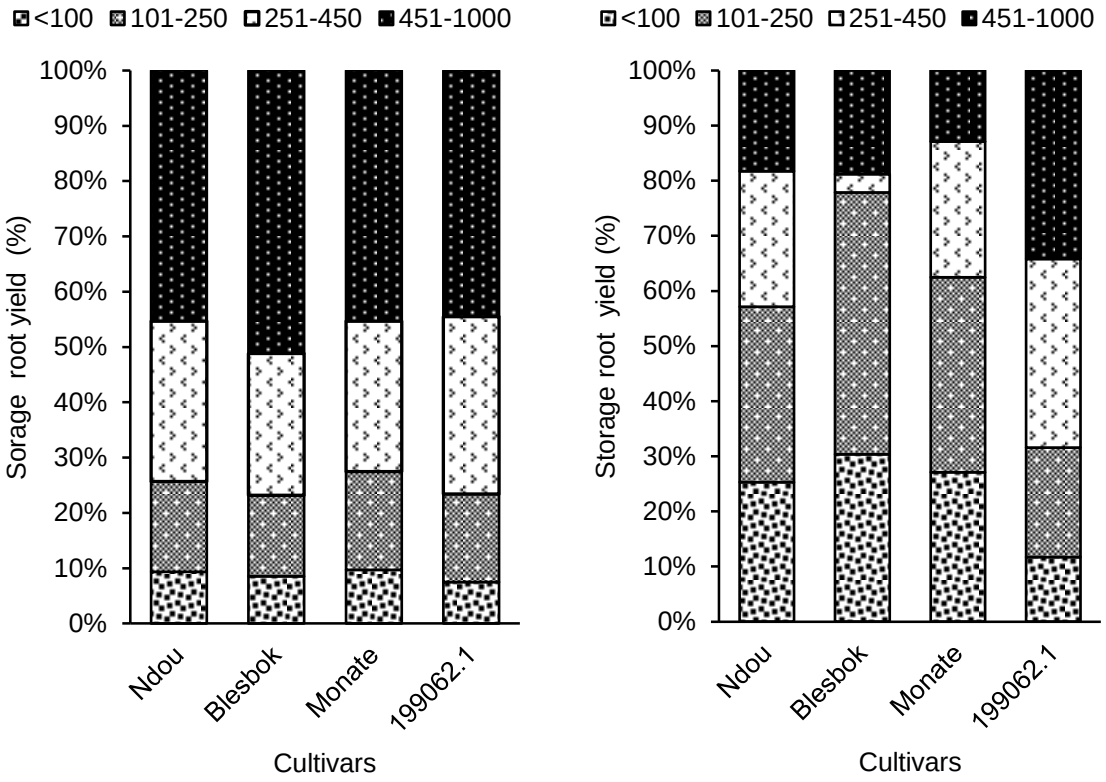


Figure 3.4: Relative proportional contribution of each storage roots size class to total storage root yield of different sweet potato cultivars for two planting seasons**.**

3.4 Discussion

In the current study cultivars were significantly different from each other with regards to vine length in season II, but not in season I. A study by Laurie et al. (2015d) showed significant differences in vine length among cultivars Monate, Ndou and Blesbok when tested in different locations in KwaZulu-Natal. In the current study cultivar Ndou and Monate consistently had the longest vines in both seasons while cultivars 199062.1 and Blesbok had shorter vines (Figure 3.2.) Laurie et al. (2015d) also found in their study that cultivar 199062.1 recorded the shortest vines compared to other cultivars tested in various locations in KwaZulu-Natal. Several studies

concluded that differences in vine length can be attributed to variation in plant establishment after planting which in turn depends on environmental and genetic factors (Belehu and Hammes 2004; Kathabwalika et al. 2013; Laurie et al. 2015d).

The relatively short vines observed in cultivar 199062.1 in the current study could be attributed to its growth pattern. Cultivar 199062.2 is characterized by short thick stems with small leaves and instead of growing as a runner it grows semi-erect and becomes bushy when it has its full cover. Cultivar Blesbok also had relatively short vines in this study which can be attributed to its branching growth pattern which is associated with shorter vines (Laurie 2004). Branching in sweet potato plants is known to increase plant density and decrease stem length due to an increase in competition for irradiance and nutrients (Sasaki 1991; Hamid and Sasaki 2001).

The vines for season II were longer than in season I (Figure 3.2). Ahmed et al. (2012) and Graves (2013) reported that variation in vine lengths among the cultivars was attributed to rainfall variations during the growth seasons in their studies. In the current study it could not be determined if rainfall affected vine length. The total rainfall for season I was higher than season II (467.6 mm and 434.0 m, respectively), but the mean rainfall was lower in season I than in season II (77.9 mm and 86.9 mm, respectively) (Table 3.2). Differences in temperature between the two seasons were also minor and thus not considered a factor, which could have affected growth (Table 3.2).

Several studies showed that planting cuttings in either vertical or horizontal orientation determines the arrangement of nodes and root direction in the soil thereby creating either limited or even space from which water and nutrients could be tapped for photosynthesis, thus reducing or increasing vine growth (Coleman et al. 2005; Parwada et al. 2011; Chagonda et al. 2014). However, it could not be determined from the current study why vertical orientated cuttings resulted in significantly longer vines in season II, but not in season I.

Cultivar 199062.1 had the highest above ground fresh biomass (ABM) of all cultivars for both seasons (Table 4.3). This could be due to the fact that, cultivar 199062.1 has numerous short stems and branches that enables this cultivar to retain more water and remain succulent for longer periods without major defoliation than cultivars with long thin stems (Motsa 2014). Cultivars with a high ABM yield may be used as a cheap source for livestock feed by livestock farmers during drought seasons (Woolfe 1992; Lebot 2009). The fact that cultivar 199062.1 had the highest ABM yield in the current experiment, could thus make it useful as a fodder crop.

Cultivars Blesbok and 199062.1 produced the highest MY in both seasons and cultivars Ndou and Monate recorded lower (Table 3.4). According to Nedunchezhiyan et al. (2012), differences in storage root yield production can be attributed to differences in environmental conditions or genetic makeup. Since environmental conditions for all cultivars are assumed to be similar, the observed differences could be because of genetic differences among cultivars. Cultivar Monate produced the highest NMY of all cultivars in season I due to high production

of undersized storage roots (Table 3.4). This is contrary to Laurie et al. (2017) who found that cultivar Ndou produced the highest MY in some KZN areas compared to cultivars Monate and 199062.1, but supports studies by Laurie et al. (2015c; 2017) where cultivar Ndou produced the highest MY of all tested cultivars in other KZN areas.

There was a reduction in the production of large and extra-large storage roots in season II when roots were harvested earlier than in season I (Table 3.4 and Figure 3.4). As all cultivars used in this study were early maturing cultivars this could be an indication that the early maturing high yielding cultivars need to be harvested within their growth period (4 months) in order to obtain the targeted storage root size (Table 3.3). Motsa (2014) also indicated that techniques such as adjusting planting date, harvesting period and cultivar substituting have been used by farmers in KZN to maximise yield in sweet potatoes. Manipulation of the length of the growing season has successfully been used to control the size of the products of many horticultural crops including fruit and vegetables such as tomatoes, chillies and bell peppers as well as root crops and bulb crops such as carrots and onions (Bañados and Strik 2006). In this study, there may be no bases of comparison of the two planting seasons due to differences in the harvest age of these trials.

It is important to note that the classification of storage root sizes into small, medium, large and extra-large categories used in this study was for marketing purposes in the Verulam context only. In small-scale farming, oversized storage roots are consumed by the farmers themselves and therefore large sized storage roots are still important for food security or they may also be used for making other products such chips or

used in baking. The medium (101-250 g) and large (251-450 g) size storage roots are sold as whole or packed in small packages for income generation.

The total storage root yield revealed significant differences among cultivars for season I, but not for season II. Nonetheless in both seasons, cultivars 199062.1 and Blesbok showed the highest total storage root yield and cultivar Ndou the lowest (Table 3.4). The results concur with those reported by Laurie et al. (2017) where cultivar 199062.1 produced the highest total root yield compared to cultivar Ndou and Monate. Nakatani and Komeichi (1992) postulated that storage root production in sweet potato is dependent on a source-sink relationship. The sink strength differs among sweet potato cultivars resulting in yield variations (Bhagsari and Ashley 1990; Lebot 2009).

Some sweet potato cultivars partition more towards shoot production and others towards storage root production. However, those that partition more towards shoot growth may do so at an expense of storage root development and growth (Laurie et al. 2017). The above statement could have been true in the current study for the two cultivars (Ndou and Monate) that tended to have longer vines, yet produced a relatively low storage root yield. Likewise, cultivars Blesbok and 199062.1 recorded relatively high root storage yield, but had shorter vines. It was possible that for cultivars Ndou and Monate more of their photosynthates were partitioned into shoot production resulting in longer vines, but a lower storage root yield and the opposite for cultivars Blesbok and 199062.1. The observed inverse relationship between vine length and storage root yield was also reported by Parwada et al. (2011) and Kareem (2013). The findings of the current study were contrary to a study by Laurie

et al. (2015c) who reported high storage root yield for cultivars Ndou and Monate than Blesbok when tested in different locations in South Africa including KZN.

For season I, horizontally orientated cuttings produced a significantly ($p<0.05$) higher number of storage roots than plants grown from vertically orientated cuttings, but in season II the difference in total storage root yield did not differ significantly between plants grown from the different orientations (Table 3.4). All of the yield components in season I was also higher for plants grown from horizontally orientated cuttings, even though the differences were not significant. The observed results for season I support several studies where horizontally orientated cuttings produces higher yields than vertically orientated cuttings (Parwada et al. 2011; Chagonda et al. 2014; Markos and Loha 2016). It was reported that horizontally planted cuttings developed adventitious roots at the callus tissues at the cut vine end with ample space for full expansion of roots (Lewthaite and Triggs 2009; Chagonda et al. 2014). Vertically planted cuttings, on the other hand, only formed roots downwards with little space to draw water and nutrients resulting in lower storage root yield (Chagonda et al. 2014).

In season II, there were no significant differences between plants grown from horizontally orientated cuttings and plants grown from vertically orientated cuttings in any of the storage root yield parameters measured and a trend could not be identified. It is not known, why horizontal orientation of cuttings resulted in higher yield in season I, but not in season II. Cultivars Monate and Blesbok had a significantly ($p<0.05$) higher HI than cultivar Ndou in season I, while cultivar 199062.1 did not differ significantly from the other cultivars in HI in season II. It was

noted that although cultivar Ndou had the highest HI, it did not have the highest total root storage yield (Table 3.4). Differences in HI among cultivars in this study were likely linked to genetic differences among cultivars in how they partition photosynthates (Bhagsari and Ashley 1990). Radford (1967), Vimala et al. (2011b) also showed significant differences among cultivars in HI in their studies. In season II, differences in HI among cultivars were not significant. In this study, the HI varied between 26% and 69% and is in agreement with other studies (Huett and O'Neil 1976; Enyi 1977; Kays 1985; Bhagsari and Ashley 1990) where an HI of between 9.5 to 85% when harvesting was done at 12 to 24 weeks after planting was reported. Orientation of the cuttings did not have a significant effect on the HI in the current experiment (Table 3.4).

The HI for season II was lower than for season I, which suggested that partitioning favoured the production of storage roots in season I and of aboveground growth in season II. This observation suggests that the additional 4 weeks of growing time that season II had, resulted in accumulation of more storage roots dry matter resulting in a higher HI. This trend of increasing HI with increasing growing time (season length) was alluded to by Belehu (2003), Huett and O'Neil (1976), Enyi (1977), Kays (1985) and Bhagsari and Ashley (1990).

It is evident from the results in the current study that there were marked differences in the yield performance of each of the cultivars in the two seasons. Each cultivar produced different total tuber yield in both planting seasons. The component and total root yield for season II is on average two and half times less than the yield obtained in the previous planting season I (Table 3.4). The same trend of

observations i.e. markedly lower yields in the second season can also be observed for the marketable and non-marketable yields. Although these yield differences across seasons were evidently significant, they could not be quantified statistically due to the lack of homogeneity of the variances for the two seasons. This lack of homogeneity resulted from harvesting done earlier in season II (12 weeks after planting) as compared to season I (20 weeks after planting). Thus, a combined analysis to reveal season effects, although possible, was not valid.

As already pointed out, the reduction in tuber yield from season I to II was attributed to early harvesting in season II. The early harvesting in season II was necessitated due to wild animals that were starting to destroy the plants. Sweet potatoes require a maximum of 120 - 150 days to reach maturity (Niederwieser, 2004). The plants in season I had enough time to accumulate photosynthates in their storage roots before harvesting which resulted in larger storage roots (Chua and Kays, 1982) compared to the plants of season II which were harvested earlier. This was evident, not only from the reduction in total storage root yield, but also from the shift towards storage roots that were smaller than the marketable size.

3.5 Conclusion

Cultivar 199062.1 outperformed all the cultivars tested in season I, in terms of total storage root yield and ABM yield. Yet, cultivar 199062.1 did not have the highest HI in season I. Cultivar Ndou had the lowest total storage roots (season I and II) marketable yield (season I) and ABM (season I and II), yet it produced the longest vine length in season II compared to the other cultivars. Sweet potato cuttings orientated horizontally at planting resulted in plants with a significantly ($p<0.05$)

higher total root storage yield and HI than cuttings planted vertically in season I, but had the shortest (significant, $p<0.05$) vines in season I at 3, 6 and 9 WAP. Most parameters measured were not significantly affected by cultivar and cutting orientation at planting in season II and there was a lower yield in season II compared to season I.

CHAPTER 4

EFFECT OF DEPTH AND PLANTING ORIENTATION ON THE GROWTH AND YIELD OF SWEET POTATO CULTIVAR BOPHELO UNDER RAIN-FED CONDITIONS AT VERULAM, KWAZULU-NATAL.

Abstract

Information regarding the best sweet potato cutting orientation and planting depth for maximum yield in the Verulam area of northern KZN is lacking. A field experiment was thus conducted to study the effect of cutting planting depth and orientation at planting on sweet potato (cultivar Bophelo) growth and yield in the Verulam area under rain fed conditions. Five planting depths (5 cm, 10 cm, 15 cm, 20 cm and 25 cm) and two planting orientations (horizontal and vertical) were tested in a randomised complete block design (RCBD) with four replications. Data on vine length (at 3, 6, 9 and 12 weeks after planting) and storage root yield and harvest index (HI) were collected over two growth seasons (2014/2015 and 2015/2016). Vine length increased with an increase in planting depth showing significant differences ($p<0.05$) in vine length at 12 weeks after planting (WAP) in growth season II. Although differences in yield-related parameters were not significant among treatments, plants grown from 10 cm deep cuttings and from horizontally orientated

cuttings generally had the highest values of all treatments. The lowest values for yield-related parameters where generally observed in plants from the 20 cm planting depth and vertically orientated cuttings.

4.1 Introduction

Sweet potato is the root crop mostly grown for its storage roots and it is one of the most important starchy crop throughout the tropics (Sharma and Dayal 1990; Laurie 2004; Clarke 2009). It is drought tolerant (Motsa et al. 2015), versatile and one of the 12 principal plant species with highest dry matter content used for human feeding (Ramirez 1992). Sweet potato can be produced under marginal soils with low crop inputs thus making it a cost effective cash crop for small scale farmers in KwaZulu-Natal (KZN) (Domola et al. 2008; Laurie 2010; Motsa 2014). However, lack of appropriate agronomic practices in sweet potato production can affect storage root yield (Lebot 2009).

Small scale farmers in northern KZN are also following different agronomic practices depending on the farmer`s knowledge of sweet potato planting (Motsa 2014). Information on the suitability of cultivation practices of new sweet potato cultivars to different specific environments in KZN is scarce (Motsa 2014). It was observed that sweet potato farmers in the Verulam area use either horizontal or vertical orientation of cuttings at planting and usually bury two thirds of the cutting with leaves in the ridge, however according to DAFF (2011) cuttings should be planted at about 45˚

angle with the ridge, inserting half of the cutting with 3-4 nodes buried into the soil. In view of these varied agronomic practices, an experiment was conducted to i) measure the growth and yield of sweet potato (cultivar Bophelo) of which cuttings were planted at different depths at Verulam and ii) compare the growth and yield of sweet potato (cultivar Bophelo) cuttings planted horizontally and vertically at Verulam.

4.2 Materials and methods

4.2.1 Description of site

As described in Section 3.2.

4.2.2 Treatments and experimental design

The experiment tested 5 planting depths in 2 planting orientations. All cuttings planted in this experiment had a total length of 30 cm, but were inserted into the ridge to different depths. The 2 planting orientations were vertical and horizontal. Each of the 10 treatments was replicated 4 times in a randomised complete block design (RCBD). Plots size and inter- and intra-row spacing were similar to Experiment 1 (Section 3.2.2). For vertical planting, cuttings were inserted and buried at different depths, exposing a portion of a cutting above the soil (Figure 4.1) Cuttings were inserted on top of the ridge using a wooden peg marked with different lengths. For horizontal planting, cuttings were planted by creating a shallow furrow using a hand hoe and cuttings were placed horizontally at different planting depths with two thirds (20 cm) of the cutting buried in the ridge and one third (10 cm) exposed to the side of the ridge.

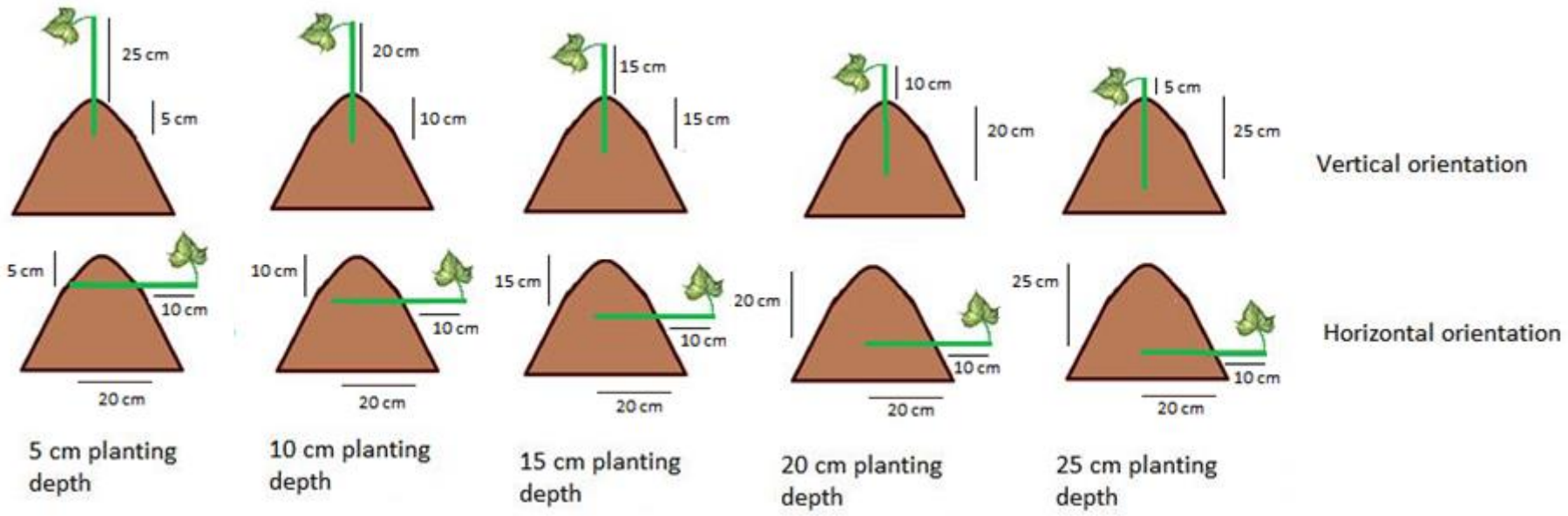


Figure 4.1: Cutting orientation and planting depth treatments tested in the experiment.

4.2.3 Planting material

The experiment was conducted using sweet potato cultivar Bophelo. It was selected because of its dry and sweet taste as well as its popularity among the sweet potato producers in Verulam. Bophelo is described as a high yielding cultivar with a dark orange skin and orange flesh colour. It is an intermediate maturing cultivar with a recommended growing period of 90-150 days (Laurie et al. 2002; 2004). The plant material (vines) used for the experiment was sourced from a virus-indexed scheme at ARC-VOP at Roodeplaat, Pretoria.

4.2.4 Crop management

Soil preparation and experimental management was similar to Experiment 1 (Section 3.2). Experiment 2 was also conducted over two planting seasons. The planting and harvesting dates for season I was 21 November 2014 and 5 May 2015, respectively, which allowed a growth period of 5 months. Planting for season II was on 20 December 2015, but storage roots harvesting could not be done in this season, since the crop was destroyed by wild animals. Only vine length data were recorded in season II. Data on rainfall and temperature during the experiment is shown in Table 3.2.

4.2.5 Data collection and analysis

As in Section 3.2.5

4.3 Results

4.3.1 Effect of cutting planting depth on vine length

For season I, planting depth showed no significant differences in vine length among the planting depth treatments. However, there was an increase in vine length with an increase in planting depth. The final vine length at 12 WAP for the 25 cm treatment was 86 cm and for the 5 cm treatment was 81 cm (Figure 4.2). A similar trend was observed in season II with significant ($p<0.05$) differences in vine length at 12 WAP where the 25 cm treatment recorded vine length of 90 cm and the 5 cm treatment recorded the lowest vine length of 74 cm. As expected, there was an increase in vine length over time for both seasons.

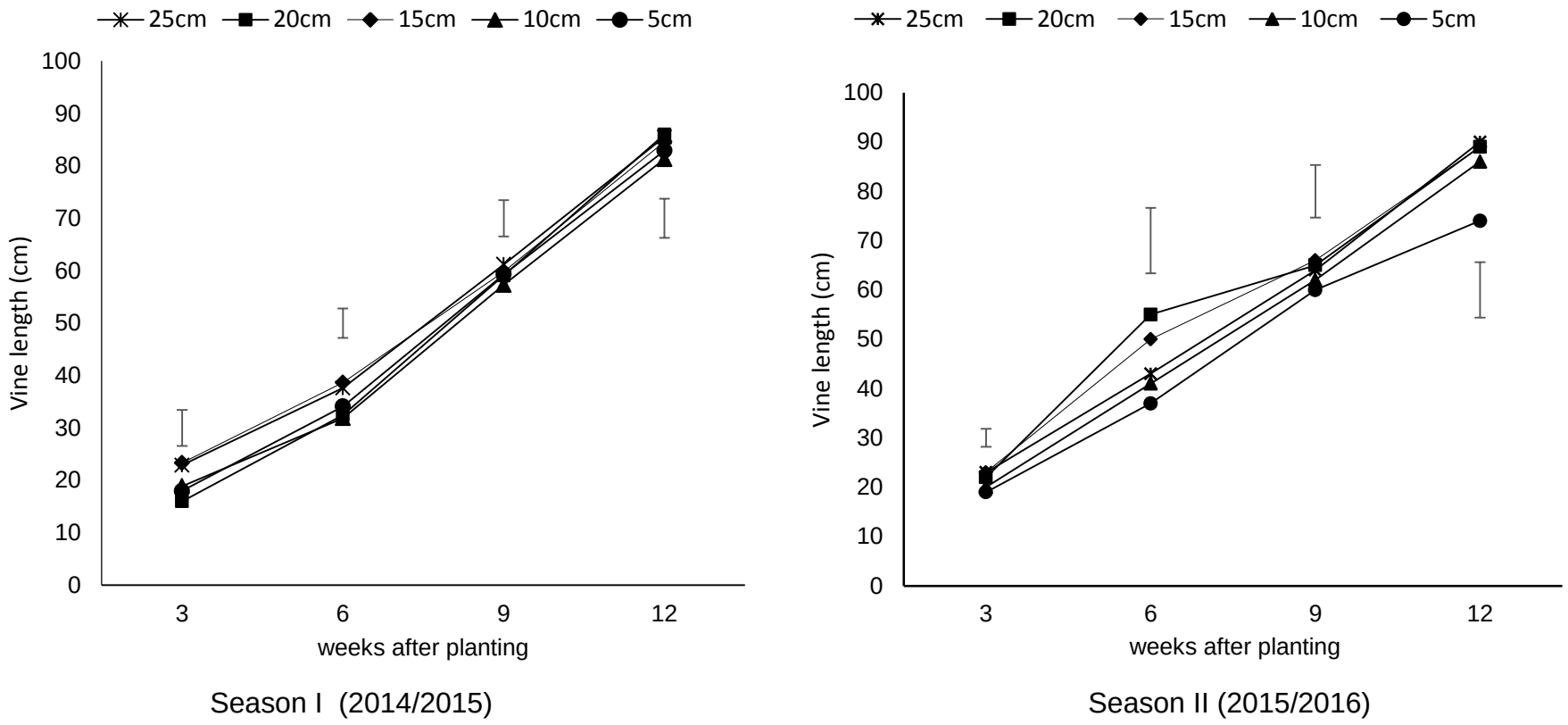
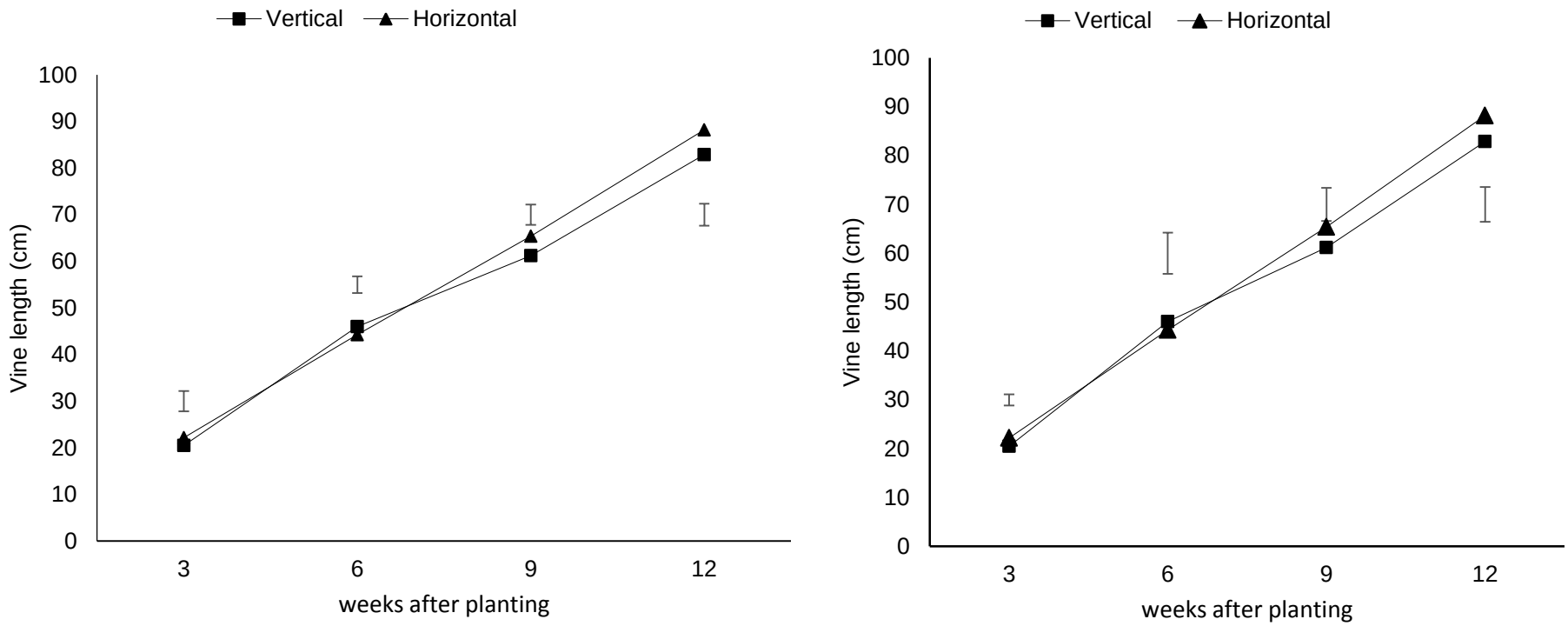


Figure 4.2: Effect of planting depth of cuttings on vine length of sweet potato cultivar Bophelo over a 12 weeks period for season I and II.

4.3.2 Effect of cutting orientation at planting on vine length

The statistical analysis showed that cutting orientation at planting had no significant effect on vine length. It was however observed that vines grown from horizontally orientated cuttings were consistently longer than vines produced from vertically orientated cuttings across both growing seasons (Figure 4.3). The vine length at 12 WAP for season I was 85 cm and 83 cm for plants grown from horizontally orientated and vertically orientated cuttings, respectively, and for season II 88 cm and 83 cm, respectively.



Season I (2014/2015) Season II (2015/2016)

Figure 4.3: Effect of cutting orientation at planting on vine length of sweet potato cultivar Bophelo over a 12 week`s period for season I and II.

4.3.3 Effect of planting depth and cutting orientation at planting on above ground fresh biomass

The planting depth and orientation interacted significantly ($p<0.05$) to influence the above ground biomass (ABM) (Figure 4.4). Horizontal orientation of cuttings resulted in higher ABM yield, irrespective of planting depth, with the exception of the 20 cm planting depth where the ABM was higher for vertical orientation. The highest ABM yield of 12.8 t ha^{-1} was recorded where cuttings were planted horizontally to a depth of 15 cm and the lowest value of 8.8 t ha^{-1} where cuttings were planted vertically to a depth of 15 cm.

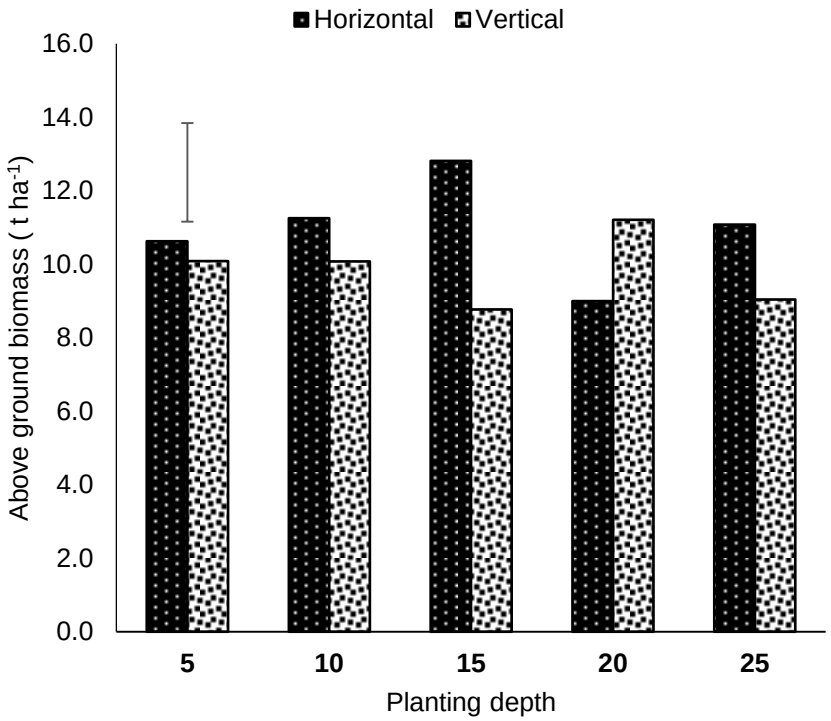


Figure 4.4: Effect of interaction between planting depth and cutting orientation at planting on aboveground biomass (ABM) yield of cultivar Bophelo for season I. Vertical bars show Lsd at $p<0.05$.

4.3.4 Effect of planting depth and cutting orientation at planting on storage root yield and harvest index

Neither total storage root yield nor any of the yield attributes was significantly affected by planting depth, but the general trend was that cuttings planted at 10 cm depth to have the highest values (with the exception of the 251 – 450 g root size class where the highest value was scored at 15 cm planting depth) (Table 4.1). Likewise, the lowest values with regards to storage root yield and its components were recorded for the 20 cm planting depth treatment (with the exception of the 451 – 1000 g size class which scored lowest for the 5 cm planting depth treatment). For example, the total storage root and marketable yield for the 10 cm planting depth were 37.5 t ha^{-1} and 33.5 t ha^{-1} respectively, and for the 20 cm treatment, they were 32.6 t ha^{-1} and 30.1 t ha^{-1}, respectively.

When storage roots were categorized as small, medium, large and extra-large, it was observed that the biggest portion (45% - 50%) of storage roots produced were extra-large storage roots (451 - 1000 g), irrespective of planting depth (Table 4.1 and Figure 4.5). This was followed by large storage roots (25% to 30%), medium size storage roots (9% to 28%) and small storage roots (5% to 12%).

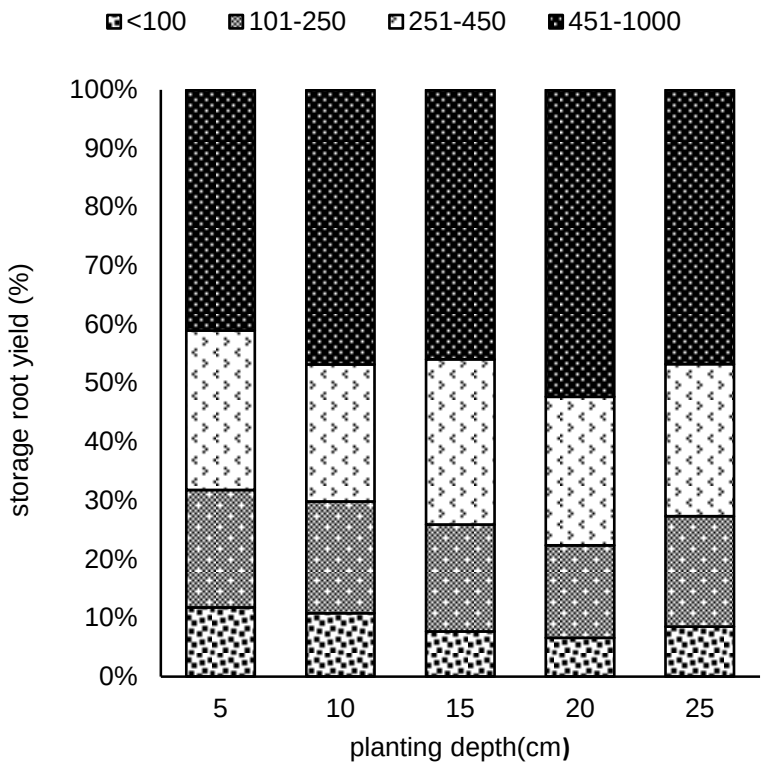


Figure 4.5: Relative proportional contribution of each storage roots size class to total storage root yield of sweet potato cultivar Bophelo as affected by planting depth for season I.

None of the differences in total storage root yield or its attributes was significant between plants grown from vertically and horizontally orientated cuttings (Table 4.1). Storage root yield and its attributes were, however, higher for plants grown from horizontally orientated cuttings than for plants grown from vertically orientated cuttings. The only exception was the 451 – 1000 g size class, where plants grown from horizontally orientated cuttings and vertically orientated cuttings were 16.3 t ha^{-1} and 16.4 t ha^{-1}, respectively. Both orientations produced the highest number of extra-large storage roots and lowest number of small size storage roots (Table 4.1 and Figure 4.6).

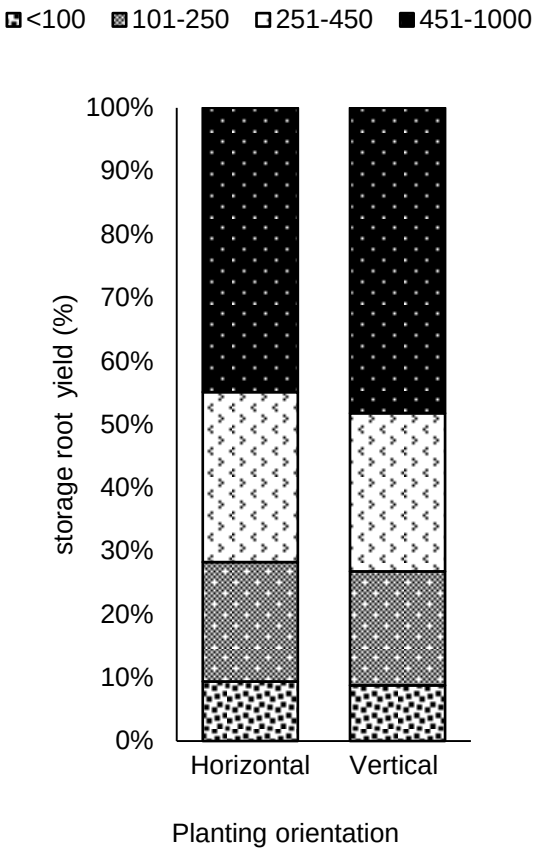


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Figure 4.6 Relative proportional contribution of each storage root size class to total storage root yield of sweet potato cultivar Bophelo as affected by cutting orientation at planting for season I.

Harvest index showed a significant ($p<0.05$) interaction between planting depth and orientation (Figure 4.7). Vertical orientation at 15 and 25 cm planting depth resulted in the highest HI of 79.7% and 82.2%, respectively. The lowest HI of 74.5% was recorded where cuttings were orientated vertically to a depth of 20 cm.

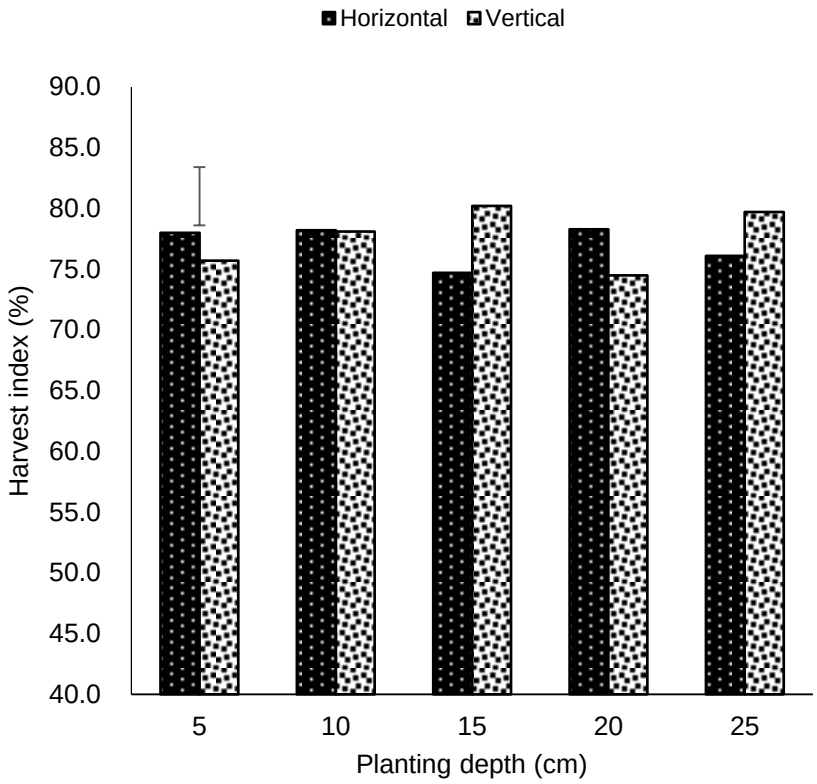

Figure 4.7: Effect of interaction between planting depth and cutting orientation on harvest index (HI) of cultivar Bophelo for season I. Vertical bars show Lsd at $p<0.05$.

Table 4.1: Effect of planting depth and cutting orientation at planting on aboveground biomass (ABM) and storage root yield and its attributes of sweet potato cultivar Bophelo for season I

Treatments	ABM[2]	MY[3] (101-1200g)	NMY[4] (<100g)	101-250 g	251– 450 g	451– 1000 g	Total yield	HI[5] (%)
	---------- t ha [-1] ----------							
5 Planting depths								
5	10.36	30.48	4.04	6.92	9.39	14.17	34.52	76.50
10	10.66	33.47	4.06	7.15	8.75	17.57	37.53	78.20
15	10.10	33.35	2.78	6.58	10.17	16.60	36.13	77.50
20	10.06	30.08	2.13	5.07	8.16	16.85	32.21	76.40
25	10.06	32.58	3.02	6.69	9.24	16.65	35.60	77.90
Significance	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]
Orientation								
Horizontal	10.95	32.87	3.43	6.83	9.75	16.30	36.46	77.10
Vertical	9.84	31.11	2.99	6.14	8.53	16.44	34.07	77.70
Significance	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]	ns[1]

[1]ns=non-significant; [2]ABM=above ground biomass; [3]MY=marketable yield; [4]NMY=non-marketable yield; [5] HI=Harvest Index

4.4 Discussion

Vine length is one of the most important indicators of plant growth in sweet potato production (Somda and Kays 1990; Parwada et al. 2011). Yet, inserting sweet potato cuttings to different depths had no significant effect on vine length in the current study for most measuring events across the two seasons. The only exception was in season II at 12 WAP, where differences among vine length were significant ($p<0.05$) (Figure 4.2). This concurs with Ravindran and Mohankumar (1985) and Beyene et al. (2015) who also did not find a significant effect of planting depth on vine length in their studies. Gommez (1999) reported that early sweet potato vine growth did not differ significantly during early growth stages, but only in the mid and late growth stages, which was also observed in the current study, but only in season II. The results of the current experiment showed that cuttings that were planted deeper resulted in longer vines (Figure 4.2).

The superior vine growth observed at 6 WAP in season II (Figure 4.2) compared to season I could have been attributed to a higher rainfall recorded in season II during this time. In December of season I (when the plants were 6 weeks old), the rainfall was 79.5 mm, while in January of season II (when the plants were also six weeks old), the rainfall was 111.5 mm (Table 3.2) It has been reported that most sweet potato cultivars tend to limit or reduce their vine extension during water stress periods resulting in plants with short vines (Blum 2009). This can be attributed to a decrease in the photosynthetic rate and assimilation mechanism during water stress, resulting in reduced leaf or shoot development which in turn results in short vines (Ravi and Saravanan 2001; Ravi 2003; Cen and Sage 2005).

Several other studies also found a reduction in vine length due to water stress (for example Indira and Kabeerathumma 1988; Farrooq et al. 2009; Jaleel et al. 2009). Horizontally planted cuttings produced longer vines compared to vertically orientated vines in the present experiment, but not significantly so (Figure 4.3). Parwada et al. (2011) postulated that the position of a cut vine at planting determines the direction of adventitious roots which affects the extraction of water and nutrients from soil, and this in turn determines the length of stems and branches per plant. The absence of significant differences for vine length for most measuring events in the current study was probably because, only one cultivar was used or because gaps between the planting depths or levels were too small to see differences (Beyene et al. 2015).

The ABM yield was significantly ($p<0.05$) affected by the interaction between planting depth and cutting orientation at planting (Table 4.1). Horizontally orientated cuttings produced the highest ABM yield, across all planting depths, except at 20 cm planting depth where vertical orientation resulted in a higher ABM yield than horizontal orientation of cuttings. Results obtained in the current study showed that the planting depth of the cutting did not significantly affect the total storage root yield or its attributes. However, the general trend on the 10 cm treatment recording the highest values for all storage root yield-related parameters (including total storage yield, marketable yield, non-marketable, ABM) was observed and for 20 cm planting depth the lowest values (Table 4.1). Van den Berg and Laurie (2004) found that cuttings planted at a depth of 10 - 12 cm result in optimum storage root yield. Yet, Ravindran and Mohankumar (1985) suggested that planting vines at depths ranging from 2.5 – 10.0 cm and orientated vertically had no influence on final storage root yield.

With respect to total storage root yield, the production of high storage roots yields at 10 cm planting depth could be due to sufficient soil nutrients, water and air at this specific planting depth, which favoured the development of more storage roots compared to other planting depths (Ravindran and Mohankumar 1985). According to Lebot (2009), and Rukundo et al. (2013) deeper planting results in a delay in storage roots initiation due to poor stimulation of fibrous roots in deeper depths. The results obtained in the current experiment contradict Graves (2013) who concluded that planting cuttings at deeper depths results in high production of storage roots.

Villordon et al. (2009) also concluded that sweet potato cuttings planted to deeper depths usually delay their establishment after planting. The delay in plant establishment could be ascribed to soil physical factors or assimilate partitioning. If plants delay root formation their developmental growth would also be affected thus affecting assimilates partitioning and consequently lower yields (Du Plooy et al. 1992). However, the low storage root production was observed at a depth of 20 cm, not 25 cm, which was the deepest planting depth in the current experiment (Table 4.1). This observation could not be explained with available data and repeating the same experiment might provide answers to this observation.

Orientation of the cuttings at planting did not have any significant effect on total storage yield, marketable, non-marketable yield, as well different storage root sizes (Table 4.1). Plants grown from horizontal orientation yielded higher than vertically orientated cuttings yet without any significant differences. Hall (1986); Malcom (1982); Belehu (2003), Bose et al. (2003); Laurie 2004; Parwada et al. (2011)

reported no effect of the orientation of the cuttings at planting on storage root yield. However, Allison and Chen (1980), Chen and Allison (1982), Coleman et al. (2005) Pandey (2007) and Nwankwo et al. (2012) reported that plants grown from vertically orientated cuttings yielded higher than horizontally orientated cuttings. The HI was significantly affected by the interaction between planting depth and the orientation of the cuttings at planting, yet a trend could not be identified. It was nonetheless noted that the lowest HI was recorded for vertically orientated cuttings planted to 20 cm depth (Figure 4.7).

4.5 Conclusion

The two factors (planting depth and orientation of the cuttings at planting) did not significantly influence most of the growth and yield parameters measured in this experiment for sweet potato cultivar Bophelo. Vine length increased with an increase in planting depth, but there were no significant differences among the different planting depth treatments except at 12 WAP for season II. There was a general trend of yield-related parameters scoring highest values on total storage roots, marketable, non-marketable yield and ABM when cuttings were planted to 10 cm planting depth and lowest scores for 20 cm planting depth. There was also a trend observed for cutting orientation at planting in that most parameters measured showed higher values for plants grown from horizontally orientated cuttings compared to plants grown from vertically orientated cuttings.

CHAPTER 5

GENERAL CONCLUSION AND RECOMMENDATIONS

Sweet potato (*Ipomoea batatas L. (Lam)* production in KwaZulu-Natal is mainly concentrated in rural communities practiced by small scale farmers on marginal lands (Laurie 2004; Motsa 2014). Recently, the crop has been identified as a means to improve rural economic development, food security and nutrition status (Mabhaudi et al. 2017). However, its production in the smallholder sector has been faced by challenges of improving yield due to poor selection of adaptable cultivars and possibly using inappropriate cultivation practices. The two experiments conducted in this area sought to investigate the effect of cultivar, planting depth and orientation in relation to growth and yield of sweet potato under dryland conditions.

5.1 Effect of cultivar

Vine length was not significantly affected by cultivar in season I, but in season II, cultivar Ndou had the longest (significant, $p<0.05$) vine length compared to other cultivars (Figure 3.2). Differences among cultivars were significant ($p<0.05$) with regards to ABM, the 451 – 1000 g size class and HI and highly significant ($p<0.01$) for MY in season I (Table 3.4). In season II differences among cultivars were significant ($p<0.05$) with regards to the 451 – 1000 g size class. Other differences among cultivars were not significant. There was a tendency for cultivars 199062.1 and Blesbok in season I to score the highest values for all yield-related parameters measured (except for HI) and cultivar Ndou the lowest (Table 3.4). Lebot (2009) concluded from his study that the photosynthate translocation to storage roots differs from one cultivar to another, depending on the sink –source strength relationship of

an individual cultivar and this was the main cause for storage root yield variations observed among sweet potato cultivars in the study. It is hypothesized that the observed differences among cultivars in the current study was also due to genetic differences among them. However, the above mentioned observation was mostly absent in the second season and the reason for this could not be determined. The ABM yield was higher in season II than in season I, but the storage root yield was higher in season I. The reason for these differences was not clear from the study, and could not be explained by differences in rainfall and/or temperature. Although cultivar 199062.1 in particular did well in terms of ABM and storage root yield in the Verulam area in this study, it will have to confirmed by a repeated study in this area before a recommendation can be made to farmers.

5.2 Effect of cutting orientation at planting

Vine length was significantly ($p<0.05$) higher for plants grown from vertical cuttings for most measuring events in season II of Experiment 1 (Figure 3.3). Both the total storage root yield and HI were significantly ($p<0.05$) higher where cuttings were orientated horizontally at planting in season I of Experiment 1 (Table 3.4). In season I of Experiment 1 all storage root yield attributes recorded higher values for horizontal orientation although the differences were not significant. The difference in ABM yield between plants from horizontally and vertically orientated cuttings in season I was also not significant. For season II of Experiment 1, the results were inconsistent and differences between the two orientations were not significant.

In Experiment 2, vine length was consistently higher in cultivar Bophelo grown from horizontally orientated cuttings across both seasons, but not significantly so (Figure 4.3). The ABM yield was also higher for plants grown from horizontally orientated cuttings across all planting depths, except at 20 cm planting depth in season I of Experiment 2. (Table 4.1). Storage root yield and its attributes were generally higher for plants grown from horizontally orientated cuttings in season I of this experiment, but differences were not significant. Data of the effect of orientation on HI were inconsistent and a trend could not be identified.

Some studies have shown higher storage root yields when cuttings were orientated horizontally and it was suggested that this is the result of more space for storage roots to develop and having more access to nutrients and water compared to when cuttings are planted vertically (Belehu 2003; Parwada et al. 2011). This could also have been the case in the current study. Although the results of this study showed a tendency for sweet potato yield to be higher when cuttings are orientated horizontally, it is not sufficient to make a recommendation. More studies will be required to determine the effect of orientation of cuttings at planting on the growth and in particular the storage root yield of sweet potato.

5.3 Effect of planting depth

According to Meyers (2013), one of the major cultivation practices that causes yield variations in sweet potato production is planting depth. The current study showed that planting depth had no significant effect on the growth and yield of sweet potato cultivar Bophelo at Verulam (Table 4.1), except for vine length at 12 WAP for season

II (significant, $p<0.05$). There was a tendency of vine length to increase with an increase in planting depth (Figure 4.2). There was also a tendency for storage root yield to be highest when cuttings were planted to a depth of 10 cm and lowest when planted to a depth of 20 cm (Table 4.1). The reason for this phenomenon needs further investigation. Literature is also unclear on how planting depth affects storage root yield in sweet potato. Graves (2013) reported that deeper planting results in higher yields, due to a more stable environment for roots deeper within the soil profile. Other studies have concluded that shallow planting favours higher yields, because, deeper planting delays root development especially on vertical planting (Laurie and Niederwieser 2004).

The fact that most data in Experiment 2 was only collected over one season was a major drawback in this study, and there is need to repeat this Experiment over more than one season and also for different cultivars to be used. Data collected from such a study could be valuable in understanding the effect of planting depth on growth and yield of sweet potato and to ultimately guide farmers in following the best practice for maximum yield.

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APPENDICES

ANALYSIS OF VARIENCE TABLES

Chapter 3, Experiment I and planting season I (2014/2015)

Table A1: Analysis of variance for vine length at 3 WAP for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	543.7	181.2	0.92	
Rep.*Units* stratum					
Cultivar	3	97.4	32.5	0.16	0.919
Orientation	1	60.2	60.2	0.31	0.587
Cultivar. Orientation	3	248.9	83.0	0.42	0.740
Residual	21	4146.4	197.4		
Total	31	5096.6			

Table A2: Analysis of variance for vine length at 6 WAP for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1841.	614.	0.36	
Rep.*Units* stratum					
Cultivar	3	1396.	465.	0.27	0.845
Orientation	1	358.	358.	0.21	0.652
Cultivar. Orientation	3	1491.	497.	0.29	0.831
Residual	21	35872.	1708.		
Total	31	40957.			

Table A3: Analysis of variance for vine length at 9 WAP for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1243.	414.	0.11	
Rep.*Units* stratum					
Cultivar	3	1878.	626.	0.16	0.922
Orientation	1	502.	502.	0.13	0.724
Cultivar. Orientation	3	5214.	1738.	0.44	0.725
Residual	21	82483.	3928.		
Total	31	91321.			

Table A4: Analysis of variance for vine length at 12 WAP for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1921.	640.	0.13	
Rep.*Units* stratum					
Cultivar	3	3728.	1243.	0.25	0.858
Orientation	1	311.	311.	0.06	0.804
Cultivar. Orientation	3	8398.	2799.	0.57	0.641
Residual	21	103229.	4916.		
Total	31	117587.			

Table A5: Analysis of variance for aboveground biomass (ABM) for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	119597595.	39865865.	4.69	
Rep.*Units* stratum					
Cultivar	3	89016432.	29672144.	3.49	0.034
Orientation	1	20081953.	20081953.	2.36	0.139
Cultivar. Orientation	3	58455148.	19485049.	2.29	0.108
Residual	21	178578655.	8503745.		
Total	31	465729783.			

Table A6: Analysis of variance for marketable storage root yield (MY) (100-1200 g) for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	9.364E+07	3.121E+07	1.18	
Rep.*Units* stratum					
Cultivar	3	3.417E+08	1.139E+08	4.31	0.016
Orientation	1	8.461E+07	8.461E+07	3.21	0.088
Cultivar. Orientation	3	2.078E+07	6.926E+06	0.26	0.852
Residual	21	5.544E+08	2.640E+07		
Total	31	1.095E+09			

Table A7: Analysis of variance for non-marketable storage root yield (NMY) (<100 g) for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1738281.	579427.	1.24	
Rep.*Units* stratum					
Cultivar	3	2210503.	736834.	1.58	0.224
Orientation	1	36675.	36675.	0.08	0.782
Cultivar. Orientation	3	1454210.	484737.	1.04	0.396
Residual	21	9799045.	466621.		
Total	31	15238715.			

Table A8: Analysis of variance for medium size storage roots mass yield (101-250 g) for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	7325148.	2441716.	1.56	
Rep.*Units* stratum					
Cultivar	3	9019418.	3006473.	1.92	0.158
Orientation	1	4987535.	4987535.	3.18	0.089
Cultivar. Orientation	3	3109392.	1036464.	0.66	0.585
Residual	21	32925512.	1567882.		
Total	31	57367005.			

Table A9: Analysis of variance for large size storage roots mass yield (251- 450 g) for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	7583359.	2527786.	0.58	
Rep.*Units* stratum					
Cultivar	3	39463446.	13154482.	3.04	0.051
Orientation	1	9280868.	9280868.	2.15	0.158
Cultivar. Orientation	3	4719253.	1573084.	0.36	0.780
Residual	21	90784453.	4323069.		
Total	31	151831380.			

Table A10: Analysis of variance for extra-large storage root mass yield (451 - 1000 g) for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	122717413.	40905804.	4.04	
Rep.*Units* stratum					
Cultivar	3	124896997.	41632332.	4.11	0.019
Orientation	1	15355035.	15355035.	1.52	0.232
Cultivar. Orientation	3	18945990.	6315330.	0.62	0.608
Residual	21	212642726.	10125844.		
Total	31	494558160.			

Table A11: Analysis of variance for total storage root mass yield for Experiment I and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	5.968E+08	1.989E+08	14.91	
Rep.*Units* stratum					
Cultivar	3	1.924E+08	6.414E+07	4.81	0.011
Orientation	1	7.644E+07	7.644E+07	5.73	0.026
Cultivar. Orientation	3	1.804E+07	6.014E+06	0.45	0.720
Residual	21	2.803E+08	1.335E+07		
Total	31	1.164E+09			

Table A12: Analysis of variance for harvest index (HI) for Experiment and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	264.16	88.05	2.54	
Rep.*Units* stratum					
Cultivar	3	338.41	112.80	3.25	0.042
Orientation	1	336.98	336.98	9.72	0.005
Cultivar. Orientation	3	102.47	34.16	0.99	0.419
Residual	21	728.18	34.68		
Total	31	1770.20			

Chapter 3, Experiment I and planting season II (2015/2016)

Table A13: Analysis of variance for vine length in cm at 3 WAP for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	5023.4	1674.5	3.35	
Rep.*Units* stratum					
Cultivar	3	5413.4	1804.5	3.61	0.030
Orientation	1	4202.2	4202.2	8.40	0.009
Cultivar. Orientation	3	2514.9	838.3	1.68	0.203
Residual	21	10508.7	500.4		
Total	31	27662.5			

Table A14: Analysis of variance for vine length at 6 WAP for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	4523.	1508.	1.11	
Rep.*Units* stratum					
Cultivar	3	12336.	4112.	3.02	0.053
Orientation	1	7492.	7492.	5.50	0.029
Cultivar. Orientation	3	11577.	3859.	2.83	0.063
Residual	21	28596.	1362.		
Total	31	64524.			

Table A15: Analysis of variance for vine length at 9 WAP for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1893.	631.	0.30	
Rep.*Units* stratum					
Cultivar	3	33234.	11078.	5.23	0.007
Orientation	1	10210.	10210.	4.82	0.039
Cultivar. Orientation	3	14016.	4672.	2.21	0.117
Residual	21	44446.	2116.		
Total	31	103800.			

Table A16: Analysis of variance for vine length at 12 WAP for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	3408.	1136.	0.30	
Rep.*Units* stratum					
Cultivar	3	42622.	14207.	3.69	0.028
Orientation	1	15895.	15895.	4.13	0.055
Cultivar. Orientation	3	20406.	6802.	1.77	0.184
Residual	21	80827.	3849.		
Total	31	163158.			

Table 1A17: Analysis of variance for aboveground biomass (ABM) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	109128689.	36376230.	2.46	
Rep.*Units* stratum					
Cultivar	3	119568359.	39856120.	2.70	0.072
Orientation	1	1063368.	1063368.	0.07	0.791
Cultivar. Orientation	3	51559896.	17186632.	1.16	0.348
Residual	21	310504123.	14785911.		
Total	31	591824436.			

Table 1A18: Analysis of variance for marketable storage root yield (MY) (100 g – 1200 g) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	11065649.	3688550.	2.44	
Rep.*Units* stratum					
Cultivar	3	10391736.	3463912.	2.29	0.108
Orientation	1	5007993.	5007993.	3.31	0.083
Cultivar. Orientation	3	156720.	52240.	0.03	0.991
Residual	21	31729263.	1510917.		
Total	31	58351361.			

Table 1A19: Analysis of variance for non-marketable storage root yield (NMY) (<100 g) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	12358670.	4119557.	6.35	
Rep.*Units* stratum					
Cultivar	3	5280545.	1760182.	2.71	0.071
Orientation	1	391981.	391981.	0.60	0.446
Cultivar. Orientation	3	475423.	158474.	0.24	0.864
Residual	21	13622667.	648698.		
Total	31	32129286.			

Table A20: Analysis of variance for medium storage root yield (101- 250 g) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	11027344.	3675781.	2.44	
Rep.*Units* stratum					
Cultivar	3	10420573.	3473524.	2.30	0.107
Orientation	1	5013889.	5013889.	3.32	0.083
Cultivar. Orientation	3	154080.	51360.	0.03	0.991
Residual	21	31696615.	1509363.		
Total	31	58312500.			

Table A21: Analysis of variance for large storage root yield (251-450 g) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	24085232.	8028411.	4.07	
Rep.*Units* stratum					
Cultivar	3	9359104.	3119701.	1.58	0.224
Orientation	1	6308648.	6308648.	3.20	0.088
Cultivar. Orientation	3	4232368.	1410789.	0.71	0.554
Residual	21	41451660.	1973889.		
Total	31	85437012.			

Table A22: Analysis of variance for extra-large storage root yield (451 - 1000 g) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	33132813.	11044271.	6.22	
Rep.*Units* stratum					
Cultivar	3	21410156.	7136719.	4.02	0.021
Orientation	1	2000000.	2000000.	1.13	0.301
Cultivar. Orientation	3	4854601.	1618200.	0.91	0.453
Residual	21	37307292.	1776538.		
Total	31	98704861.			

Table A23: Analysis of variance for total storage root yield for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	172606554.	57535518.	4.82	
Rep.*Units* stratum					
Cultivar	3	36894314.	12298105.	1.03	0.399
Orientation	1	1953.	1953.	0.00	0.990
Cultivar. Orientation	3	11435981.	3811994.	0.32	0.811
Residual	21	250725911.	11939329.		
Total	31	471664714.			

Table A24: Analysis of variance for harvest index (HI) for Experiment I and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1302.84	434.28	4.96	
Rep.*Units* stratum					
Cultivar	3	435.64	145.21	1.66	0.206
Orientation	1	0.45	0.45	0.01	0.944
Cultivar. Orientation	3	37.08	12.36	0.14	0.934
Residual	21	1838.77	87.56		
Total	31	3614.77			

Chapter 4, Experiment II and planting season I (2014/2015)

Table A25: Analysis of variance for vine length at 3 WAP for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	60.00	20.00	0.44	
Rep.*Units* stratum					
Depth	4	303.99	76.00	1.68	0.183
Orientation	1	151.09	151.09	3.34	0.078
Depth. Orientation	4	197.54	49.38	1.09	0.380
Residual	27	1219.68	45.17		
Total	39	1932.29			

Table A26: Analysis of variance for vine length at 6 WAP for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	14.64	4.88	0.16	
Rep.*Units* stratum					
Depth	4	296.50	74.12	2.49	0.067
Orientation	1	49.55	49.55	1.66	0.208
Depth. Orientation	4	66.69	16.67	0.56	0.694
Residual	27	805.28	29.83		
Total	39	1232.66			

Table A27: Analysis of variance for vine length at 9 WAP for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1458.91	486.30	10.75	
Rep.*Units* stratum					
Depth	4	47.64	11.91	0.26	0.899
Orientation	1	89.04	89.04	1.97	0.172
Depth. Orientation	4	355.94	88.98	1.97	0.128
Residual	27	1221.21	45.23		
Total	39	3172.75			

Table A28: Analysis of variance for vine length at 12 WAP for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1418.86	472.95	8.85	
Rep.*Units* stratum					
Depth	4	119.30	29.83	0.56	0.695
Orientation	1	28.53	28.53	0.53	0.471
Depth. Orientation	4	436.23	109.06	2.04	0.117
Residual	27	1443.34	53.46		
Total	39	3446.26			

Table A29: Analysis of variance for above ground biomass (ABM) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	135851866.	45283955.	13.14	
Rep.*Units* stratum					
Depth	4	3420312.	855078.	0.25	0.908
Orientation	1	12422960.	12422960.	3.61	0.068
Depth. Orientation	4	41624132.	10406033.	3.02	0.035
Residual	27	93034852.	3445735.		
Total	39	286354123.			

Table A30: Analysis of variance for marketable storage root yield (MY) (100 – 1200 g) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	75979688.	25326563.	1.79	
Rep.*Units* stratum					
Depth	4	61080556.	15270139.	1.08	0.386
Orientation	1	36258507.	36258507.	2.56	0.121
Depth. Orientation	4	68395139.	17098785.	1.21	0.330
Residual	27	381938715.	14145878.		
Total	39	623652604.			

Table A31: Analysis of variance for non-marketable storage root yield (NMY) (<100 g) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	26704167.	8901389.	1.18	
Rep.*Units* stratum					
Depth	4	50964236.	12741059.	1.69	0.180
Orientation	1	900000.	900000.	0.12	0.732
Depth. Orientation	4	37438542.	9359635.	1.24	0.316
Residual	27	203004167.	7518673.		
Total	39	319011111.			

Table A32: Analysis of variance for medium storage root yield (101-250 g) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	32034722.	10678241.	1.71	
Rep.*Units* stratum					
Depth	4	21376042.	5344010.	0.86	0.502
Orientation	1	4784028.	4784028.	0.77	0.389
Depth. Orientation	4	20672569.	5168142.	0.83	0.518
Residual	27	168329861.	6234439.		
Total	39	247197222.			

Table A33: Analysis of variance for large storage root yield (251-450 g) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	14339410.	4779803.	1.16	
Rep.*Units* stratum					
Depth	4	17952431.	4488108.	1.09	0.380
Orientation	1	14701563.	14701563.	3.58	0.069
Depth. Orientation	4	22089236.	5522309.	1.34	0.279
Residual	27	110894965.	4107221.		
Total	39	179977604.			

Table A34: Analysis of variance for extra-large storage roots yield (451-1000 g) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	75242188.	25080729.	3.17	
Rep.*Units* stratum					
Depth	4	53336111.	13334028.	1.68	0.183
Orientation	1	189062.	189062.	0.02	0.878
Depth. Orientation	4	53134722.	13283681.	1.68	0.184
Residual	27	213901910.	7922293.		
Total	39	395803993.			

Table A35: Analysis of variance for total storage roots yield for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	46990799.	15663600.	0.65	
Rep.*Units* stratum					
Depth	4	108858681.	27214670.	1.13	0.364
Orientation	1	57001562.	57001562.	2.36	0.136
Depth. Orientation	4	75431597.	18857899.	0.78	0.547
Residual	27	651799132.	24140709.		
Total	39	940081771.			

Table A36*:* Analysis of variance for harvest index (HI) for Experiment II and season I

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	321.92	107.31	9.79	
Rep.*Units* stratum					
Depth	4	16.73	4.18	0.38	0.820
Orientation	1	3.47	3.47	0.32	0.578
Depth. Orientation	4	121.82	30.46	2.78	0.047
Residual	27	295.96	10.96		
Total	39	759.90			

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Table A37: Analysis of variance for vine length at 3 WAP for Experiment II and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	118.27	39.42	3.14	
Rep.*Units* stratum					
Depth	4	103.74	25.93	2.06	0.113
Orientation	1	29.93	29.93	2.38	0.134
Depth. Orientation	4	82.62	20.65	1.64	0.192
Residual	27	339.16	12.56		
Total	39	673.71			

Table A38: Analysis of variance for vine length at 6 WAP for Experiment II and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1109.7	369.9	2.20	
Rep.*Units* stratum					
Depth	4	1620.9	405.2	2.41	0.074
Orientation	1	29.9	29.9	0.18	0.677
Depth. Orientation	4	324.6	81.2	0.48	0.749
Residual	27	4545.7	168.4		
Total	39	7630.8			

Table A39: Analysis of variance for vine length at 9 WAP for Experiment II and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	683.4	227.8	2.10	
Rep.*Units* stratum					
Depth	4	209.7	52.4	0.48	0.748
Orientation	1	178.1	178.1	1.64	0.211
Depth. Orientation	4	376.3	94.1	0.87	0.497
Residual	27	2933.8	108.7		
Total	39	4381.3			

Table A40: Analysis of variance for vine length at 12 WAP for Experiment II and season II

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	1506.6	502.2	4.17	
Rep.*Units* stratum					
Depth	4	1395.3	348.8	2.90	0.041
Orientation	1	283.0	283.0	2.35	0.137
Depth. Orientation	4	899.9	225.0	1.87	0.145
Residual	27	3250.9	120.4		
Total	39	7335.7			