RELATIONSHIP BETWEEN VINE PROPAGATION METHOD, AND GROWTH AND YIELD IN SWEETPOTATO [*Ipomoea batatas* (L.) Lam.]

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DECLARATION

I, Mulundu Mwila, hereby declare that 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_____

APPROVAL

This dissertation of Mr Mulundu Mwila was approved as fulfilling part of the requirements of the award of degree of Master of Science in Agronomy by the University of Zambia.

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ABSTRACT

Timely availability of high volumes of good quality planting materials is a challenge especially for crops propagated by vegetative means such as sweetpotato [*Ipomoea batatas* (L.) Lam.]. Zambian growers rely on volunteer plant sprouts to generate vines. Recently the use of root sprouts has been promoted. Past studies have shown the wide influence of method of propagation of sweetpotato planting materials on growth and yield. The objective of this study was to investigate the effect of propagation method on the development and yield of sweetpotato. This study evaluated the physiological performance of the crop propagated by vines from either volunteer plants or storage roots. Varietal effects, as well as propagation method by variety interaction effects were investigated. Four varieties were used; Orange Chingovwa, Chingovwa, Olympia and Zambezi. This was a factorial experiment arranged in a Randomized Complete Block Design (RCBD) with four replications. The experiment was conducted at Kaithinde agricultural camp of Lundazi district of eastern Zambia. Specific Leaf Area (SLA), Leaf Area (LA), Leaf Area Ratio (LAR), Leaf Area Index (LAI), Vine Length (VL), Storage root diameter (RD) and length (RL) and the root/ shoot ratios (RSRs) were determined. Root yield at full maturity was also measured. There were no differences in establishment rates between methods probably because plants were grown under optimal conditions. There were significant differences in LA, LAI and the VL between propagation methods in the early growth phase ($p \leq 0.05$). During this phase the LA was higher in plants grown from volunteer sprouts (0.27 m^2) in comparison to the root sprouts' treatments (0.21 m^2). The differences in LA in the early phase may have been due to varying pre-planting shocks experienced by the vines from the two methods. Volunteer sprouts' treatment also had higher VL (222.90 cm) compared to the root sprouts treatment (154.00 cm) during this phase probably due to differing pre-planting shocks experienced by the vines from the two methods. Both LA and VL were not different between propagation methods in the latter two phases of growth evaluated ($p \leq 0.05$). Total storage root yield per plant (0.67 kg for root sprouts' and 0.71 kg for volunteer sprouts' respectively) was not influenced by propagation method ($P \leq 0.05$). This study concluded that propagation method does not affect the development and yield of sweetpotato ($p \leq 0.05$). Some studies suggest that differences may occur if the volunteer sprouts are compared with sprouts generated under optimal conditions.

DEDICATION

To my wife Namonda for carrying our family's responsibilities during my absence, our son David whose infancy I missed as a result of the pursuit of this MSc. study programme, and mum and dad.

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CHAPTER 1

1. INTRODUCTION

Sweetpotato [*Ipomoea batatas* (L.) Lam.] is an important crop with varied and extensive consumption among a significant portion of the world's population. It's prominence among the major crops of the world is highly and widely recognised; it is an important food crop for humans and animals due to its desirable starch, sugar, protein and vitamins content (Ozturk *et al*, 2012). It is also a valuable source of industrial raw material (Jarret and Florkowski, 1990; Far, 2007). The crop is considered the seventh most important food crop in the world and is ranked fourth in developing countries (FAO, 1997; Far, 2007). It is cultivated in more than 100 tropical and subtropical countries (Horton, 1987; Far, 2007). In 2010 it was estimated that the world annual sweetpotato production was about 106 million tons (Ozturk *et al*., 2012).

In spite of the relative importance and potential for increased production, sweetpotato is constrained by a number of factors. Pests, diseases and unfavourable environmental conditions prevent the crop from reaching its maximum utilization in the agricultural sector (Far, 2007). The propagation phase in sweetpotato production is a subject recognized as important in increasing sweetpotato productivity and use. Accordingly, propagation and transplanting are phases in sweetpotato production that are recognized for further research (Jones 1992; Fukazawa 1998; Lewthwaite, 2004).

According to Serenje & Mwala, (2010) sweetpotato is one of the most important sources of carbohydrates for small-scale farmers in Zambia and ranks second only to Cassava. Its production in the country has grown over the years. Recently, its nutritional significance has increased along with its role as a key source of income for small-scale farmers. This is especially true for those farmers with access to major highways or those able to transport the produce to formal markets for sale. Consequently there has been an increase in the number of farmers growing sweetpotato exacerbating the low supply of planting materials. Ndiyoi *et al.*, (2007) recognized the need to establish a more efficient and cost effective multiplication and distribution system for root and tuber crops planting materials in order to effectively

address periodic food deficiencies in the drought prone areas of Zambia by crop diversification.

While sweetpotato is conventionally propagated from stem cuttings/ vines from mature plants, other options abound such as the use of root sprouts. The sweetpotato plant is generally propagated as a cutting rather than a seedling (Weaver and Bruner 1927; Coleman 1972; Lewthwaite, 2004). Due to the fact that the crop is propagated through vegetative means one key challenge is storage of the bulky and largely perishable material (Setimela *et al*., 2004). One common method for the conservation of sweetpotato planting materials among small scale farmers in the Eastern Province of Zambia is the use of sprouts from volunteer plants left in the field from the previous harvest. The roots are traditionally harvested in piecemeal fashion leaving the mother plant with an established storage root or roots intact underground in the field. With the on-set of the rainy season, these volunteer plant sprouts provide the farmer with start-up seed for the following growing season. No additional water is supplied with this practice which for this study, is referred to as the "volunteer sprouts method".

Increasingly, efforts in some parts of the world, such as East Africa, have invested in alternative methods of sweetpotato propagation with particular interest in establishing planting material from storage root sprouts. In this method, the "root sprouts method", sweetpotato storage roots are stored in containers of dry sand under a shelter, and are later planted out and watered to encourage early sprouting (Gibson *et al*., 2011). This method also known as the "Triple S" method allows farmers to access planting material at the start of the season (Gibson *et al*., 2011) and presents a practical alternative for accelerating the availability of sweetpotato planting material among farmers.

Earlier research has shown that the method of sweetpotato vine generation has an influence on the storage root yields of subsequent populations of the crop. One of the major factors for rapid plant formation and early formation of its thick roots in sweetpotato is the method of propagation (Novak *et al*., 2007). Wide variability in storage root yield among sweetpotato cultivars and individual plants of the same cultivar has been attributed to propagation material (Lowe and Wilson 1975; Belehu, 2001). Plant field establishment represents the interaction of both propagation and

growth phases of storage root production and variations in crop performance may also be due to the nature of the transplant and its vulnerability at establishment (Lewthwaite, 2004). Lewthwaite (2004) showed that by using appropriate propagation material and techniques, significant gains may be made in early plant establishment. The yield potential of sweetpotato may be further increased by introducing new technologies or production methods (Islam *et al.,* 2002).

Insufficient high quality planting materials for sweetpotato is a serious, recognised challenge. Small-scale farmers have traditionally used the volunteer sprouts method. There is a recently introduced option of the use of the root sprouts method. While farmers have relied on the volunteer sprouts method for many years, there is no information on the effect of root sprouts method on the growth and yield of sweetpotato in Zambia. It is expected that information from this study, ultimately would assist in improving access and timely delivery of high quality planting material especially to the rural poor.

1.1 Objectives

The objective of this study was to investigate the effect of propagation method on the development and yield of the sweetpotato plant.

1.1.1 Specific Objectives

Specifically, the study aimed to:

- Compare the development of sweetpotato grown from volunteer sprouts versus those grown from root sprouts.
- Evaluate the development and yield of different sweetpotato varieties propagated by the two methods.
- Investigate the propagation method by variety interaction effects on sweetpotato development and yield traits.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Origin of sweetpotato

The sweetpotato is an ancient crop developed within the prehistoric civilisations of Central and South America with early cultivation beginning about 3000 B.C (O'Brien 1972; Lewthwaite, 2004). Results of a recent study (Roullier *et al.*, 2011; Wennekes *et al*., 2013) consolidate this suggestion that at least two domestications occurred, one in Caribbean/Central America, and one in north-western South America, giving rise to two domesticated gene pools (the Northern and Southern ones). By 2500 to 2000 B.C. the crop was widely grown in Peru and Mexico (O'Brien, 1972; Lewthwaite, 2004). The contemporary version of the crop is grown throughout the tropical and subtropical regions of the globe, across cultures and continents (Huaccho and Hijmans 2000; Lewthwaite, 2004), although as hinted the origins of its domestication remain unclear (Wennekes *et al*, 2013).

2.2 Sweetpotato Morphology/ anatomy

The sweetpotato plant is primarily made up of the apical shoot, leaves, flower, fruits, nodes, internodes, main stem, secondary stem, pencil roots, fibrous roots and the storage roots (Huaman, 1992). Characteristic of the growth of the plant is a predominantly prostrate vine system that can either be erect or spreading (Huaman, 1992). It has a vine system that expands rapidly and horizontally along the ground which although mainly prostrate in its growth habit, varies from erect and semi-erect to spreading (Rossel *et al*., 2000).

The plant's root system primarily is composed of fibrous roots that absorb nutrients, water and anchor the plant (Huaman, 1992). As the plants mature some roots that have some lignification are produced, the pencil roots, while others have no lignification, are fleshy and thicken a lot (Huaman, 1992). These are the storage roots that store products of photosynthesis (Huaman, 1992). The storage root comprises the proximal end that joins it to the stem, the central part which is more expanded and the distal end that is opposite to the root stalk (Huaman, 1992). The adventitious buds located in the central and distal parts usually sprout later than those located in the proximal end (Huaman, 1992). The transverse section of a storage root will

characteristically show the periderm or skin, the cortex or cortical parenchyma whose thickness may vary depending on cultivar, the cambium ring where the latex vessels are found, and the medulla or central parenchyma (Huaman, 1992). The stem, whose colour may vary depending on cultivar from green to red-purple (pigmented with anthocyanins) is cylindrical and maybe 1 metre to 5 metres long depending on cultivar (Huaman, 1992). The hairiness in the apical shoots, and in some cultivars in the stems as well varies from glabrous (without hairs) to very pubescent (Huaman, 1992).

2.3 Sweetpotato growth, development and yield

Three growth phases are identified for the sweetpotato plant. The first phase is characterized by slow vine growth and rapid growth of adventitious roots, followed by the intermediate phase in which there is the rapid growth of vines and an increase in leaf area as well as storage root initiation (CARDI, 2010). At 100 days after planting (DAP), the leaf area is at its maximum and any further increase in biomass is due to storage root formation (CARDI, 2010). The first 20 days of the initial phase are important as they determine the total number of storage roots formed (CARDI, 2010). Storage root formation can be visible as early as 28 DAP and 49 DAP, 80% of the storage roots can be identified (CARDI, 2010). In the final phase of growth bulking of the storage roots can reach a maximum 90 DAP or may enlarge throughout the life of the plant peaking at 120 DAP (CARDI, 2010).

Sweetpotato roots develop as adventitious roots (Togari, 1950; Belehu, 2001) and normally arise from the underground stem portion of a vine cutting used as planting material (Belehu, 2001). These adventitious roots develop from the nodal part of the stem (Belehu, 2001). Accordingly, studies in Bangladesh showed that increasing the number of nodes per vine increased the number of vines per plant, the vine length and the root yield (Nedunchezhiyan *et al*., 2012 a). The root development involves two processes; initiation and expansion (Eguchi, 2000). The roots are originated from the activation of primary cambia, along with anomalous cambial activity in the secondary and vascular cambia (Tsu *et al*., 2008). During the secondary-thickening growth, the procambial ring gradually aligns outwardly; meanwhile, parenchyma cells inside become highly proliferated and finally differentiate into starch-storage cells (Tsu *et al*., 2008).

It should be noted that most of the growth phases are controlled genetically (i.e. variety) and environmentally (i.e. agro- ecological conditions of the area where the crop is established) (CARDI, 2010). The initiation of organized development is a complex morphogenetic phenomenon, in which extrinsic and intrinsic factors play important roles (Aswath and Kim, 2005; Tsu *et al*., 2008). Thus, inputs from environmental cues, hormone signals and nutrient status are driving factors during organogenesis (Tsu *et al*., 2008). In addition, the internal balance of plant hormones such as abscisic acid (ABA) and cytokinins is crucial to the phase transition and root development (Matsuo, 1983; Wang *et al*., 2005; Tsu *et al*., 2008). It is suggested that the first two phases of growth may occur more rapidly under tropical conditions, after which a long root bulking period ensues (Wilson & Lowe 1973b; Lewthwaite, 2004).

2.4 Environmental requirements

2.4.1 Light

Duration of light has been reported to be one of the critical environmental factors affecting the growth and yield of sweetpotato (Bouwkamp, 1985; Mortley *et al*, 1996) and most cultivars are sensitive to daylength (Ngailo *et al*., 2013). For instance, stimulated storage root formation under long days has been reported (Kim 1957; Mortley *et al*., 1996). Higher storage root yields have also been reported when sweetpotato was grown under 12 - hour light periods than when plants were grown under shorter (8 - hour) or longer (18 - hour) light periods (McDavid and Alamu 1980; Mortley *et al*., 1996). These suggestions are augmented by reports of higher yields when sweetpotato was grown under 14 – hour light periods compared to 8 – hour light periods (Porter 1979; Mortley *et al*., 1996). The significance of light periods on sweetpotato growth has been reported even under controlled environments. Mortley (1996) showed that sweetpotato physiological responses, growth and yield varied with light when the Nutrient Film Technique (NFT) was used in a hydroponics system.

2.4.2 Water

Abiotic constraints which significantly affect sweetpotato production include low soil fertility and drought (Kapinga *et al*., 1995; Mwololo *et al*., 2007; Mihale *et al*., 2009; Pareek *et al*., 2010; Ngailo *et al*., 2013) The storage root yields are affected by

the amount, timing and distribution of water (Ravi *et al*., 2009). The crop's water requirement over the growing season is between 360 and 800 mm (Gomes and Carr, 2003; Belehu, 2003). Normally, the crop requires 500 mm water over 16-20 weeks growth period (King, 1985; Kays, 1985; Onyekwere and Nwinyi, 1989; Chukwu, 1995; Ravi *et al*. 2009).

2.4.3 Nutrients

As is the case with water availability the sweetpotato plant has been widely said to perform favourably under conditions of marginal nutrients. However, the crop performs far much better under optimal nutrition conditions. Most farmers do not apply fertilizers to their crop resulting in poor yields (Yeng *et al*., 2012). Adequate levels of potassium, nitrogen and phosphorus are required to ensure an acceptable yield of good quality roots (Lewthwaite, 2004), and these are the three predominant nutrients in sweetpotato root tissue; so soils may require their replenishment following repeated harvests (O'Sullivan *et al*., 1997; Lewthwaite, 2004). NPK at 75:50:75 and lime at 2t ha^{-1} were found to be optimum (Nair and Mohankumar, 1984; Latha *et al*., 2004). Lime at the above rate not only increased the yield but also improved the starch and sugar contents in the root (Nair and Mohankumar 1984; Latha *et al*., 2004).

Like other root crops, sweetpotato has a high requirement for potassium (O'Sullivan *et al*., 1997; Lewthwaite, 2004). Potassium is the most common mineral in sweetpotato roots and, therefore, the addition of potassium fertilizer to deficient soils generally provides a yield increase (Lewthwaite, 2004). Potassium deficiency tends to have a greater effect on storage root yield than on the plant canopy, unlike nitrogen or phosphorous deficiency (Bourke 1985; Lewthwaite 2004). The crop does not require large quantities of phosphorus to produce good yields and is relatively tolerant to low soil phosphorus levels (de Geus, 1967; Lewthwaite 2004), but under particularly low soil phosphorus conditions such as in volcanic ash soils, additions of phosphorus produce a yield increase (Floyd *et al*., 1988; Halavatau *et al*., 1996; Lewthwaite, 2004).

2.4.4 Temperature

Although sweetpotato is grown in the tropical, sub-tropical and warm temperate regions of the world, it is essentially a warm weather crop (Onwueme, 1978; Belehu,

2003) and is therefore sensitive to low temperatures. It is reported that the crop could not survive temperatures of less than 12^{o}C, survived at 15^{o}C but did not grow (Harter and Whitnet, 1962; Belehu, 2003). Growth increased above 15^{o}C up to 35^{o}C eventually showing retardation at 38^{o}C (Harter and Whitnet, 1962; Belehu, 2003). The thermal optimum is reported to be above 24^{o}C (Kay, 1973; Belehu, 2003) and normal root production has been reported from sweetpotato raised in the growth chamber at 27^{o}C for 5 months (Liu and Cantliffe, 1984; Schultheis *et al*., 1994). Higher temperature (>28^{o}C) diverts photosynthate partitioning toward fibrous roots than to storage roots (Eguchi *et al*., 2003; Ravi *et al*., 2009).

2.5 Production and utilization

2.5.1 Current

According to FAO (2013) sweetpotato ranked fifteenth among the various crops of the world produced in the year 2011 in terms of quantity at 105,043,249 metric tons. Much of this production was attributed to China (75,567,929 metric tons) while Tanzania (3,573,302 metric tons), Nigeria (3,300,000 metric tons) and Uganda (2554000 metric tons) were the leading producers in Africa in the year (FAO, 2013). At 236,611 metric tons the crop ranked seventh in Zambia in terms of quantities produced among various other crops in the same year (FAO, 2013). Global production is generally considered fairly stable at around 100 million metric tons per year (Lewthwaite, 2004).

Sweetpotatoes are usually consumed without special processing with the fresh root either boiled, roasted, baked, or fried as chips, while young leaves are stir-fried as a leafy vegetable (Egbe *et al*., 2012). The crop is also fed to livestock or processed industrially into alcohol, starch, noodles, candy, desserts and flour (Egbe *et al*., 2012). The crop is primarily grown for its swollen storage roots and this is the organ most commonly traded and consumed around the world (Lewthwaite, 2004).

2.5.2 Projected trends

Sweetpotato utilization looks set to increase in the future with the crop most likely to be used ever for health purposes. The value of sweetpotato as a basic food stuff may be considered secondary to its ability to synthesize useful phytochemicals, such as natural food colourants (Odake 1998; Lewthwaite, 2004). Cultivars whose roots are used as a natural colourant have actually been developed (Yoshimoto 2001; Islam

and Jalaludin 2004; Sivakumar *et al*. 2009) just like purple-coloured sweetpotatoes were developed in Japan in the 1990s (Yang *et al*., 2006; Yang 2010). Several reports have indicated that the anthocyanins in the purple-coloured sweetpotatoes displayed antioxidative or radical-scavenging activity and exerted several health-promoting functions in humans (Konczak-Islam *et al*., 2003; Suda *et al*., 2003; Rabah *et al*., 2004; Yang 2010). The beta-carotene rich sweetpotatoes are a major topic currently. These are one of the most promising plant sources of Vitamin A and can be a cheaper and complimentary source of Vitamin A to the rural and urban poor (Tumwegamire *et al*., 2004). sweetpotato can therefore be a high value-added food particularly for children and pregnant women who are more often exposed to vitamin A deficiency in sub-Saharan Africa (Degras, 2003; Uwah *et al*. 2013). The sweetpotato roots are also rich in vitamins B, and C; and minerals such as K, Na, Cl, P and Ca (Onwueme and Sinha, 1991; Uwah *et al*., 2013) and, would also supplement diets with essential micronutrients, such as iron and zinc (Serenje & Mwala, 2010). The crop has been used to treat diabetes, hookworm, internal bleeding and jungle ulcers as well as asthma (Woolfe, 1992; El-baky *et al*. 2009).

In view of increasing demand for energy world over, sweetpotato may play an increasing role in generating energy. This role will be more pronounced in the developed world compared to the developing countries where the food role still remains relevant. In the period 1990 to 2007, China the world's biggest producer continued to witness declining use of sweetpotato as a staple food but increased utilization for animal feed and industrial starch (Huang *et al*., 2003; Fuglie 2007). Due to high starch production per unit of land area, root crops, including sweetpotato, hold potential in the production of ethanol for use as liquid fuel (Hammond, 1977; Bhagsari 1990). The crop plays an important role in the development of first-generation biofuels in China (Tian *et al*., 2009; Fan *et al*., 2012).

2.6 Propagation

2.6.1 Challenges, historical background

The sweetpotato plant has been reported to be propagated from plant stems or vines of established plants for years. Bouwkamp (1982) reported the use of vine cuttings from established plants primarily for production as far back as 3 decades ago. Even

in recent times the use of plant stems from established plants is widely regarded as a front-runner choice in sweetpotato propagation methods. sweetpotato is cultivated from shoot cuttings grown in the field from the previous season (Far and Ashoub, 2009). In developing countries, sweetpotato is propagated through vegetative means using vine cuttings, roots, and slips (shoots emerging from roots) (Fuglie, 2007). Usually, apical vine cuttings are commonly used, however, in case of dearth of planting materials, proper selection of cuttings is often neglected and other portions of the vines are utilized (Alcoy *et al*., 1993). The apical and middle portion of the vine is found to be the best for getting higher root yield (Mukhopadhyay *et al*., 1990; Nedunchezhiyan *et al*. 2012 a). Bottom portions, usually thick and woody, sometimes fail to establish and there is a greater chance of weevil incidence due to proximity to the crown portion where sweetpotato weevil multiplies (Nair, 2006; Nedunchezhiyan *et al*., 2012 a). Commercial production most commonly involves planting seedlings grown from dormant root sprouts or planting top cuttings (Lewett, 1993; Novak *et al*., 2007). The major challenge with the use of stems has been the presence of diseases, usually viral, inherited from previous generations of the plant. When cuttings are used as propagating material, the parent material can transmit the disease to the next generation of plants (Nandwani and Tudela, 2010; Ogero *et al*. 2012). The alternative has been the use of pathogen free planting materials usually through use of costly procedures such as Tissue culture. However, high production cost has been an impediment to tissue culture adoption especially in the sub-Saharan Africa and this has limited the technology to a few institutions and rich farmers while locking out the resource-challenged subsistence farmers (Ogero *et al*., 2012). One factor contributing to the high cost of production is the cost of the culture nutrient medium which requires chemicals that are often very expensive (Savangikar, 2002; Ogero *et al*., 2012) and in order to increase its application in sweetpotato farming, innovative approaches are needed to lower the cost of micropropagule production (Ogero *et al*., 2012).

2.6.2 Methods, Mechanisms and concepts

As hinted in the preceding paragraph, on account of constraints inferred by vines through viral diseases various procedures are now applied for the production of quality planting materials through micropropagation. This is because it is widely recognized that good quality seed can significantly improve sweetpotato production.

China is one of the few countries that has successfully applied mass propagation of disease-free planting material and achieved impressive improvements in yields as a result (Fuglie *et al*., 1999; Fuglie, 2007).

2.6.2.1 Tissue Culture Plantlets

Production of pathogen-free materials and disease indexing are the first steps of an effective control strategy of viral diseases in crops propagated through vegetative means (Lepoivre, 1998; Ogero *et al*., 2012). Tissue culture has an important role to play in the generation of pathogen-free propagules for sweetpotato production. It has many advantages; such as production of disease-free planting materials in large numbers hence permits rapid dissemination of healthy and improved plants within and among countries, as the materials are readily certified as disease-free (FAO, 2003; Ogero *et al*., 2012). These materials can also grow uniformly hence they are highly marketable (Vuylsteke and Talengera, 1998; Ogero *et al*., 2012).

2.6.2.1.1 *De novo in vitro* Plantlet regeneration

Plant regeneration has been reported from petioles and leaves, (Gosukonda *et al*., 1995; González *et al*. 2008) and so has sweetpotato regeneration from stems and roots (Hwang *et al*., 1983; Dodds, 1989). It is actually possible to regenerate *de novo in vitro* plantlets from almost all plant parts when placed in culture and in all cases, the first step is the formation of callus at the cut surface (Dodds, 1989). When an appropriate hormonal stimulus is applied *de novo* meristems are formed which eventually form regenerating plantlets (Dodds, 1989). There are reservations about the use of this method. Dodds (1989) suggests that the labour involved in dissecting individual plantlets would make the method cost ineffective. It is also reported that the regenerated plantlets would not be genetically the same as the original genotype (Dodds, 1989) as the callus-derived plantlets may experience major genetic aberrations during the callus stage (Bayliss, 1980; Dodds, 1989). *De novo* plantlet regeneration may be executed either through organogenesis (direct organ formation) or through embryogenesis (direct formation of embryos from somatic cells) (Dodds, 1989).

2.6.2.1.1.1 Organogenesis

According to Yang (2010) several reports have been made about the use of *in vitro* organogenesis in sweetpotato using explants. However, the very low frequency of

regeneration and the absence of shoots on callus cultures have been cited as disincentives for the use of the procedure in sweetpotato (Henderson *et al*., 1983; Kuo, 1991; Sihachakr *et al*., 1997; Yang, 2010).

2.6.2.1.1.2 Somatic embryogenesis

In sweetpotato, mass produced *in vitro* somatic embryos may be used as propagules (Liu and Cantliffe 1984; Schultheis *et al*., 1994) and these could reduce planting costs when compared to the use of root sprouts (Schultheis *et al*., 1994). Somatic embryos have the additional advantage of mass production in limited time and space as well as production of disease free propagules (Fujii *et al*., 1987; Schultheis *et al*., 1994).

2.6.2.2 Plug transplants

The use of plug transplants for the rapid production of low cost, pathogen-free sweetpotato plug transplants has been reported (Kozai *et al*., 1999; Islam *et al*., 2002) that uses single node leafy cuttings as propagules (Islam *et al*., 2002). These propagules are placed in root supporting media in multi - cell plug trays and placed inside a closed system with artificial light to facilitate growth and development (Islam *et al*., 2002). During the two weeks of production the cuttings develop roots first and then produce a further shoot growth (about 0.14 m long) with 4 to 6 unfolded leaves (Islam *et al*., 2002). It is at this stage that they are ready for planting in the field (Islam *et al*., 2002). In a closed production system high numbers of pathogen- and pest-free plug transplants can be produced with minimum space, labour, and cost in limited time (Kozai *et al*., 1999; Islam *et al*., 2002). The use of these rooted plug transplants has the advantage of increasing the initial growth rate in comparison to the conventional transplants, particularly under dry field conditions (Islam *et al*., 2002).

2.6.2.3 Propagation in Liquid Culture

In this method stem lengths with five to eight nodes, apical shoot and root incised, are placed in flasks to be bathed by the culture medium (Dodds, 1989). The medium contains Gibberellic acid which breaks the dormancy in the axillary buds (Dodds, 1989). After about three to four weeks the flasks are full of growing sweetpotato shoots (Siquenas, 1987; Dodds, 1989).

2.6.2.4 Seed

Shultheis *et al*. (1994) identify the use of seed as an option with great reservations. The use of zygotic seed for production is impossible because sweetpotato is a hexaploid and has a complex quantitative inheritance, such that each seed-derived plant is unique (Schultheis *et al*., 1994). The heterozygous nature of the crop confers a wide range of variability (Soenarjo, 1995).

Whatever the method applied for sweetpotato production the generation of planting materials is one of the costly inputs that are associated with the crop. Large commercial plantings of sweetpotato for biomass production are cost prohibitive because of the expense of vegetative propagation (Cantliffe *et al*., 1987; Schultheis *et al*, 1994).

2.6.3 Current Research

A number of research works have been undertaken with regard to the influence of propagation method on sweetpotato growth and yield components. Sweetpotato yields obtainable from cuttings obtained from dormant sweetpotato root sprouts by standard methods, and the more recent method of seedling production in containers have been reported (Novak *et al*. (2007). The method of seedlings production had a significant effect on the yield (Novak *et al*., 2007). Ozturk *et al*. (2012) compared the performance of *in vitro* plantlets derived from the meristem cultures of rootstocks through micro-propagation with the performance of the traditional seed roots. Their observations amplify the suggestions that sweetpotato storage root yields are influenced by the method of propagation. *In vitro* plantlets derived from seed stocks had superiority over traditional seed roots in sweetpotato production for yield and yield components studied (Ozturk *et al*., 2012).

A comparison of single node and terminal shoot propagule cuttings for transplant production under field conditions has been reported in which different cell volumes (35 or 55mL) of multicell plug trays for transplant production were used (He *et al*., 2000; Islam *et al*., 2002). There were no differences found among treatments in the growth and yield of sweetpotato, but it was observed that some storage roots were coiled (abnormal shaped storage roots) from the plug transplants at harvest (He *et al*., 2000; Islam *et al*., 2002). Although they coiled during plug transplant period in the closed chamber, such initiated roots continued to produce abnormally shaped storage

roots in the field (He *et al*., 2000; Islam *et al*., 2002). Such roots tend to have reduced market value although the value is not decreased when they are used as industrial material (Islam *et al*., 2002).

Islam *et al*. (2002) conducted a similar study in which transplants were produced in a closed system in plugs of different volumes. These transplants were then planted either intact with roots or without roots (Islam *et al*., 2002). In this study Islam *et al*., (2002) sought to determine the role of plug volume and root removal on growth and yield in the field. The plug transplants were compared with conventional cuttings with respect to the growth and development of the plant vegetation and storage roots, and yield of sweetpotato under field conditions (Islam *et al*., 2002). It is reported that growth and yield from plug transplants were significantly higher than from conventional cuttings, regardless of the plug volume or root removal (Islam *et al*., 2002). Plug transplants with intact roots produced greater growth and yield regardless of plug volume than did plug transplants without roots (Islam *et al*., 2002).

Schultheis *et al*., (1994) investigated early plant growth and yield in sweetpotato grown from Seed, Vegetative Cuttings, and Somatic Embryos. Vegetative growth, larger-sized storage roots (>6 cm in diameter), and total yields were consistently reduced when plants were derived from somatic embryos compared with propagules of stock plant origin (Schultheis *et al*., 1994). Plants grown from somatic embryos required more bulking time than the other propagule types, and root yield from plantlets derived from somatic embryos showed a 14-fold increase when harvest was delayed at least 53 more days (Schultheis *et al*., 1994). Root weight was greater when plants were derived from stock plants rather than from somatic embryos, while in most cases plants derived from somatic embryos yielded a greater number of roots than those from stock plants (Schultheis *et al*., 1994). Plants obtained through somatic embryony and harvested at a later date typically had yields exceed 1.8 kg per plant, and the morphology of plants obtained from somatic embryos was uniform and identical to plants derived from stock plants (Schultheis *et al*., 1994).

2.7 Sweetpotato production in Zambia

Sweetpotato, a useful food crop in Zambia accounts for 2% of the total land area cultivated (Orlowski *et al*., 2010; Fanworth et al., 2011). It is an important root crop grown throughout Zambia (Soenarjo, 1995). According to FAO (2013) production

stood at only 20,000 tons in the year 1961 while the organization puts the country's production at 40,000 tons in the year 1980. FAO (2013) estimates production for the country at 163,484 tons in the year 2012, generally indicating an upward trend in sweetpotato production in the country in the last few decades. There has been an increase in both production and consumption (SARRNET, 2003).

In terms of cultivation practices the crop may be planted in Zambia from early November to late January of the subsequent year (FoDis information series, 2009). The country's crop yields reported at 2 to 4 tons per hectare, are the lowest in the region (FoDis information series, 2009). These could however be improved to 15 tons per hectare with some improvement in Agronomic practices (FoDis information series, 2009). There is high potential for increasing sweetpotato yields in many countries through the introduction of improved clones and more efficient cultivation practices (Serenje and Mwala, 2010).

2.7.1 Incentives for growing sweetpotato

Sweetpotato is generally seen as a more resilient crop than many in Zambia, often thriving in marginal conditions and therefore widely seen as an "insurance" crop. It can thrive in a wide range of conditions and gives large returns on modest investment (Soenarjo, 1995). It is in this regard that the crop seems to be highly favoured by the Zambian farmer. For instance, the removal of subsidies on Maize production and marketing in the early 1990's created a shift in the preference of crops grown among Zambian farmers who sought out more profitable crops such as sweetpotato (Howard and Mungoma 1996 and, Zulu *et al*., 2000; Nyembe and Haggblade, 2007). The crop is an important alternative because it is less demanding in terms of external inputs (SARRNET, 2003). Also, sweetpotato has become an increasingly important food crop in Zambia because of the challenges of meeting food requirements (SARRNET, 2003). The importance of the crop for the Eastern Province of Zambia is acknowledged although it is hindered by the limited availability of planting materials (Ndiyoi *et al*., 2007).

2.7.1.1 Marketing of produce

Sweetpotato is a subsistence crop in Zambia although a portion of it finds itself on markets (Agrisystems, 2007). The crop is gaining momentum as a cash crop in the country, thus being used not only for consumption but as a source of income as well

(SARRNET, 2003). It has for many years now been an important food for self-consumption in Zambia and has increasingly become a cash crop as well particularly among rural women living in the vicinity of urban markets and highways (Fanworth *et al*., 2011). In fact, a sizeable portion of Zambian sweetpotato finds itself on the markets in neighbouring Botswana (Fanworth *et al*., 2011) while the variety Chingovwa is also on demand in Zimbabwe and Namibia (Manintveld et al., 2004). The crop is mostly sold in its fresh form and the marketing channel takes the route of a Producer selling directly to either a rural consumer or an urban consumer (SARRNET, 2003). In the other route intermediaries are employed and these could be brokers/ commission agents or middlemen who sell to the urban consumer (SARRNET, 2003). The Zambian households obtain about 60% to 70% of their staple foods like sweetpotato from traditional markets (Fanworth *et al*., 2011). There is a general practice of transporting sweetpotato in sacks about 60kg to 120 kg in retail as well as wholesale markets (Fanworth *et al*., 2011). The lack of information on the supply and demand of the crop's fresh produce in Zambia has been a constraint to the development of postharvest utilization strategies as well as commercialization of the crop (Agrisystems, 2007).

2.7.2 Historical perspective of sweetpotato Research in Zambia

The sweetpotato is considered to be a low value, poor man's crop (Minde *et al*., SARRNET, 2003) and hence the crop has received little research attention in Southern Africa (SARRNET, 2003). Prior to the 1980's the crop received little attention in terms of research in Zambia. Serious work started in 1987 through the Root and Tuber Improvement Programme (RTIP) funded by the Swedish International Development Authority (SIDA) (SARRNET, 2003) and the role of the research function in improved sweetpotato production and productivity in Zambia is now acknowledged. sweetpotato productivity has benefited from the investments in Research and Development of the 1980's leading to the development of varieties released in the 1990's (Jayne *et al*., 2007). Varieties are developed by the Root and Tuber Improvement Programme (RTIP) through selection from mainly local varieties (Soenarjo, 1995). A hybridization programme embarked on to improve cultivars through population combination relies on selection based on yields, taste and cooking traits (Soenarjo, 1995). The RTIP maintains foundation sites for seed and these efforts have successfully yielded improved sweetpotato cultivars that are

multiplied and distributed to farmers (Ndiyoi *et al*., 2007). The availability of these improved varieties has led to an expansion in the production area of sweetpotato in non-traditional areas like the Southern Province (Manintveld *et al*., 2004).

2.7.3 Propagation chain and supply of planting materials in Zambia

In order to maintain sweetpotato germplasm, the Government of Zambia sponsors foundation seed sites at regional Research stations in collaboration with the RTIP (Ndiyoi *et al*., 2007). Some germplasm from international partners is imported in order to broaden the national germplasm base (Ndiyoi *et al*., 2007).

Both the public sector and Non-Governmental Organizations (NGO's) are involved in the distribution of sweetpotato planting materials in Zambia (Ndiyoi *et al*., 2007). In fact, there is evidence of NGO's working with the Government system through the Ministry of Agriculture and Livestock to multiply planting materials at research stations and distribute them to farmers for on-farm multiplication and further distribution to other farmers (Ndiyoi *et al*., 2007). The availability of planting materials for sweetpotato in Zambia is constrained by the lack of participation from the private sector that may not find such an enterprise lucrative. The private sector concentrates on crops like Maize leaving crops like sweetpotato unattended to and therefore leading to the shortage of planting materials for such crops, a gap that Non-governmental organizations have been critical in filling (Chipili, 2008). The crop attracts apparent minor economic interest from breeding companies (Manintveld *et al*., 2004).

2.7.3.1.1 On farm Sources of materials

Although farmers regularly visit research stations and NGO's to obtain planting materials, the major source of planting material for farmers is their own gardens (SARRNET, 2003) and these vines are usually kept over from the previous season (Fanworth *et al*., 2011). This process presents opportunities for the possible dissemination of pests and diseases in production systems. Planting for production of vines under irrigation may occur between August and September (FoDis information series, 2009).

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Study Location

This Study was conducted over a two year period (2011-2013) at the Kaithinde Agricultural Camp (S 12^{o} 23.148' E 033^{o} 06.635') located in the Lundazi district of the Eastern province of Zambia. The site lies 1167 m above sea level. Soil samples were obtained at the start of the study to determine the soil chemical and physical status (Appendix EE). The site is characterized by sandy soils which were classified as Acrisols. The normal annual rainfall is 833 mm and normal air temperatures are around 20.3 °C. A unimodal rainfall pattern occurring between October and April is characteristic of the site and the total rainfall received in the 2012/2013 season was 569.9 mm.

3.2 Field preparation and planting

3.2.1 Land preparation

The land was tilled to a fine tilth to a depth of 30 cm using hand hoes. Ridges were then made at an inter-ridge spacing of 1 m and a height of about 40 cm.

3.2.2 Plant materials

The plant materials used in the study were obtained from the Root and Tuber Crops Improvement Programme of the Zambia Agriculture Research Institute (ZARI). Four sweetpotato varieties were used in this study; these were three orange fleshed sweetpotato (OFSP) varieties namely Zambezi, Olympia and Orange Chingovwa and one white fleshed sweetpotato variety Chingovwa. These varieties were selected because they were available for farmers to use at the time of the study. Olympia and Orange Chingovwa, alternately referred to as Chiwoko (AGRA, 2015) have maturity periods ranging between 4 and 5 months with yield potentials of 25 tons per hectare and 20 tons per hectare respectively, while Zambezi matures in 5 to 6 months and can yield 15 tons per hectare (Chipungu *et al*., 2015). Chingovwa on the other hand matures in 4 months and may yield up-to 23 tons per hectare (Mwanga, 2001). A 30 cm length of vine cutting was planted at an intra-ridge spacing of 30 cm.

3.2.2.1 Pre treatments

At the start of the study a sweetpotato multiplication block with four plots was established at the experimental site in the 2011/2012 Agricultural season to generate required volumes of planting materials. The plots each measuring 96 square metres were planted with the four sweetpotato varieties mentioned above namely, Olympia, Chingovwa, Zambezi and Orange Chingovwa. At maturity the plants were harvested by removing all visible storage roots except those about 2 cm in diameter and less. These as well as the vines and pencil roots were left in the ground. The small sized healthy roots (about 100 grams) were carefully selected and buried in plastic domestic 15 L buckets containing river sand. The buckets were stored at room temperature throughout the rest of the duration of the dry period (from June to October). Eight weeks before the anticipated start of the rainy season these roots were removed from the buckets and planted out in planting basins prepared in the field (first week of November 2012). The roots were placed in shallow basins that allowed only about 5 cm of soil cover. This was in a block separate from the initial one that now only had volunteer plants standing. The emerging plants were watered until the start of the rains. 6 mm of water were applied every two days. The plants established from these shoots were designated the "root sprouts treatment". The block containing root sprouts was weeded once, 30 days after planting. The plants that were left standing in the ground during the dry season but allowed to sprout with the onset of the rains generated vines that were used to establish plantings that were designated the "volunteer plant sprouts treatment". There was no weeding in this block. Vines were collected from the two blocks and planted out in the field in the 2012/2013 agricultural season.

3.3 Crop management and agronomic practices

Standard sweetpotato practices were followed to manage the crop (FoDis information series, 2009).

3.3.1 Fertilisation regime

A total of 592 kg ha^{-1} of D-Compound fertilizer was supplied to the crop in order to attain the targeted minimum requirement of 75 kg of N, 150 kg of P_2O_5 and 75 kg of K_2O per hectare (Nair and Mohankumar 1984; Latha *et al*., 2004). Fertilizer was incorporated into the ridges in two equal instalments, the first at planting and the second 45 days after planting (Bhagsari and Ashley, 1990).

3.3.2 Plant protection

There were no major pest and disease incidences noted in the study plots and therefore no plant protection measures applied. Weeding was done on two occasions early after establishment, 16 days after planting and 33 days after planting respectively.

3.4 Experimental design and data management

3.4.1 Experimental Design

A factorial experiment arranged in a Randomized Complete Block Design (RCBD) with four replications was used. The factors were Propagation Methods and Varieties. There were two propagation methods and four varieties used in the study. Each variety (Orange Chingovwa (OC), Olympia (O), Chingovwa (C) and Zambezi (Z)) was propagated by the two methods; root sprouts (R) and volunteer plant sprouts (V). In total there were 8 treatment combinations; OC-R, C-R, OC-V, O-V, Z-R, C-V, Z-V and O-R where the letter R represents the method root sprouts and V represents volunteer plant sprouts, and the letter(s) OC, C, Z and O represent the varieties Orange Chingovwa, Chingovwa, Zambezi and Olympia respectively.

3.4.2 Data collection and analysis

In order to fully assess treatment effects plants were sampled at 3 stages. These were, 40 (early vegetative growth phase), 80 (full vegetative growth phase) and 120 (full maturity phase) Days after Planting (DAP). Three plants were randomly selected from each plot at each of the sampling times and used to determine values for a wide range of morpho-physiological parameters (van der Werf, 1996).

3.4.2.1 Plant establishment

Plant establishment was determined as a percentage count of the total number of vines that had established out of the total planted per plot. The parameter was evaluated 30 days after planting. Oggema *et al*. (2007) observed that a generally stable plant count in sweetpotato was achieved 28 days after planting.

3.4.2.2 Leaf traits

Leaf traits evaluated were the Specific Leaf Area (SLA), Leaf Area (LA), Leaf Area Ratio (LAR) and the Leaf Area Index (LAI). The method of Kelm *et al.* (2000) was used to determine SLA. Briefly, 30 leaf disks of diameter 2.2 cm were incised from

leaf samples collected from each of the sampled plants. Each disc had 0.00038 m^2 leaf area. The fresh weight and dry weights were then determined. SLA was determined as the ratio of the total area of disks to the dry weight of the disks while LA per plant was determined as the product of SLA and Leaf dry matter content per plant (Kelm *et al.*, 2000).

The LAR was determined as the ratio of the plants total leaf area to the plants total biomass (Medek *et al*., 2007) while LAI which is an indicator of leaf development (Nedunchezhiyan *et al*., 2012 b) was determined as the ratio of the total plant leaf area to the ground area occupied by the plant (Kuhlase *et al*., 2009).

3.4.2.3 Vine length (VL) and Root traits

Vine Length (VL), Storage root diameter (RD), Storage root length (RL) and the root/ shoot ratios (RSRs) (van der Werf, 1996) were the other traits measured. VL was measured by use of a standard measuring tape. RD was determined by use of vernier callipers and the RL determined by use of a hand-held rule. RD and RL were measured to elucidate the quality of storage roots resulting from the treatments (El-baky *et al*., 2009).

3.4.2.4 Yield parameters

Yield was evaluated based on the total storage root yield per plant, marketable and non-marketable root yields per plant, and the Harvest Index (HI) (Claessens *et al*., 2008). Total plant root yield, plant marketable and non-marketable root yields were determined by weighing on a scale. A root was considered to be marketable if it had a minimum weight of 100 g (Ossom, 2007; Ossom *et al*., 2010). Harvest Index was estimated as a ratio of the plant's total storage root yield to the total plant biomass at harvest (Yeng *et al*., 2012).

3.4.2.5 Data analysis

Data analysis was done using GenStat 14th Edition and where significant treatment effects were observed means were separated using the Least Significant Differences (LSDs) at 5 % probability (Buysse *et al*., 2004).

CHAPTER 4

4 RESULTS

4.1 Early vegetative growth phase

4.1.1 Plant establishment as affected by propagation method and variety

There were no significant differences in establishment rates between the two propagation methods ($p = 0.075$) (Tables 1 and 2). However, there were very highly significant differences between varieties regarding plant establishment ($p < 0.001$). While plant establishment rates did not differ between varieties Orange Chingovwa, Chingovwa and Olympia the variety Zambezi had lower establishment at 89.69%. The propagation method by variety interaction had a highly significant effect on plant establishment ($p = 0.01$). Plant establishment in the variety Zambezi was higher in the root sprouts method.

4.1.2 Leaf traits during the early vegetative growth phase

The data showed that the propagation method and variety affected some of the parameters during early vegetative growth (Tables 1 and 2). Although there were no differences between propagation methods for the traits SLA ($p = 0.209$) and LAR ($p = 0.245$), there were highly significant differences between the two methods with regard to LA ($p = 0.009$) and the LAI ($p = 0.009$). The LA and consequently the LAI were superior when plants were grown from volunteer plant sprouts.

The differences in the SLA among varieties were highly significant ($p = 0.004$). The varieties Olympia (24.53 m^2/kg) and Orange Chingovwa (22.77 m^2/kg) had higher SLA compared to Zambezi which had 20.41 m^2/kg. Variety also had highly significant effects on the LA ($p = 0.013$) and consequently the LAI. Orange Chingovwa, Chingovwa and Olympia had higher LAs than Zambezi. Consequently, Zambezi had the lowest LAI while there were no differences between Olympia, Orange Chingovwa and Chingovwa for this trait during the early vegetative growth phase. Variety had no effect on the LAR during this early growth phase ($p = 0.530$).

There were no propagation method by variety interaction effects on all the leaf traits evaluated at $p \leq 0.05$ during the early vegetative growth phase.

Table 1: Summary of Analysis of Variance for measured traits of sweetpotato [*Ipomoea batatas* (L.) Lam.] during early vegetative growth phase

Sources of Variation	Df	Plant establishment	Specific Leaf Area	Leaf Area	Leaf Area Ratio	Leaf Area Index	Vine Length	Root Diameter	Root Length	Root: Shoot Ratios
Replication	3									
Method	1	ns	ns	**	ns	**	***	ns	ns	ns
Variety	3	***	**	**	ns	**	*	**	**	*
Method.variety	3	**	ns	ns	ns	ns	*	ns	ns	ns
Residual	21									
CV (%)		3.60	9.10	21.10	24.00	26.10	27.10	32.80	11.90	39.30

[ns]not significant at 5% probability, *significant at 5% probability, **significant at 1% probability, ***significant at 0.1% probability.

Table 2: Plant establishment and Leaf traits in sweetpotato [*Ipomoea baVLtatas* (L.) Lam.] as influenced by vine propagation method and variety, determined 40 days after planting (Early vegetative growth).

	Plant establishment (%)					Specific Leaf Area (m^2/kg)					Leaf Area (m^2)					Leaf Area Ratio (m^2/kg)					Leaf Area Index				
Variety / Method	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means
Root Sprouts	98.75	99.38	100.00	95.00	98.28	23.00	21.53	23.55	19.37	21.86	0.25	0.25	0.20	0.12	0.21	8.55	7.87	9.25	6.86	8.13	0.83	0.82	0.68	0.40	0.68
Volunteer Plant sprouts	100.00	99.38	100.00	84.38	95.94	22.54	21.70	25.51	21.44	22.80	0.28	0.29	0.28	0.22	0.27	8.75	8.40	9.60	9.25	9.00	0.93	0.98	0.94	0.72	0.89
Variety Means	99.38	99.38	100.00	89.69		22.77	21.61	24.53	20.41		0.26	0.27	0.24	0.17		8.65	8.13	9.43	8.06		0.88	0.90	0.81	0.56	
Grand mean	97.11					22.33					0.24					8.57					0.79				
Lsd (5%) (Method)	2.60					1.50					0.05					1.51					0.15				
Lsd (5%) (Variety)	3.68					2.12					0.06					2.13					0.21				
Lsd (5%) (Method x Variety)	5.21					2.99					0.09					3.02					0.30				
CV (%)	3.60					9.10					26.10					24.00					26.10				

4.1.3 Differences in vine length, root length and diameter, and root: shoot ratios during the early vegetative growth phase

Propagation method had a very highly significant effect on vine length (VL) ($p < 0.001$) but not on the root length (RL) ($p = 0.268$), root diameter (RD) ($p = 0.987$) or the root: shoot ratios (R:SR's) ($p = 0.760$) (Table 1) during the early vegetative growth phase. During this phase vines were longer in the volunteer plant sprouts method (Table 3).

There were also significant differences in VL among varieties ($p = 0.026$), where Olympia and Zambezi had longer vines than Chingovwa during this phase (Table 3). The variety Orange Chingovwa was intermediate. There was also a significant propagation method by variety interaction effect on vine length ($p = 0.018$). Vines in the volunteer plant sprouts method were longer in Zambezi but longer in the root sprouts method in Olympia.

Variety also exerted significant differences on R:SRs ($p = 0.045$) and highly significant differences on the traits RD ($p = 0.002$) and RL ($p = 0.005$). During the phase Olympia (0.38) had higher RSRs than Zambezi (0.21) while Orange Chingovwa (0.31) and Chingovwa (0.28) were intermediate. Chingovwa (0.74 cm) and Olympia (0.73 cm) had thicker roots than Zambezi (0.36 cm) during the early vegetative growth phase. Orange Chingovwa (0.55 cm) had roots that were intermediate during this phase. Zambezi had the longer RL (21.19 cm) when compared to the Orange Chingovwa (18.73 cm), Chingovwa (16.81 cm) and Olympia (17.75 cm). During this early phase the factors propagation method and variety had no significant interaction effect on the RD ($p = 0.144$), RL ($p = 0.480$) nor on the R:SRs ($p = 0.774$).

Table 3: Vine length, root length, root diameter and root: shoot ratios as affected by propagation method and variety in sweetpotato [*Ipomoea batatas* (L.) Lam.], determined 40 days after planting (Early vegetative growth).

	Vine Length (cm)					Root Diameter (cm)					Root Length (cm)					Root: Shoot Ratios				
Method \ Variety	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means
Root Sprouts	141.20	152.80	190.20	131.60	154.00	0.56	0.88	0.63	0.32	0.60	19.64	16.64	18.97	21.01	19.06	0.32	0.25	0.41	0.22	0.30
Volunteer Plant sprouts	217.80	156.50	243.60	273.80	222.90	0.54	0.61	0.83	0.40	0.60	17.82	16.97	16.53	21.37	18.17	0.29	0.31	0.35	0.19	0.29
Variety Means	179.50	154.70	216.90	202.70		0.55	0.74	0.73	0.36		18.73	16.81	17.75	21.19		0.31	0.28	0.38	0.21	
Grand mean	188.40					0.60					18.62					0.29				
Lsd (5%) (Method)	29.28					0.14					1.63					0.08				
Lsd (5%) (Variety)	41.40					0.20					2.31					0.12				
Lsd (5%) (Method x Variety)	58.55					0.29					3.26					0.17				
CV (%)	21.10					32.80					11.90					39.30				

4.2 Responses to propagation methods and variety during stage 2: Full-vegetative development phase

4.2.1 Leaf traits during the full vegetative development phase

In the full vegetative development phase there were no significant differences in the SLA ($p = 0.556$), LA ($p = 0.626$), LAR ($p = 0.529$) and LAI ($p = 0.626$) resulting from the two propagation methods (Table 4). There were however, very highly significant differences in the SLA among the varieties ($p < 0.001$) during this phase (Table 5). The SLA in Olympia (21.40 m^2/kg) did not differ from that in Orange Chingovwa (20.90 m^2/kg); these two had higher SLAs compared to Zambezi (17.78 m^2/kg) which had the lowest of the four varieties. The SLA of Chingovwa (20.20 m^2/kg) did not differ from that of Orange Chingovwa. Variety did not influence the LA ($p = 0.630$), LAR ($p = 0.152$) and LAI ($p = 0.630$) during this phase of growth. Also, there was no interaction effect of propagation method and variety on the SLA ($p = 0.077$), LA ($p = 0.219$), LAR ($p = 0.759$) nor on the LAI ($p = 0.219$) during this phase.

4.2.2 VL, root diameter, root length and root: shoot ratio during the full vegetative development phase

The effects of treatments on VL, RL, RD and R:SR during full vegetative growth phase are presented in Tables 4 and 6. There were no differences in the VL ($p = 0.094$), RL ($p = 0.740$), RD ($p = 0.786$) nor in the R:SR ($p = 0.992$) between the two propagation methods during the full vegetative development phase.

There were very highly significant varietal effects on VL ($p < 0.001$), RD ($p < 0.001$) and the R:SRs ($p < 0.001$). The RL did not differ among the varieties during this phase ($p = 0.739$). Storage roots were thicker in the variety Olympia (3.84 cm) when compared to Orange Chingovwa (2.87 cm) and Zambezi which had the lowest RD (1.75 cm). Chingovwa (3.24 cm) could not be separated from Olympia and Orange Chingovwa during this phase. Olympia had the highest R:SR (1.86), Zambezi had the least (0.49) while Orange Chingovwa (1.07) and Chingovwa (1.26) were intermediate and could not be separated from each other. There was no significant Propagation method by variety interaction effect on the VL, RL, RD and the R:SR at $p \leq 0.05$.

Table 4: Summary of Analysis of Variance for measured traits of sweetpotato [*Ipomoea batatas* (L.) Lam.] during stage 2: full-vegetative development phase

Sources of Variation	df	Specific Leaf Area	Leaf Area	Leaf Area Ratio	Leaf Area Index	Vine Length	Root Diameter	Root Length	Root: Shoot Ratios
Replication	3								
Method	1	ns	ns	ns	ns	ns	ns	ns	ns
Variety	3	***	ns	ns	ns	***	***	ns	***
Method.variety	3	ns	ns	ns	ns	ns	ns	ns	ns
Residual	21								
CV (%)		4.80	23.20	24.70	23.20	31.10	19.90	31.00	37.50

[ns]not significant at 5% probability, *significant at 5% probability, **significant at 1% probability, ***significant at 0.1% probability.

Table 5: Leaf traits in sweetpotato [*Ipomoea batatas* (L.) Lam.] as influenced by vine propagation method and variety, determined 80 days after planting (full vegetative development phase).

	Specific Leaf Area (m^2/kg)					Leaf Area (m^2)					Leaf Area Ratio (m^2/kg)					Leaf Area Index				
Variety / Method	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means
Root Sprouts	20.24	20.77	21.00	17.86	19.97	0.56	0.59	0.55	0.61	0.57	5.51	3.87	3.98	4.85	4.55	1.86	1.96	1.82	2.02	1.91
Volunteer Plant sprouts	21.56	19.62	21.81	17.70	20.17	0.69	0.60	0.64	0.47	0.60	5.07	4.66	4.28	5.24	4.82	2.31	1.98	2.12	1.56	1.99
Variety Means	20.90	20.20	21.40	17.78		0.63	0.59	0.59	0.54		5.29	4.27	4.13	5.05		2.09	1.97	1.97	1.79	
Grand mean	20.07					0.59					4.68					1.95				
Lsd (5%) (Method)	0.70					0.10					0.85					0.33				
Lsd (5%) (Variety)	0.99					0.14					1.20					0.47				
Lsd (5%) (Method x Variety)	1.40					0.20					1.70					0.67				
CV (%)	4.80					23.20					24.70					23.20				

Table 6: Vine length, root diameter, root length and root: shoot ratio as affected by propagation method and variety in sweetpotato [*Ipomoea batatas* (L.) Lam.], determined 80 days after planting (full vegetative development phase).

	Vine Length (cm)					Root Diameter (cm)					Root Length (cm)					Root: Shoot Ratios				
Variety / Method	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means	O. Chingovwa	Chingovwa	Olympia	Zambezi	Method Means
Root Sprouts	427.00	343.00	402.00	827.00	500.00	2.90	3.04	3.92	1.95	2.95	16.14	15.94	14.90	15.49	15.62	1.01	1.25	2.00	0.43	1.17
Volunteer Plant sprouts	624.00	377.00	620.00	807.00	607.00	2.83	3.43	3.76	1.56	2.90	17.49	14.84	14.86	13.02	15.05	1.14	1.27	1.72	0.54	1.17
Variety Means	525.00	360.00	511.00	817.00		2.87	3.24	3.84	1.75		16.82	15.39	14.88	14.26		1.07	1.26	1.86	0.49	
Grand mean	553.00					2.92					15.34					1.17				
Lsd (5%) (Method)	126.70					0.43					3.49					0.32				
Lsd (5%) (Variety)	179.10					0.61					4.94					0.46				
Lsd (5%) (Method x Variety)	253.30					0.86					6.98					0.64				
CV (%)	31.10					19.90					31.00					37.5				

4.3 Responses to propagation methods and variety at Stage 3: Full maturity phase

4.3.1 Leaf traits during the full maturity phase

The effects of the treatments on the measured leaf traits during the full maturity phase are presented in Table 8 and, Figures 1, 2, 3, 4, 5, 6, 7 and 8. Propagation method did not affect any of the measured leaf traits during the full maturity phase at $p \leq 0.05$ (Figures 1, 2, 3 and 4). During this phase there were significant differences in the LAR between varieties ($p = 0.027$) and very highly significant differences between varieties in the SLA ($p < 0.001$) (Figures 5 and 6). Zambezi had higher LAR (1.929 m^2/kg) compared to Chingovwa (1.358 m^2/kg) while Orange Chingovwa (1.660 m^2/kg) and Olympia (1.674 m^2/kg) were not different from either extremes during this full maturity growth phase. Zambezi had the least SLA (14.88 m^2/kg) during the phase while Orange Chingovwa (20.88 m^2/kg), Olympia (20.81 m^2/kg) and Chingovwa (19.54 m^2/kg) were not different at $p \leq 0.05$. Variety did not affect the LA ($p = 0.255$), nor the LAI ($p = 0.255$) during the phase (Figures 7 and 8). There was no significant propagation method by variety interaction effect either on the SLA ($p = 0.542$), LA ($p = 0.115$), LAR ($p = 0.442$), nor on the LAI ($p = 0.115$).

4.3.2 Differences in VL, root length and diameter, and root: shoot ratios during the full maturity phase

There were no significant differences between propagation methods in the VL ($p = 0.075$), RL ($p = 0.278$), RD ($p = 0.055$) nor in the R:SRs ($p = 0.733$) during the full maturity phase (Table 8 and Figures 9,10,11 and 12). There were however, significant varietal differences in the RD ($p = 0.048$) but no such differences in the RL ($p = 0.473$) (Figures 13 and 14). There were very highly significant varietal differences in the VL ($p < 0.001$) and highly significant varietal differences in the the R:SRs ($p = 0.005$) (Figures 15 and 16). Olympia, Orange Chingovwa and Chingovwa had the thicker roots although Zambezi was not different from Orange Chingovwa at $p \leq 0.05$. Zambezi had the longer vines while the rest of the varieties were not different from each other. Zambezi also had the least R:SRs while similarly, the rest of the varieties could not be separated from each other during the full maturity phase. There was no significant propagation method by variety interaction effect on the VL ($p = 0.900$), the RL ($p = 0.302$), the RD ($p = 0.829$), nor on the R:SRs ($p = 0.252$) during the full maturity growth phase.

Table 7: Summary of Analysis of Variance for measured traits of sweetpotato [*Ipomoea batatas (L.) Lam.*] during the full maturity phase

Sources of Variation	df	Specific Leaf Area	Leaf Area	Leaf Area Ratio	Leaf Area Index	Vine Length	Root Diameter	Root Length	Root: Shoot Ratios	Total root weight per	Marketable roots' weight (kg)	Non-marketable roots' weight	Harvest Index (%)
Replication	3												
Method	1	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Variety	3	***	ns	ns	ns	**	*	ns	**	*	**	***	**
Method.variety	3	Ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Residual	21												
CV (%)		14.80	35.20	24.40	35.20	39.00	19.30	16.80	28.00	27.40	32.40	26.40	7.40

[ns]not significant at 5% probability, *significant at 5% probability, **significant at 1% probability, ***significant at 0.1% probability.

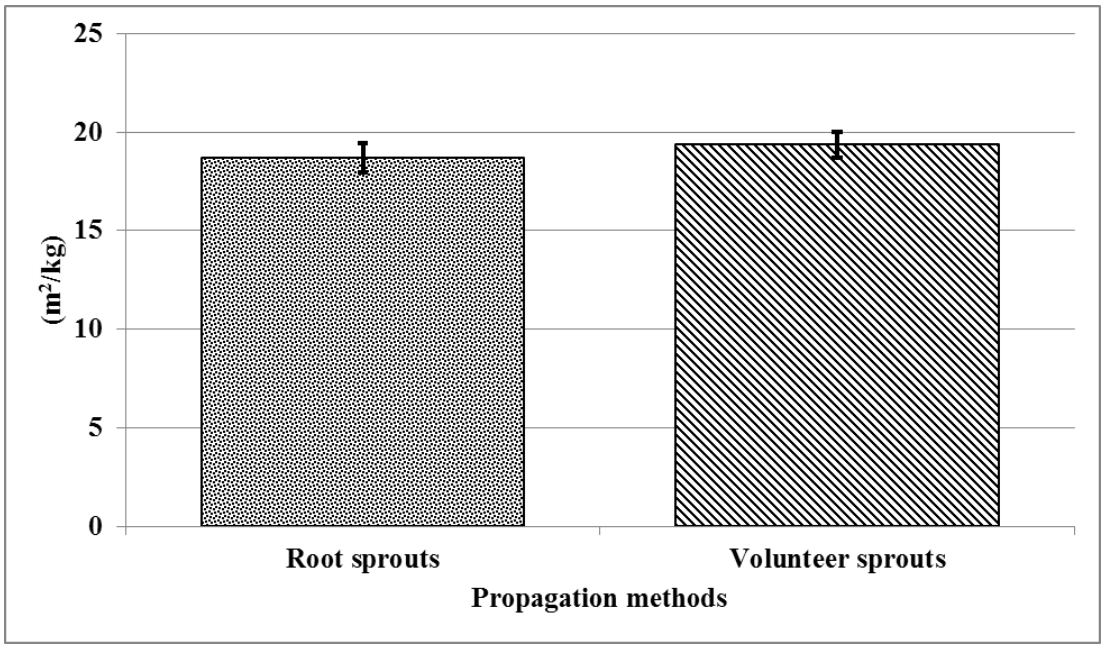

Figure 1: Differences in Specific Leaf Area of sweetpotato (*Ipomoea batatas* (L.) Lam.) under different propagation methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

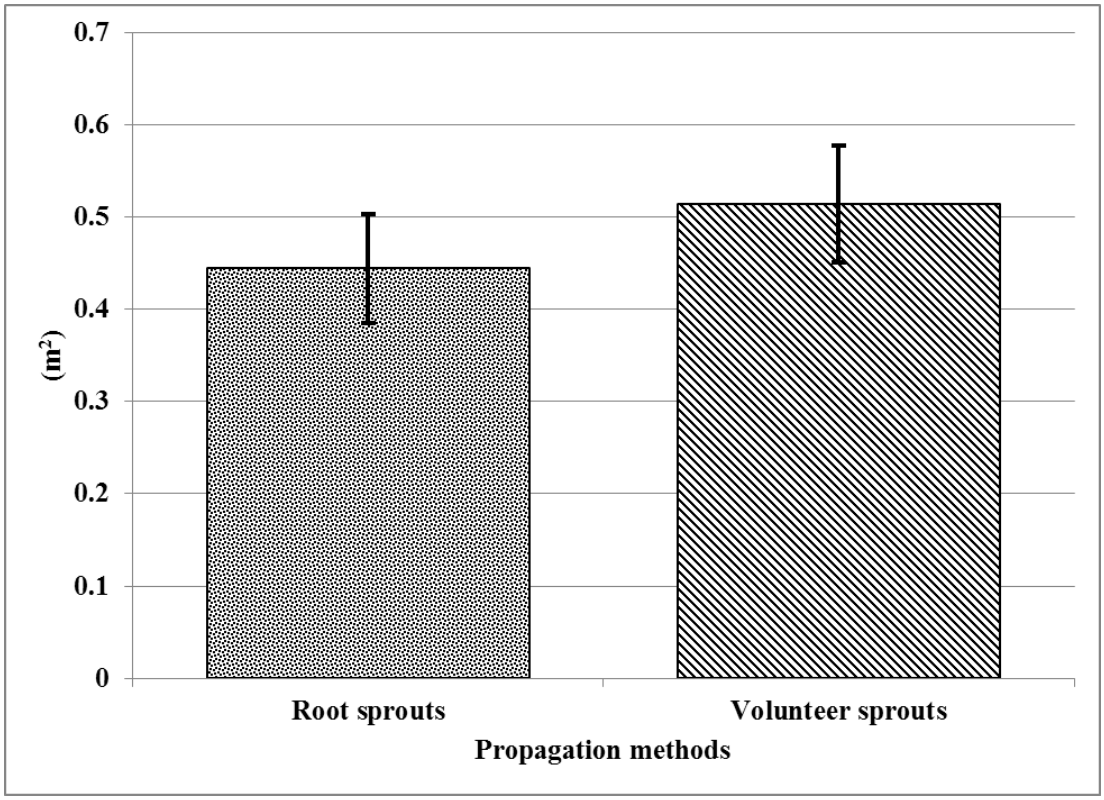

Figure 2: Differences in leaf area of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

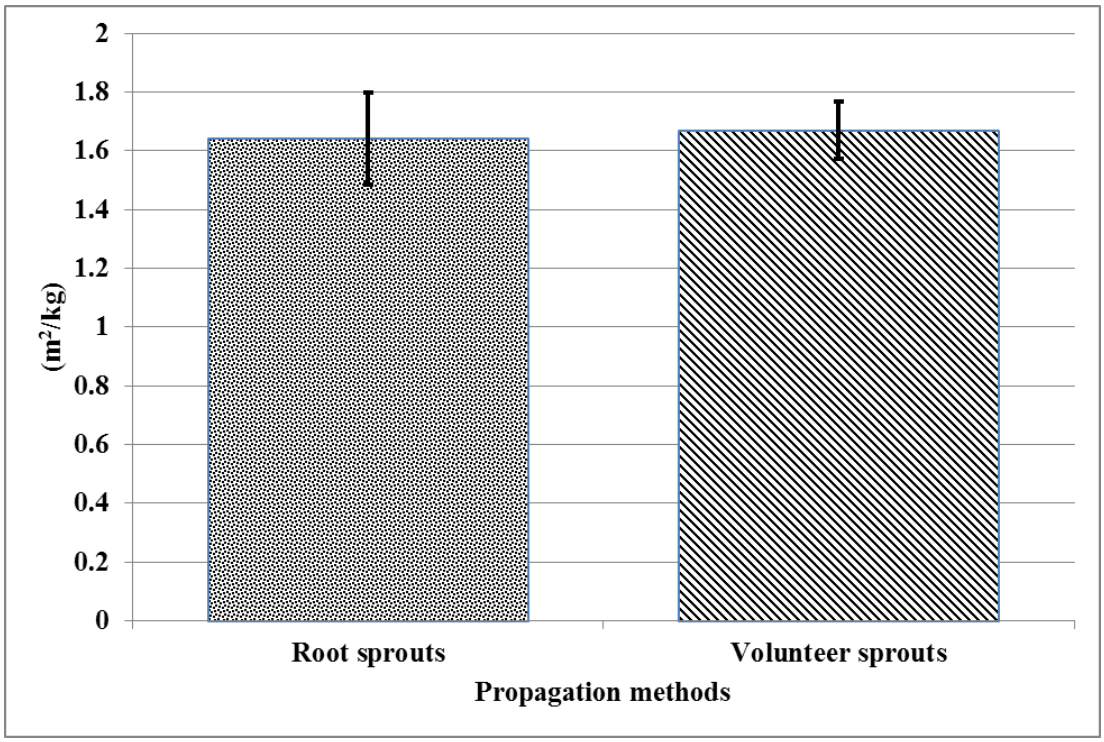

Figure 3: Leaf Area Ratio of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

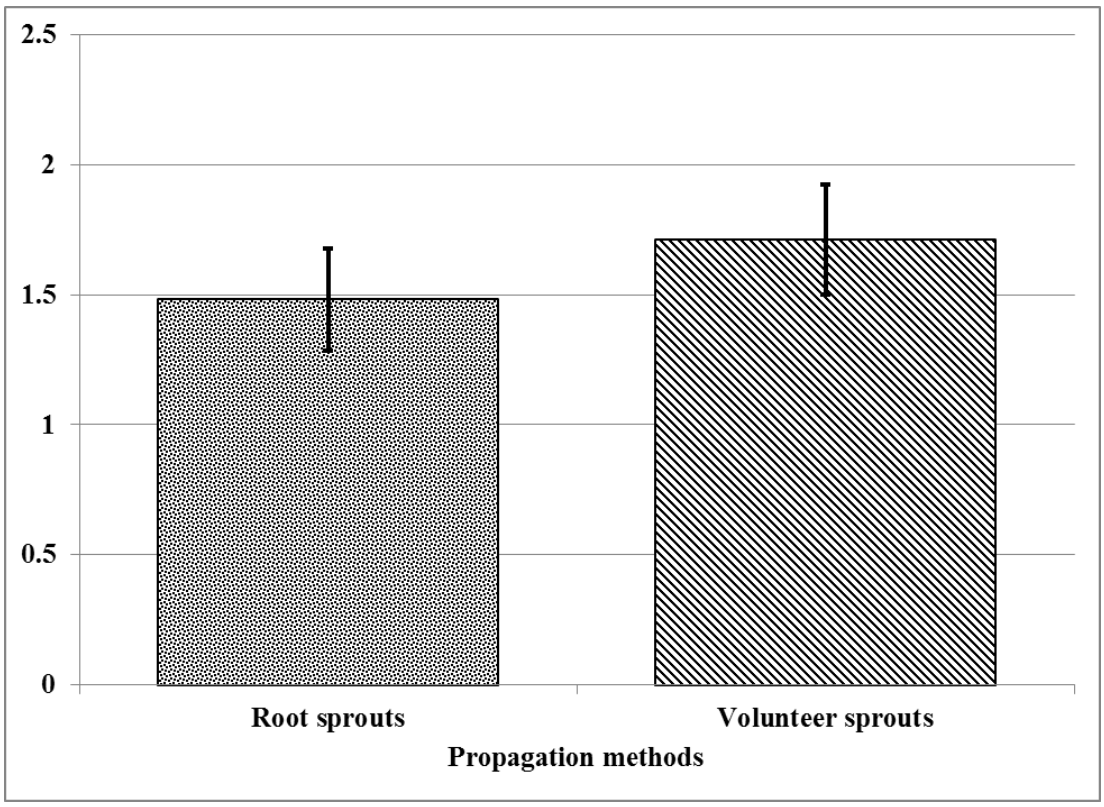

Figure 4: Differences in Leaf Area Index of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

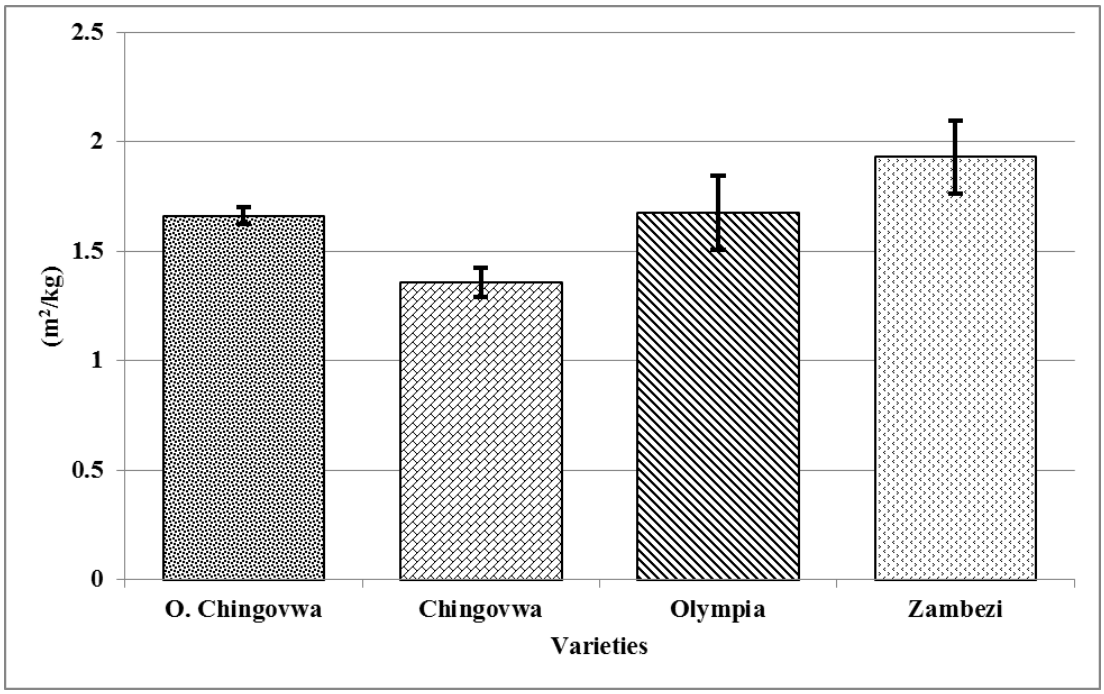

Figure 5: Varietal Leaf Area Ratio in sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs)

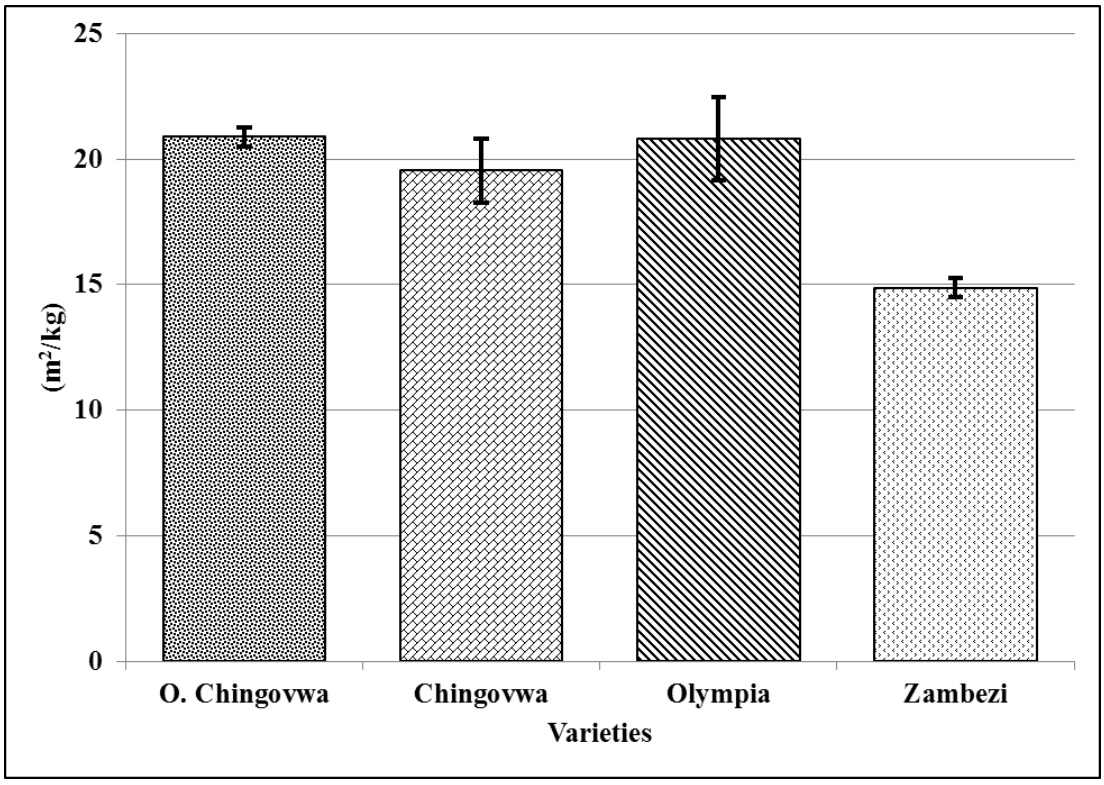

Figure 6: Varietal Specific Leaf Area of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs)

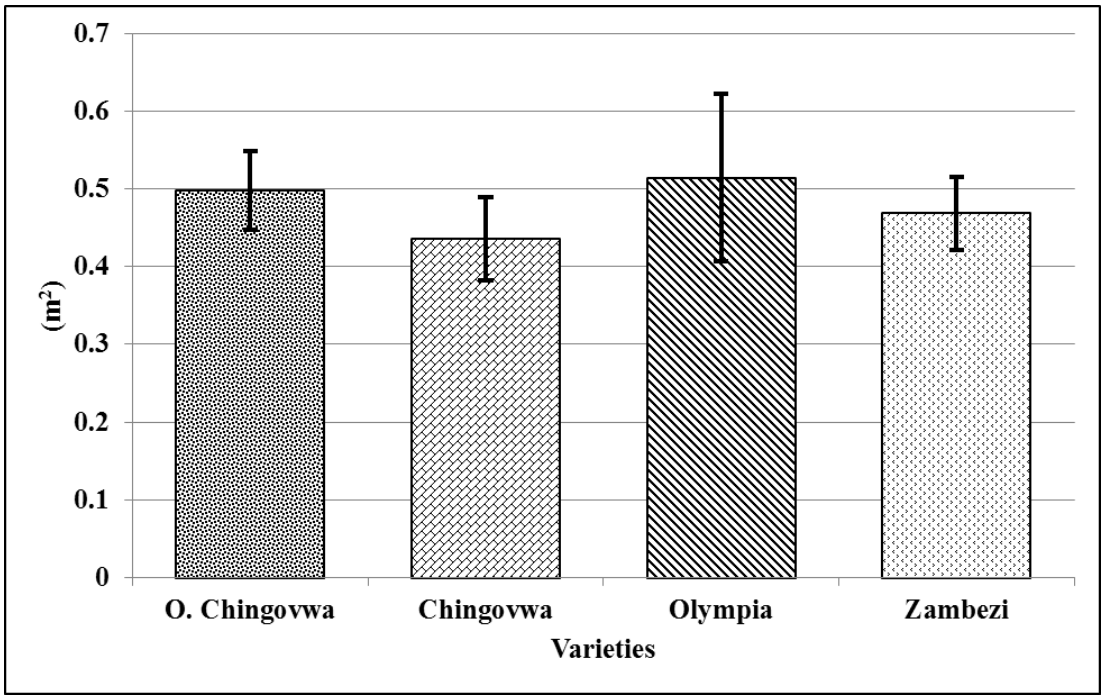

Figure 7: Varietal Leaf Area of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

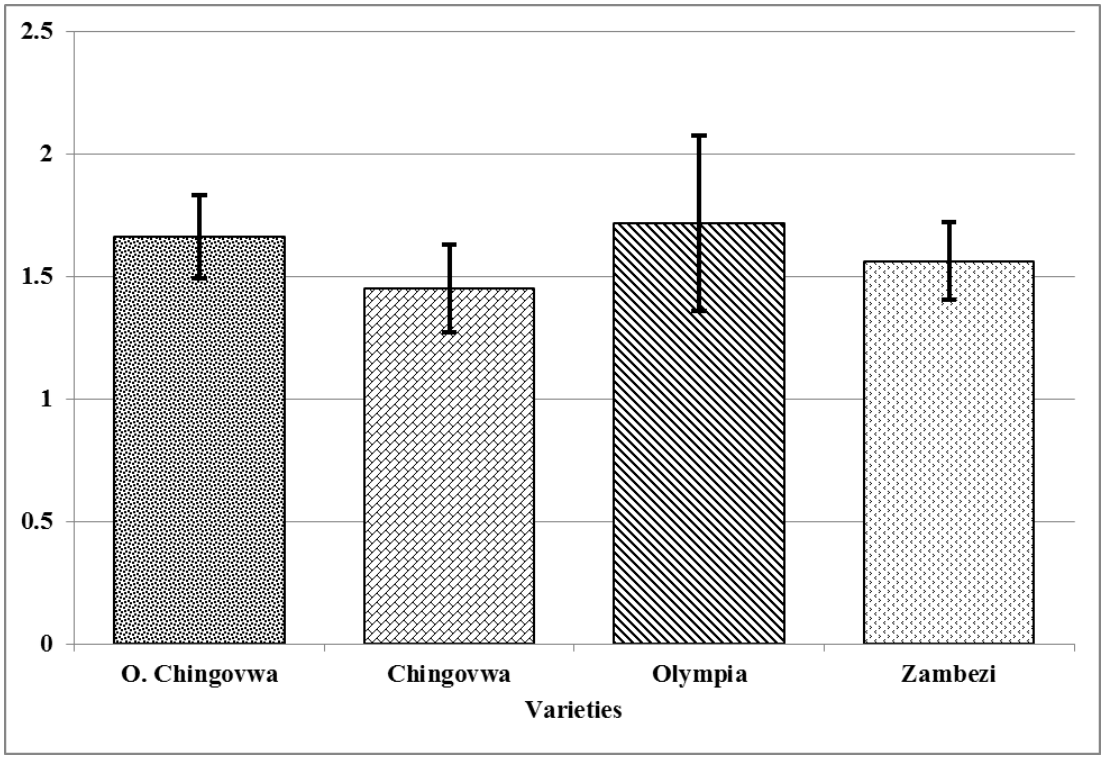

Figure 8: Leaf Area Index in different varieties of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

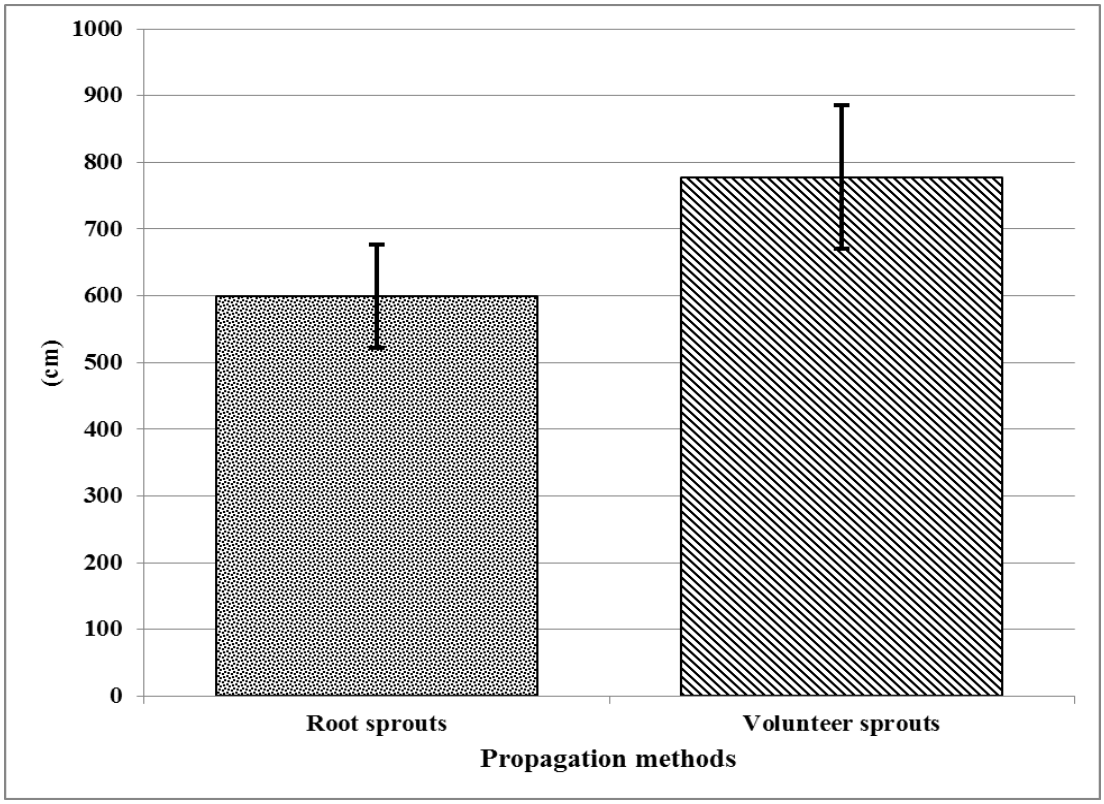

Figure 9: Differences in vine length of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

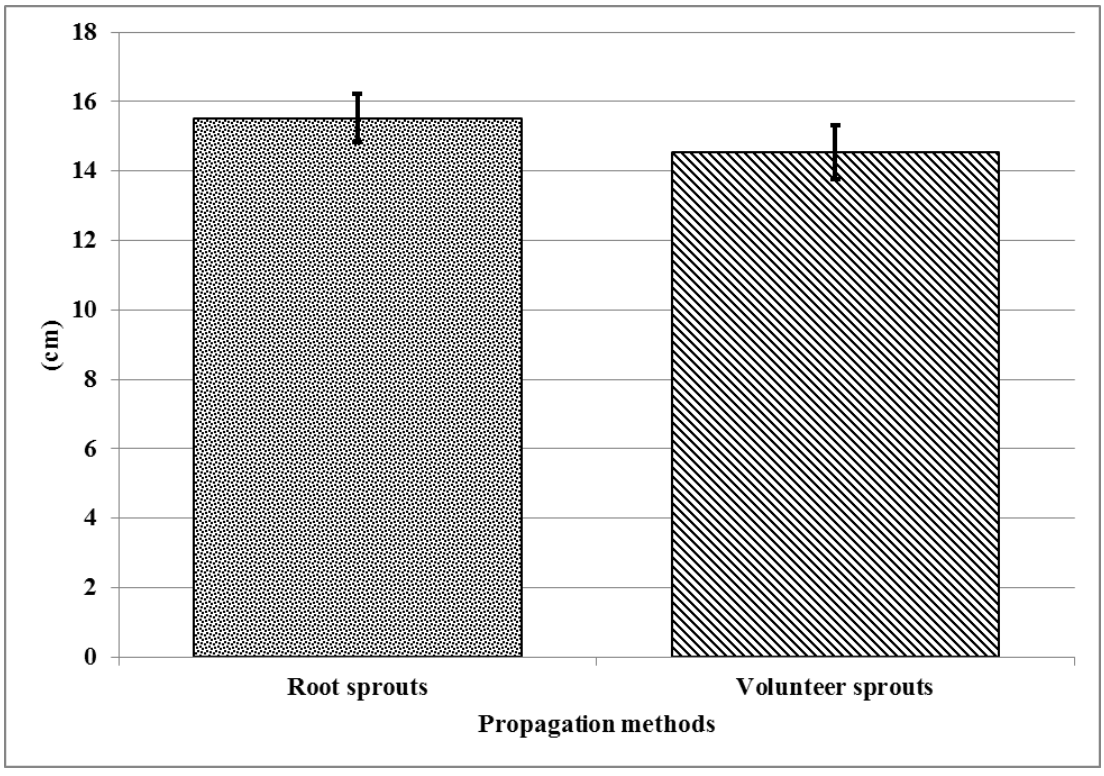

Figure 10: Root length of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

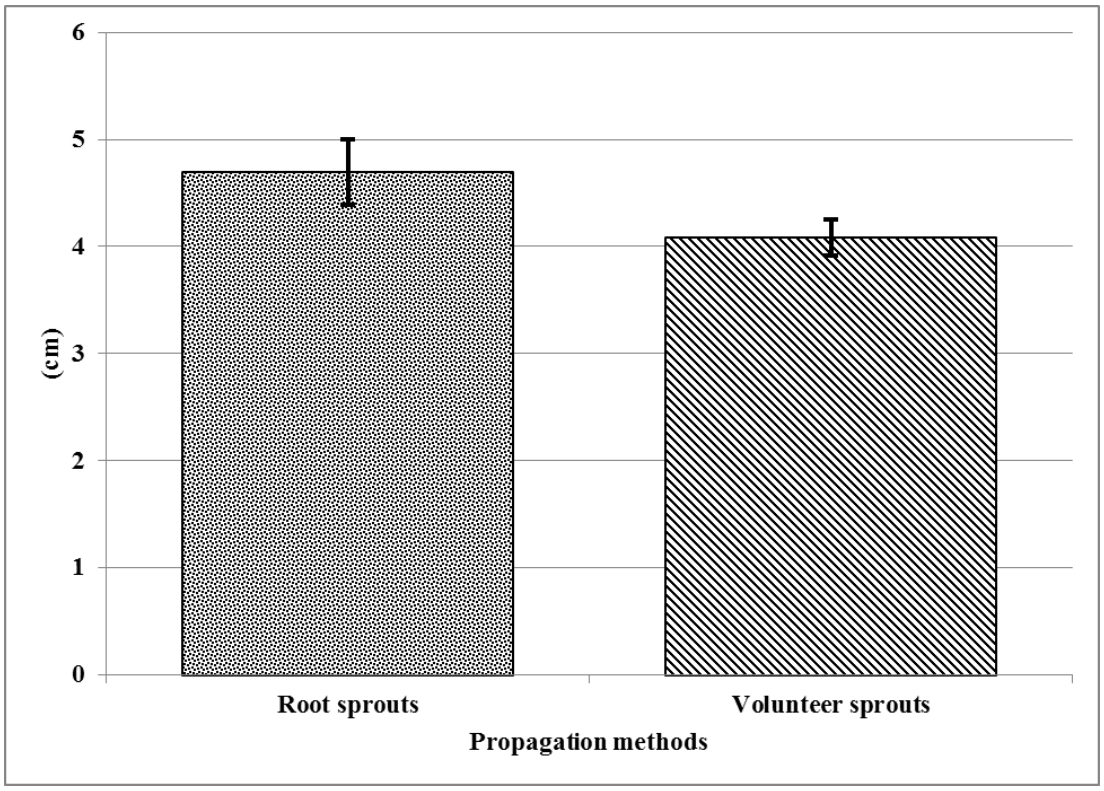

Figure 11: Differences in root diameter of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

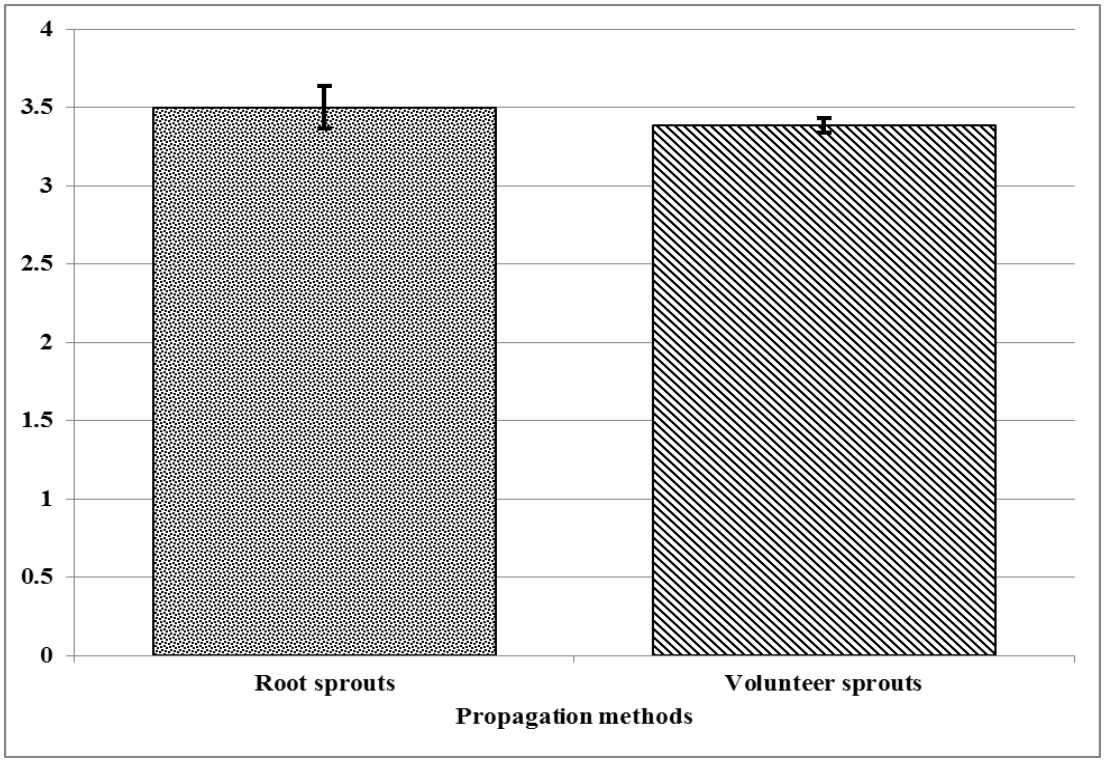

Figure 12: Root: shoot ratios in sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

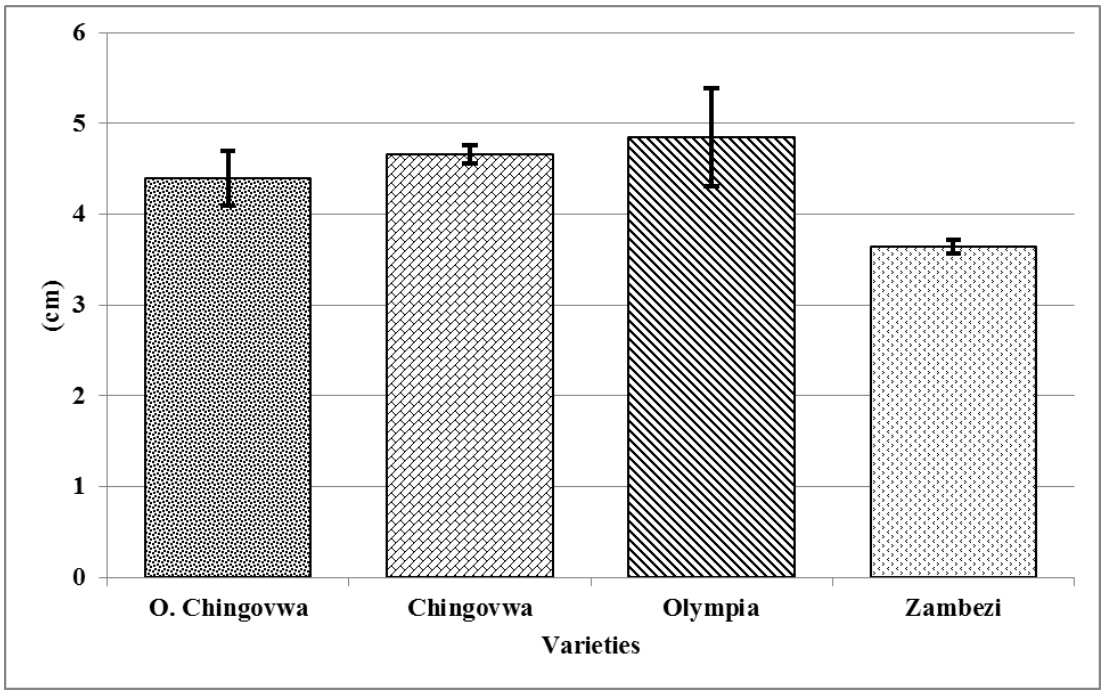

Figure 13: Varietal root diameter in sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

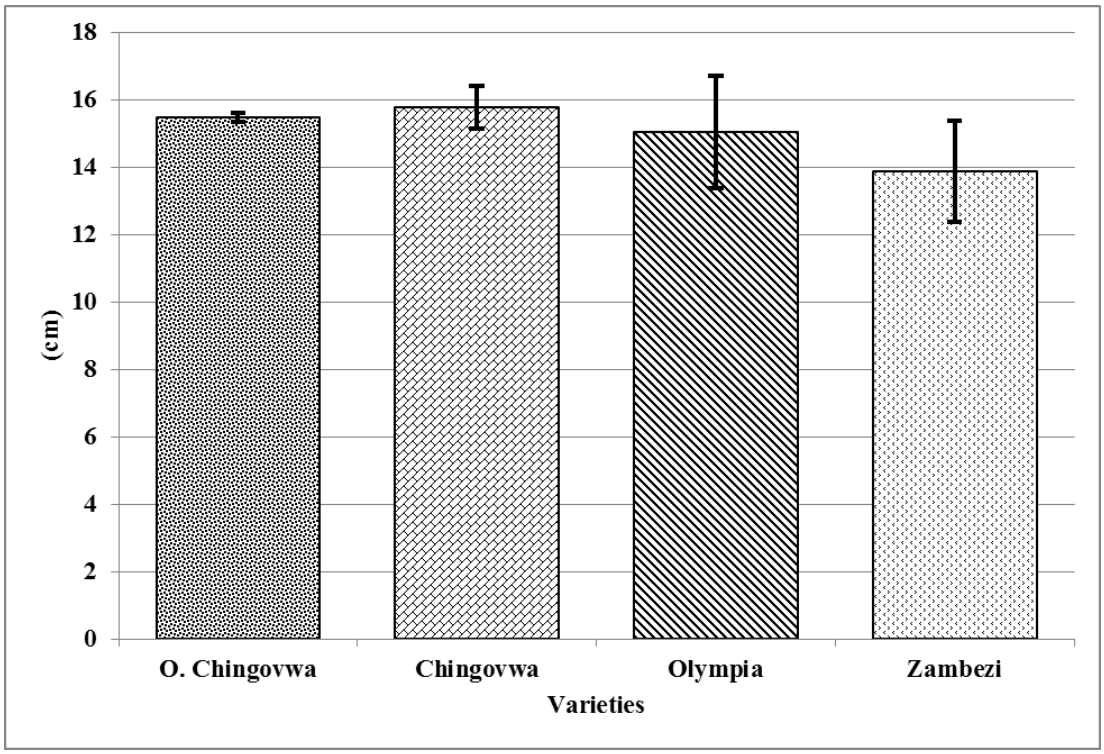

Figure 14: Varietal root length in sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

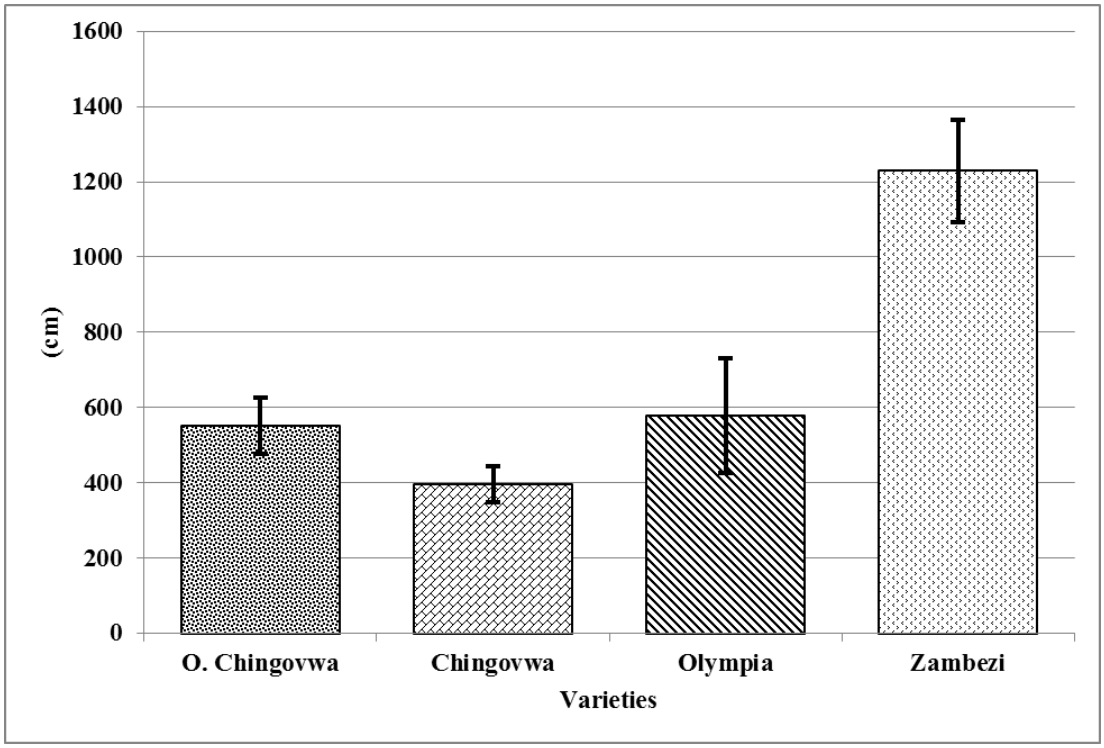

Figure 15: Varietal vine length in sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

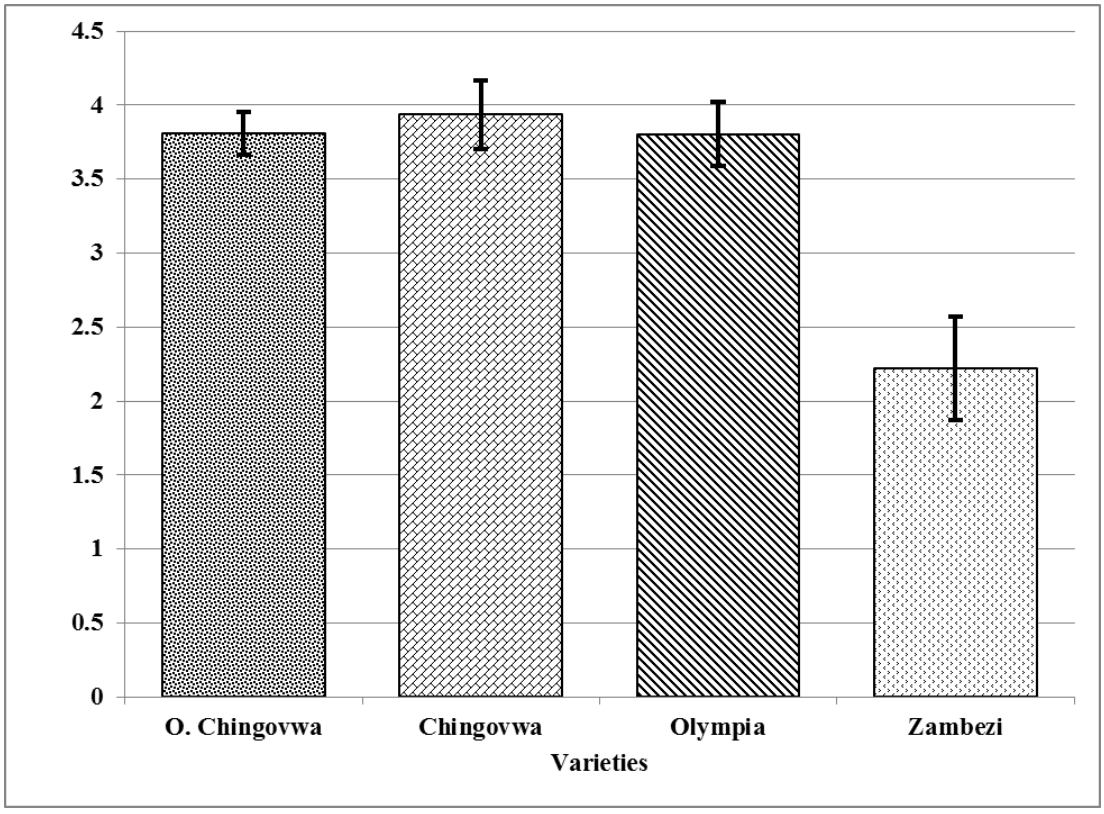

Figure 16: Varietal root: shoot ratios in sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

4.3.3 Storage root production during the full maturity phase

The effects of the treatments on storage root production during the full maturity growth phase are presented in Table 8 and Figures 17, 18, 19, 20, 21 and 22. Propagation method did not affect the total root weight per plant ($p = 0.551$), the marketable roots' weight per plant ($p = 0.724$) nor the non-marketable roots' weight per plant ($p = 0.074$) during this phase of growth (Figures 17, 18 and 19). There were however significant differences between varieties in the total roots' weight per plant ($p = 0.027$), highly significant varietal differences in the marketable roots' weight per plant ($p = 0.002$) and very highly significant varietal differences in the non-marketable roots' weight per plant ($p < 0.001$) during the full maturity growth phase (Figures 20, 21 and 22). Olympia (0.81 kg/ plant) and Orange Chingovwa (0.75 kg/ plant) had higher total root weight per plant compared to Zambezi (0.51 kg/ plant) which was not different from Chingovwa (0.70 kg/ plant). Chingovwa was not different from Olympia and Orange Chingovwa in terms of total root weight per plant. Zambezi had the least marketable roots weight per plant (0.33 kg/ plant) while Orange Chingovwa (0.70 kg/ plant), Chingovwa (0.64 kg/ plant) and Olympia (0.73 kg/ plant) were not different from each other. Zambezi also had the highest non-marketable roots weight per plant (0.17 kg/ plant) followed by Olympia (0.08 kg/ plant), while Orange Chingovwa (0.05 kg/ plant) and Chingovwa (0.06 kg/ plant) that could not be separated from each other had the least non-marketable root yields per plant.

There were no significant propagation method by variety interaction effects on any of the storage root production traits studied during the full maturity growth phase ($p \leq 0.05$).

4.3.4 Harvest Index (HI)

There were no significant differences exerted by propagation method on the Harvest Index (HI) at full maturity ($p = 0.568$) (Table 8 and Figure 23). There was no significant propagation method by variety interaction effect either on the trait ($p = 0.339$). There were however very highly significant varietal differences between varieties in the trait ($p < 0.001$) (Table 8 and Figure 24). Olympia (66.30%) and Orange Chingovwa (64.21 %) had the higher HI's although the latter was not different from Chingovwa (61.57 %) at $p \leq 0.05$. Zambezi (44.71 %) had the least HI.

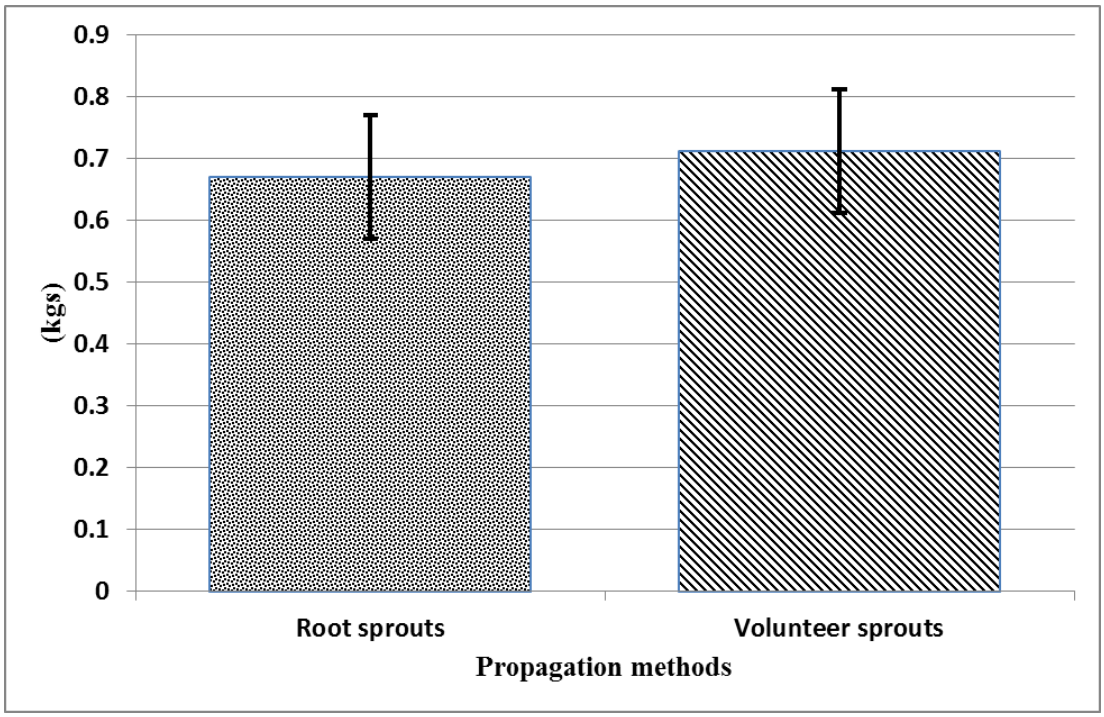

Figure 17: Differences in total root weight per plant of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

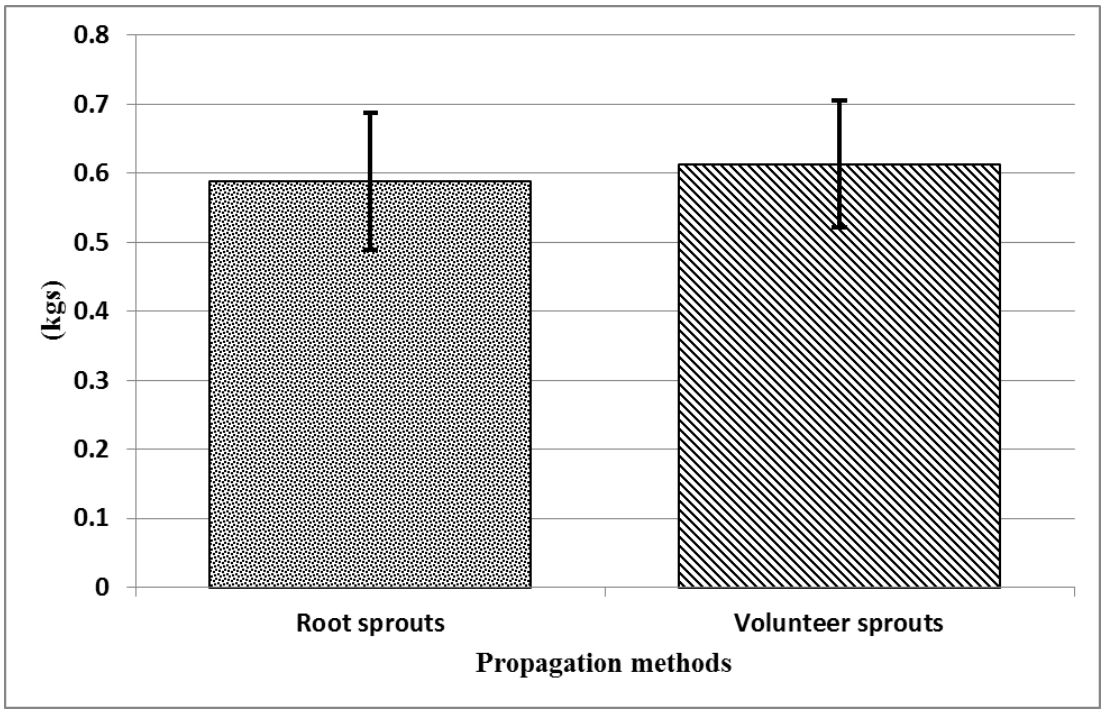

Figure 18: Differences in marketable roots' weight per plant of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

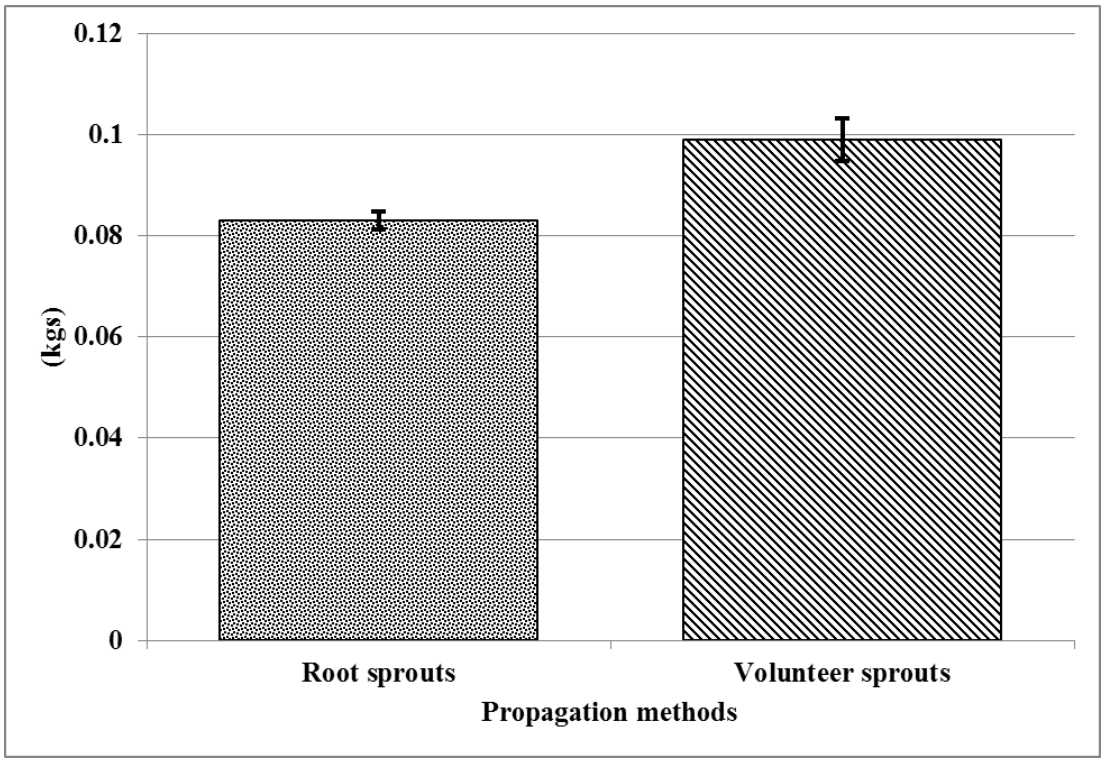

Figure 19: Differences in non-marketable roots' weight per plant of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

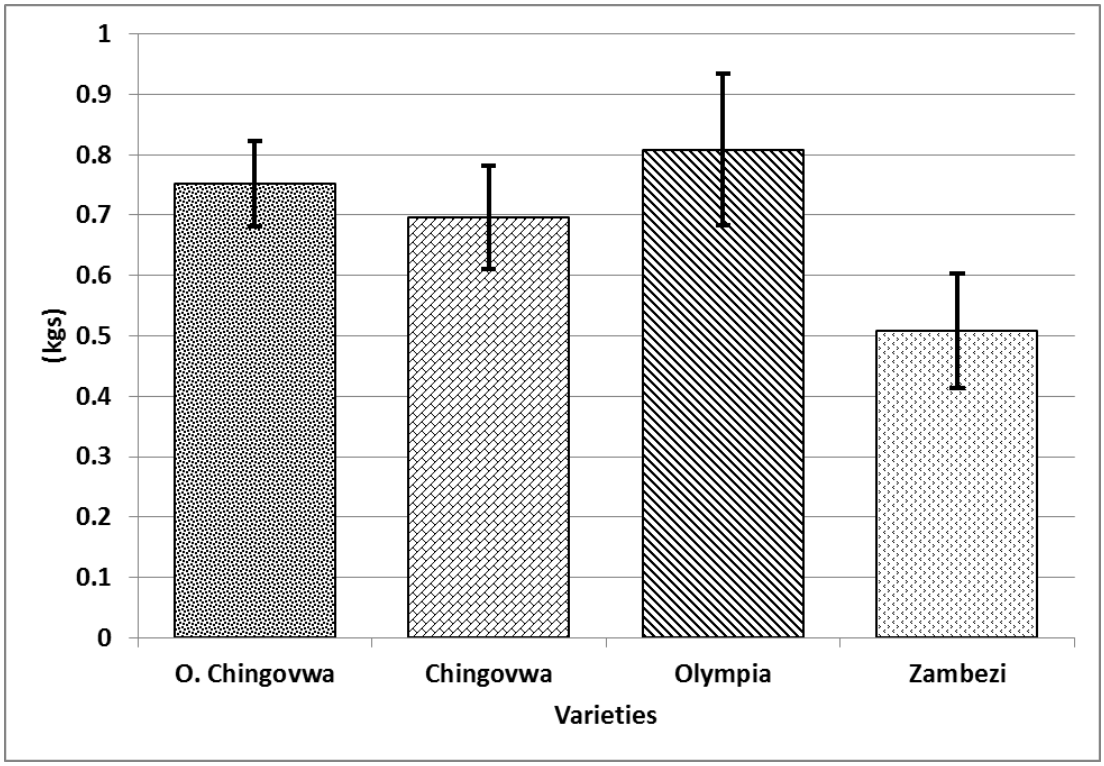

Figure 20: Total root weight per plant in varieties of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

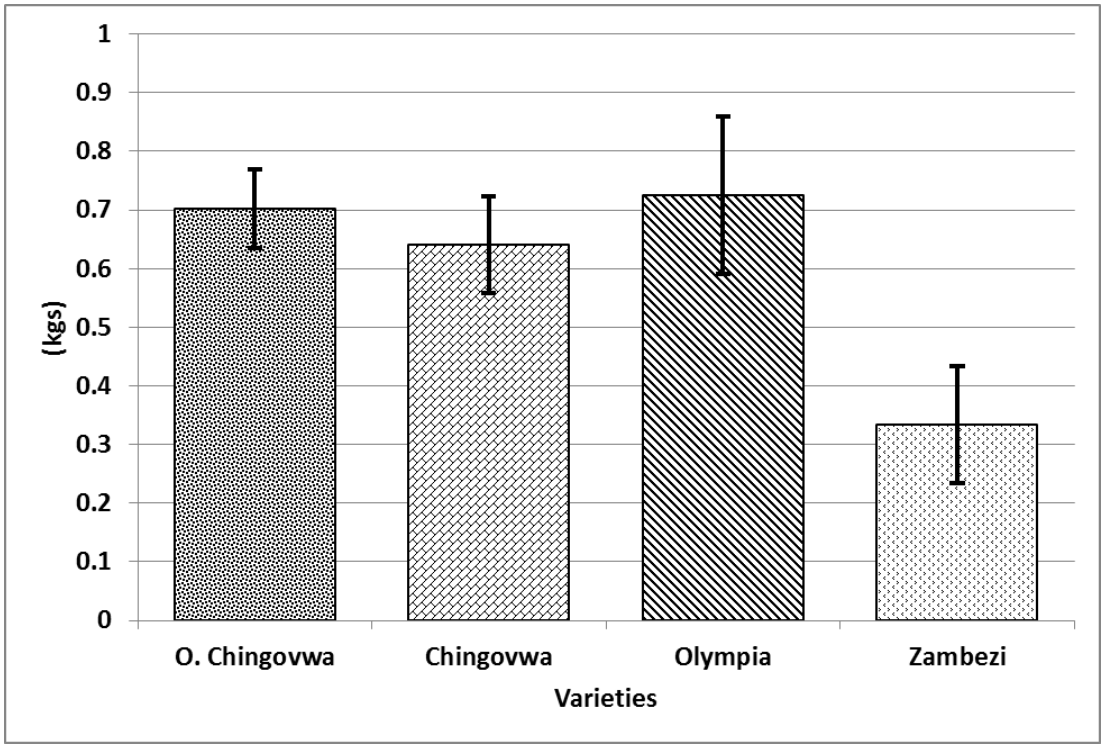

Figure 21: Marketable roots' weight per plant in varieties of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

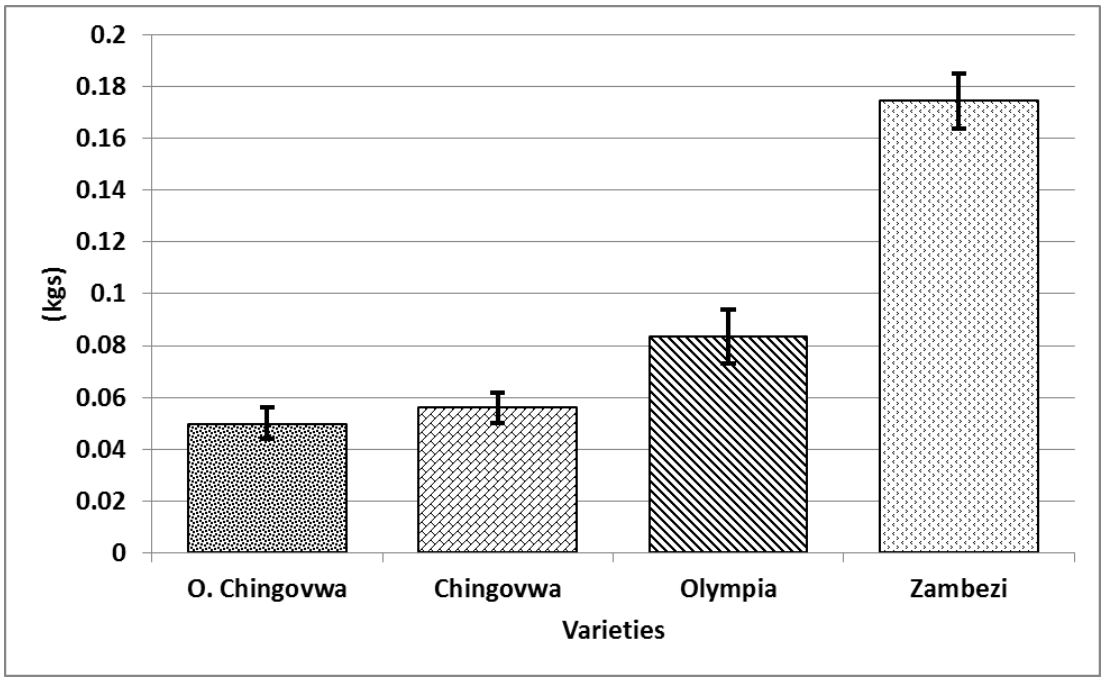

Figure 22: Non-marketable roots' weight per plant in varieties of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

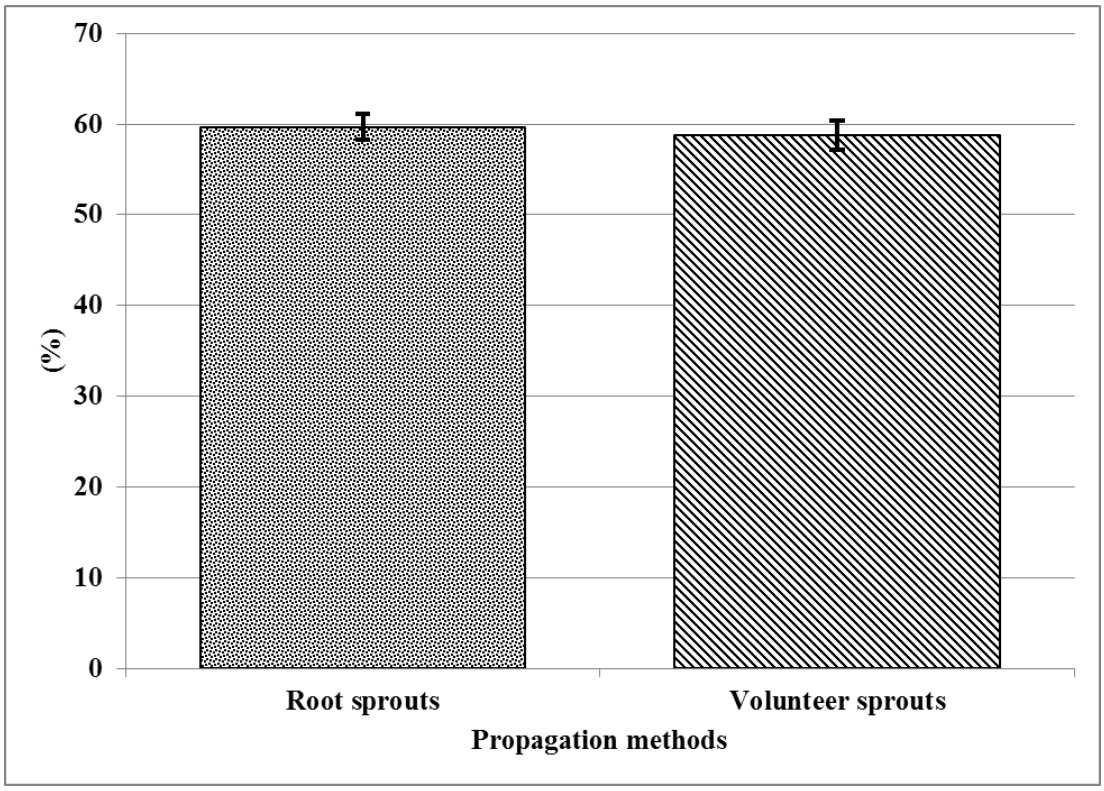

Figure 23: Differences in Harvest Index of sweetpotato (*Ipomoea batatas* (L.) Lam.) propagated under two different methods determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

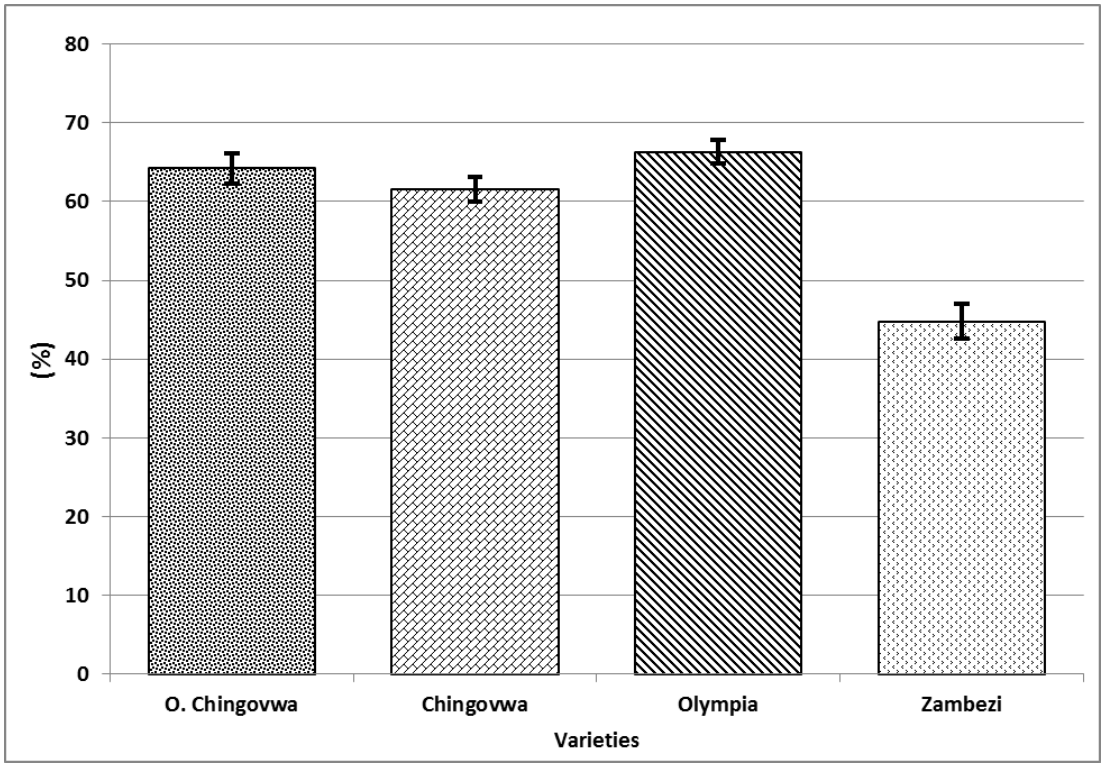

Figure 24: Varietal Harvest Index in varieties of sweetpotato (*Ipomoea batatas* (L.) Lam.) determined at full maturity. Error bars indicate the Standard Errors of the Means (SEMs).

CHAPTER 5

5 DISCUSSION

5.1 Plant establishment in sweetpotato as affected by propagation method and variety

Plant establishment was not affected by propagation method. This had important implications for the growth and yield of subsequent populations as the presence of such differences would be expected to alter growth and result in differences in plant productivity. This lack of differences in establishment between the two methods is contrary to the findings of Lewthwaite (2004) who reported that sweetpotato transplant systems have a significant impact on plant establishment and relatively minor modifications to sweetpotato transplanting systems may lead to major changes in the efficiency of plant establishment. This lack of differences in establishment rates was probably because the plants were grown under optimal conditions and although slight differences were detected early, the plants equalized at the end.

The low establishment attributable to the variety Zambezi had yield reducing implications if the variety is used. Transplant field establishment is a crucial stage in sweetpotato production, to both ensure an even plant stand and to maximise storage root quality and yield (Lewthwaite, 2004) and erratic initial plant spacing or subsequent plant death increases variation in storage root size at harvest (Wilson and Averre 1989; Lewthwaite, 2004). Achieving uniform plant establishment is critical for obtaining higher yields at a later date (Lewthwaite, 2004). Plant propagation and field establishment have the potential to introduce high levels of variability into the crop, while propagules that are morphologically, physiologically and genetically consistent throughout establishment may result in a more uniform crop (Lewthwaite, 2004). The differences in plant establishment among the varieties maybe a result of the different genetic characteristics of candidate varieties that may have affected transplant vigour in the field after transplanting.

There were significant propagation method by variety interaction effects on plant establishment. The variety Zambezi established well when root sprouts were used. The differences in the sum total of environmental effects including temperatures and

moisture attributable to the propagation methods during propagule generation meant that the methods affected vine vigour in the varieties differentially.

The establishment rates attributable to root sprouts and volunteer sprouts in this study, of 98.28% and 95.94% respectively were similar to the value of 97% reported by Alcoy et al. (1993) when apical vine cuttings were used and much higher to the value (88%) when basal cuttings were used. Establishment is lower in basal cuttings because of the relatively older plant material compared to apical cuttings. Yeng *et al*. (2012) has reported establishment percentages ranging from 97% to 100% in sweetpotato.

5.2 Influence of propagation method and variety on vegetative growth in sweetpotato

5.2.1 Leaf traits

In all the phases of growth evaluated, there were minor differences in the leaf traits due to propagation methods. In fact apart from the significant differences in LA and consequently the LAI during the first phase of growth, differences in SLA, LA, LAR and the LAI could not be attributed to propagation method. The differences in LA in the first phase may have been due to varying pre-planting shocks experienced by the vines from the two methods just before planting. Thus, the differences in LA and LAI noted in the first phase of growth were not observed in the latter two stages of growth. This suggests that the initial disadvantage that plants grown from root sprouts had when compared with those grown from volunteer sprouts in the early stages had no lasting negating influence on the leaf development of the plants grown from root sprouts. Thus, the lack of differences in the leaf traits between the propagation methods during the latter development stages meant that propagation method had no implication on storage root production. This is because in the first phase of growth the sink capacity of plants were not developed fully and therefore the initial gains in LA in plants generated from volunteer plant sprouts had no added bearing on the photosynthate accumulation and subsequently on the storage root yield. According to Bhagsari and Ashley (1990) photosynthetic rates in sweetpotato are affected by sink demand, which largely develops during the intermediate phase (CARDI, 2010) when no differences in LA due to propagation method were detected. The absence of LA differences in the latter two phases of growth, in spite

of occurring during the early vegetative growth phase, are attributed to the ability of plants to recover from shocks suffered during early growth.

The LAI values ranged from 0.68 and 0.89 for the root sprouts and volunteer sprouts treatments respectively during the early vegetative growth phase to 1.91 and 1.99 respectively during the full vegetative growth phase and finally 1.48 and 1.71 respectively during the full maturity phase. As noted earlier differences in light capture due to the different LAIs between propagation methods did not impact crop yield as they occurred early during growth. The values for both methods were slightly lower than the mean LAI values ranging from 3.10 to 4.69 reported by Saikia and Borah (2007) during the full maturity growth phase. They were however very similar to the ones reported by Nedunchezhiyan *et al*. (2012 b) who found values ranging from 2.26 to 2.88 from samples harvested during the full maturity growth phase and values ranging from 2.11 to 2.72 from samples harvested in the same phase. The values for the root sprouts treatment are also in agreement with the findings of Alcoy *et al*. (1993) who reported an increasing LAI with change in time that finally climaxes and follows a depression. In their work Alcoy *et al*. (1993) found maximum LAI values in two varieties, of 2 and 2.5 attained during the full vegetative development phase and the full maturity growth phase respectively. Agata (1982) also reported a rapidly increased LAI that reached a climax and descended although values remained above 4.0 throughout the latter half of growth. These values were much higher than the ones found in this study both for the root sprouts' as well as for the volunteer sprouts' treatments. These differences may be attributed to the different varieties used in this study.

There were significant differences in varietal SLAs in all the three phases of growth evaluated. In all the phases of growth, the variety Zambezi produced the least SLAs values of 20.41 m^2/kg, 17.78 m^2/kg and 14.88 m^2/kg respectively. The lower SLAs in Zambezi might imply the reduced translocation of photosynthates from leaves, increasing leaf dry matter and thus leading to reduced storage root yields in the variety. The decreasing values of SLA in the variety Zambezi are contrary to the findings of Lewthwaite (2004) who has reported significant increases in SLA in three varieties as the season progressed. The probable explanation in the case of this study is that there was declining translocation of photosynthates to the storage roots as the

season progressed and this may explain the relatively lower storage root yields in the variety Zambezi, later in the season in comparison to the other varieties.

The differences in LA and LAI due to variety followed the same trend as those conferred by propagation methods. While there were significant differences in LA and LAI due to variety during the first phase of growth, there were no such differences in the traits in the latter phases of growth. This scenario is in agreement with the report that LA varies widely among varieties and at different growth periods (Somasundaram and Mithra, 2008). It is suggested as stated earlier in this section that these early differences in LA conferred no advantage in the final storage root yield of any particular variety as the sink capacity of the varieties evaluated had not developed adequately during the early growth phase. As a matter of consequence, the Leaf Area Index followed the same pattern.

There were no significant differences in the LAR among varieties in all phases except the full maturity growth phase. In this phase of growth the variety Chingovwa produced a lower LAR value of 1.44 m^2/kg compared to Zambezi, probably, indicating a stronger root sink for the variety as the ratio obtained for the variety indicates a lower leaf area per unit of total plant biomass. This thought is collaborated by the absence of LA differences between varieties during the full maturity growth phase. The scenario is also collaborated by the lower storage root yield in Zambezi at full maturity. A relatively strong root sink is required in the latter stages of growth in order to maximise yield (Bhagsari, 1990; Lewthwaite, 2004).

In all the three phases of growth, there was no significant propagation method by variety interaction effects on any of the leaf traits evaluated. Therefore the LA, LAI, LAR and SLA among the varieties do not vary depending on the propagation method and neither do the propagation methods depend on the variety used with regard to the leaf traits.

5.2.2 Vine growth (VL)

There were significant differences in VL due to propagation method during the early vegetative growth phase but no such differences were noticeable in the latter two phases of growth. The longer vines attributable to the volunteer sprouts method during early growth made it favourable for use in the multiplication of planting materials as well as livestock feed if harvest was planned for 40 days after planting.

sweetpotato vines maybe used as fodder for livestock (M. Nedunchezhiyan *et al*., 2012 b).The VLs ascribed to the root sprouts' and volunteer sprouts' treatments of 599.00 cm and 778.00 cm respectively during the full maturity phase were greatly superior to those reported by Nedunchezhiyan *et al.* (2012 b) who found values ranging from 91.90 cm to 117.30 cm during the full maturity growth phase. These differences in VLs between those of this study and those reported by Nedunchezhiyan *et al.* (2011 b) could have been due to the different varieties used on the two occasions. As was the case with Leaf Area, Vine Length differed between Propagation methods only in the early phase of growth. Similarly, the differences in the first phase could have been a result of varying pre-planting shocks experienced by the vines from the two methods just before planting out in the field.

There were significant differences in VL between varieties in all the three growth phases evaluated. Notably, Olympia and Zambezi had longer vines than Chingovwa during the first phase of growth, while Zambezi was consistently superior to the other three varieties in vine length in the latter two phases of growth. These varietal differences in vine length could have been a result of the characteristic variations in the vegetative development of the evaluated varieties. El-baky *et al*., (2009) illustrated that vegetative parameters were affected by use of different cultivars and stated that these variations may be attributed to hereditary characters. The 1,229.00 cm attributable to the variety Zambezi at maturity is much longer than the values (between 197.18 cm and 456.12 cm) found by Egbe *et al*. (2012) in an evaluation of eleven varieties, although significant differences between varieties were similarly reported.

Significant propagation method by variety interaction effects on VL were detected only in the early vegetative growth phase. During this phase volunteer sprouts produced longer vines in the variety Zambezi while the variety Olympia favoured long vines in the root sprouts method. It is suggested that varieties reacted differently to the different processes of generating vines in the two methods evaluated and these effects were transferred to the field upon establishment.

5.3 Root quality in sweetpotato [*Ipomoea batatas* (L.) Lam.] as influenced by propagation method and variety

5.3.1 Root: shoot ratios (RSRs)

There were no differences in RSRs due to propagation method in all the three phases of growth evaluated. There were significant differences in varietal RSRs in all the three phases of growth evaluated. The differential rate of storage root bulking resulting from differences in sink strength as well as massive vegetative growth in some varieties may be responsible for the varietal differences in the RSR in the latter two phases of growth. In these phases clear differences had emerged in the root weights of the varieties.

There were no significant propagation method by variety interaction effects on the RSRs during any of the three growth phases evaluated. This indicates the absence of any selective influence of propagation method on the varieties for the RSR trait and vice versa.

5.3.2 Root length (RL) and diameter (RD)

There were no significant differences in the RL of plants grown from the two propagation methods at any of the three evaluated phases of growth. During the full maturity phase the two methods produced RLs of 15.53 cm and 14.53 for the root sprouts' and the volunteer sprouts' treatments respectively. These figures are similar to the ones reported by Nedunchezhiyan *et al*., (2012 b) who found mean RLs ranging between 11.50 cm and 15.30 cm. Although the variety Zambezi produced the longer roots during early vegetative growth phase there were no significant varietal differences in RLs in the last two phases of growth. The response of varieties varied with Propagation method for the trait root length during the first and last phases of growth.

There were no significant differences in the RDs due to propagation method at any of the three phases of growth evaluated. The RDs of the root sprouts' and volunteer sprouts' treatments of 4.69 cm and 4.08 cm respectively in the full maturity phase were similar to the RDs reported by Nedunchezhiyan *et al*. (2012 b) in the range of 4.90 cm to 7.70 cm. Variety conferred significant differences on RD, however, during all the three phases of growth with the variety Zambezi consistently producing the thinner roots than Chingovwa and Olympia during the first and last

phases, while it had thinner roots than all the other three varieties during the full vegetative growth phase. Varietal differences in RL and RD may be expected because of the probable differences in the genetic composition of candidate varieties (Egbe *et al*., 2012).

There were no significant propagation method by variety interaction effects on the RL nor the RD, thus indicating that varietal RL and RD did not depend on the propagation method used and neither did the propagation method depend on the variety used.

5.4 Storage root production in sweetpotato [*Ipomoea batatas* (L.) Lam.] as affected by Propagation method and Variety

There were no significant differences due to propagation method in total root yield per plant, the yield of marketable roots per plant and the yield of non-marketable roots per plant at full maturity. Either method could therefore be used in sweetpotato production without due loss of yield. This is contrary to the report of Ozturk *et al*. (2012) that root sprouts have a tendency of losing yielding capacity. The current study found 0.67 kg and 0.71 kg total plant root yield using the root sprouts' and the volunteer plant sprouts treatments, respectively. Ozturk *et al*. (2012) on the other had reported 4.00 kg and 3.00 kg when *in vitro* plantlets and root sprouts were used, respectively. The relative lack of yielding capacity loss in this study must be in the fact that Ozturk *et al*. (2012) compared root sprouts to *in vitro* plantlets that generally should perform superiorly due to the more conducive nature of propagule rearing. This study on the other hand compared root sprouts to volunteer sprouts that are not generated under guided conditions and are subject to the vagaries of the environment. The relative differences in the yield of root sprouts under this study (0.67 kg/ plant) versus those reported by Ozturk *et al*. (2012) (3.00 kg/ plant) must be in the different varieties used at the two different occasions. Although not specific to propagation method, Nedunchezhiyan *et al.* (2012 b) have reported lower plant root yields ranging from 0.12 kg/ plant to 0.18 kg/ plant. Similarly, Belehu (2003) has reported a marketable root yield of 0.72 kg per plant which is just slightly higher than the 0.59 kg/ plant and the 0.61 kg/ plant found for the root sprouts' and the volunteer plant sprouts' treatments in this study. These differences in yield can be attributed to the use of different varieties.

Zambezi had the lowest marketable roots' yield per plant as well as the highest non-marketable roots yield per plant. As stated under root length, varietal differences in growth are most probably explained by the high genetic variability that exists among varieties. Serenje and Mwala (2010) also attributed differences in the yield of marketable and non-marketable roots to variety. Bhagsari and Ashley (1990) reported differences in sink strength among sweetpotato genotypes.

In the full maturity growth phase there was no significant propagation method by variety interaction effect on either the total roots' yield per plant, the marketable roots' yield per plant or the marketable roots' yield per plant. Therefore, propagation method acted independently of variety with regard to storage root yields, and vice versa.

5.5 Harvest Index (HI) in sweetpotato [*Ipomoea batatas* (L.) Lam.] as affected by propagation method and variety

The lack of discernible differences in Harvest Index between methods implies that method had no influence on the Harvest Index achieved in the test plants. The HIs obtained from root sprouts' (59.67%) and volunteer sprouts' (58.77%) treatments respectively were lower than the mean location values (ranging from 60% to 89%) reported by Serenje and Mwala (2010). These differences in the HIs may be a result of using different varieties.

There were significant differences in HI between varieties though. The variety Zambezi gave the least Harvest Index at full maturity and this indicates lower sink strength in comparison with the other three varieties. These differences among the varieties are attributed to the inherent variations in the genetic composition of varieties and accordingly, their photosynthate partitioning habits.

CHAPTER 6

6 CONCLUSIONS AND RECOMMENDATIONS

This study sought to investigate the relationship between propagation method, and plant development and yield of sweetpotato. Specifically the study evaluated the performance of the crop when propagated from vines from either volunteer plants or storage roots.

This study has shown that differences in selected traits restricted to the early vegetative growth phase did not confer substantial effects on the growth and yield of sweetpotato when the two propagation methods were used. The differences in leaf area and consequently in the leaf area index in the early vegetative growth phase were particularly evident although these were conspicuously absent during the latter phases of growth. When such differences between the two methods occur during the early vegetative growth phase the plants recover and equalize in the latter phases and these early differences do not confer any growth and yield advantage to either of the two propagation methods.

The results show that propagation method has no significant influence on the growth and yield of sweetpotato; there are no growth and yield differences when the sweetpotato plant is cultivated using sprouts from roots versus sprouts from volunteer plants. Rather, there are differences in the morphophysiological traits evaluated when different varieties are used. Although there were isolated cases when significant interaction effects were detected, such were rare occurrences.

Since this study was undertaken in one site and over one season, it is recommended that the study be repeated over different sites in repeated growing seasons. The inclusion of other planting materials such as dambo raised vines and in vitro plantlets will shed more light on the possible growth and yield differences possible with the use of varied propagation methods. It is further recommended to conduct an inventory of the various propagation methods for sweetpotato in Zambia and quantify their current and future application. It is also recommended that further studies be conducted to determine the best length of storage time/ period for successful re-sprouting of roots in the method “Storage root sprouts”. Complementation of sand storage with initial *in situ* storage might result in better

efficacy of roots at planting time and thus result in better sprouting rates as this may reduce the shocks on roots associated with bucket-sand storage. Determining the costs of production for the two evaluated methods of propagation is another area proposed for investigation.

The key role of plant propagation is to ensure that growers have access to adequate quantities of high quality and disease free planting materials at any time of the year. In Zambia a viable sweetpotato propagation sector is yet to develop. However, the first stage which is investment in research to develop new varieties has started. The next phase after development of high performance varieties will be to put in place Certication and Registration machanisms. These will ensure that detection and elimination procedures for transmissable diseases and pests are in place. These upstream processes are largely government responsiblities. They have to be followed down stream by private sector activites such as establishment of private nurseries and retail chains.

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APPENDICES

Appendix A: Analysis of variance for plant establishment during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	19.34	6.45	0.51	
Rep.*Units* stratum					
Prop	1	43.95	43.95	3.50	0.075
Var	3	589.65	196.55	15.67	<.001
Prop.Var	3	184.96	61.65	4.91	0.010
Residual	21	263.48	12.55		
Total	31	1101.37			

Appendix B: Analysis of variance for specific leaf area (SLA) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	14.254	4.751	1.15	
Rep.*Units* stratum					
Prop	1	6.966	6.966	1.68	0.209
Var	3	73.807	24.602	5.94	0.004
Prop.Var	3	9.779	3.260	0.79	0.515
Residual	21	87.038	4.145		
Total	31	191.844			

Appendix C: Analysis of variance for leaf area (LA) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.059153	0.019718	5.21	
Rep.*Units* stratum					
Prop	1	0.031017	0.031017	8.19	0.009
Var	3	0.052029	0.017343	4.58	0.013
Prop.Var	3	0.005184	0.001728	0.46	0.716
Residual	21	0.079552	0.003788		
Total	31	0.226934			

Appendix D: Analysis of variance for leaf area ratio (LAR) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	3.975	1.325	0.31	
Rep.*Units* stratum					
Prop	1	6.035	6.035	1.43	0.245
Var	3	9.586	3.195	0.76	0.530
Prop.Var	3	6.284	2.095	0.50	0.688
Residual	21	88.453	4.212		
Total	31	114.333			

Appendix E: Analysis of variance for leaf area index (LAI) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.65725	0.21908	5.21	
Rep.*Units* stratum					
Prop	1	0.34463	0.34463	8.19	0.009
Var	3	0.57810	0.19270	4.58	0.013
Prop.Var	3	0.05760	0.01920	0.46	0.716
Residual	21	0.88391	0.04209		
Total	31	2.52149			

Appendix F: Analysis of variance for vine length (VL) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	24958.	8319.	5.25	
Rep.*Units* stratum					
Prop	1	38040.	38040.	24.00	<.001
Var	3	17859.	5953.	3.76	0.026
Prop.Var	3	19849.	6616.	4.17	0.018
Residual	21	33292.	1585.		
Total	31	133998.			

Appendix G: Analysis of variance for root diameter (RD) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.30338	0.10113	2.65	
Rep.*Units* stratum					
Prop	1	0.00001	0.00001	0.00	0.987
Var	3	0.79450	0.26483	6.93	0.002
Prop.Var	3	0.23016	0.07672	2.01	0.144
Residual	21	0.80256	0.03822		
Total	31	2.13061			

Appendix H: Analysis of variance for root length (RL) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	55.753	18.584	3.77	
Rep.*Units* stratum					
Prop	1	6.367	6.367	1.29	0.268
Var	3	85.382	28.461	5.78	0.005
Prop.Var	3	12.622	4.207	0.85	0.480
Residual	21	103.410	4.924		
Total	31	263.533			

Appendix I: Analysis of variance for root: shoot ratios (RSRs) during early vegetative growth (40 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.03313	0.01104	0.83	
Rep.*Units* stratum					
Prop	1	0.00127	0.00127	0.10	0.760
Var	3	0.12690	0.04230	3.19	0.045
Prop.Var	3	0.01480	0.00493	0.37	0.774
Residual	21	0.27815	0.01325		
Total	31	0.45425			

Appendix J: Analysis of variance for specific leaf area (SLA) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	5.6104	1.8701	2.05	
Rep.*Units* stratum					
Prop	1	0.3263	0.3263	0.36	0.556
Var	3	61.7743	20.5914	22.58	<.001
Prop.Var	3	7.1766	2.3922	2.62	0.077
Residual	21	19.1498	0.9119		
Total	31	94.0374			

Appendix K: Analysis of variance for leaf area (LA) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.44355	0.14785	8.02	
Rep.*Units* stratum					
Prop	1	0.00452	0.00452	0.25	0.626
Var	3	0.03244	0.01081	0.59	0.630
Prop.Var	3	0.08858	0.02953	1.60	0.219
Residual	21	0.38713	0.01843		
Total	31	0.95623			

Appendix L: Analysis of variance for leaf area ratio (LAR) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	10.253	3.418	2.56	
Rep.*Units* stratum					
Prop	1	0.547	0.547	0.41	0.529
Var	3	7.824	2.608	1.95	0.152
Prop.Var	3	1.573	0.524	0.39	0.759
Residual	21	28.043	1.335		
Total	31	48.241			

Appendix M: Analysis of variance for leaf area index (LAI) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	4.9283	1.6428	8.02	
Rep.*Units* stratum					
Prop	1	0.0502	0.0502	0.25	0.626
Var	3	0.3605	0.1202	0.59	0.630
Prop.Var	3	0.9843	0.3281	1.60	0.219
Residual	21	4.3014	0.2048		
Total	31	10.6247			

Appendix N: Analysis of variance for vine length (VL) (cm) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	508377.	169459.	5.71	
Rep.*Units* stratum					
Prop	1	91478.	91478.	3.08	0.094
Var	3	875556.	291852.	9.83	<.001
Prop.Var	3	84043.	28014.	0.94	0.437
Residual	21	623220.	29677.		
Total	31	2182674.			

Appendix O: Analysis of variance for root diameter (cm) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	2.2490	0.7497	2.21	
Rep.*Units* stratum					
Prop	1	0.0256	0.0256	0.08	0.786
Var	3	18.4103	6.1368	18.11	<.001
Prop.Var	3	0.6502	0.2167	0.64	0.598
Residual	21	7.1145	0.3388		
Total	31	28.4496			

Appendix P: Analysis of variance for root length (cm) during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	104.28	34.76	1.54	
Rep.*Units* stratum					
Prop	1	2.56	2.56	0.11	0.740
Var	3	28.59	9.53	0.42	0.739
Prop.Var	3	15.66	5.22	0.23	0.873
Residual	21	473.70	22.56		
Total	31	624.79			

Appendix Q: Analysis of variance for root: shoot ratios during the full vegetative development phase (80 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.3006	0.1002	0.52	
Rep.*Units* stratum					
Prop	1	0.0000	0.0000	0.00	0.992
Var	3	7.6619	2.5540	13.32	<.001
Prop.Var	3	0.2161	0.0720	0.38	0.771
Residual	21	4.0259	0.1917		
Total	31	12.2046			

Appendix R: Analysis of variance for specific leaf area (SLA) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	43.145	14.382	1.82	
Rep.*Units* stratum					
Prop	1	3.705	3.705	0.47	0.501
Var	3	192.548	64.183	8.14	<.001
Prop.Var	3	17.433	5.811	0.74	0.542
Residual	21	165.609	7.886		
Total	31	422.441			

Appendix S: Analysis of variance for leaf area (LA) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.27365	0.09122	3.21	
Rep.*Units* stratum					
Prop	1	0.03886	0.03886	1.37	0.255
Var	3	0.02926	0.00975	0.34	0.794
Prop.Var	3	0.18976	0.06325	2.23	0.115
Residual	21	0.59616	0.02839		
Total	31	1.12768			

Appendix T: Analysis of variance for leaf area (LAR) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.7360	0.2453	2.09	
Rep.*Units* stratum					
Prop	1	0.0071	0.0071	0.06	0.809
Var	3	1.3094	0.4365	3.73	0.027
Prop.Var	3	0.3281	0.1094	0.93	0.442
Residual	21	2.4601	0.1171		
Total	31	4.8406			

Appendix U: Analysis of variance for leaf area index (LAI) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	3.0406	1.0135	3.21	
Rep.*Units* stratum					
Prop	1	0.4317	0.4317	1.37	0.255
Var	3	0.3251	0.1084	0.34	0.794
Prop.Var	3	2.1084	0.7028	2.23	0.115
Residual	21	6.6240	0.3154		
Total	31	12.5298			

Appendix V: Analysis of variance for vine length (VL) (cm) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	754427.	251476.	3.48	
Rep.*Units* stratum					
Prop	1	254318.	254318.	3.52	0.075
Var	3	3271711.	1090570.	15.09	<.001
Prop.Var	3	41873.	13958.	0.19	0.900
Residual	21	1517603.	72267.		
Total	31	5839932.			

Appendix W: Analysis of variance for root diameter (cm) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	2.7493	0.9164	1.28	
Rep.*Units* stratum					
Prop	1	2.9504	2.9504	4.12	0.055
Var	3	6.7218	2.2406	3.13	0.048
Prop.Var	3	0.6324	0.2108	0.29	0.829
Residual	21	15.0542	0.7169		
Total	31	28.1081			

Appendix X: Analysis of variance for root length (cm) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	39.610	13.203	2.07	
Rep.*Units* stratum					
Prop	1	7.889	7.889	1.24	0.278
Var	3	16.593	5.531	0.87	0.473
Prop.Var	3	24.764	8.255	1.30	0.302
Residual	21	133.818	6.372		
Total	31	222.674			

Appendix Y: Analysis of variance for root: shoot ratios during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.5714	0.1905	0.21	
Rep.*Units* stratum					
Prop	1	0.1111	0.1111	0.12	0.733
Var	3	16.0290	5.3430	5.76	0.005
Prop.Var	3	4.0825	1.3608	1.47	0.252
Residual	21	19.4961	0.9284		
Total	31	40.2901			

Appendix Z: Analysis of variance for total plant root yield (kg) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.61518	0.20506	5.70	
Rep.*Units* stratum					
Prop	1	0.01319	0.01319	0.37	0.551
Var	3	0.40494	0.13498	3.75	0.027
Prop.Var	3	0.13752	0.04584	1.27	0.309
Residual	21	0.75589	0.03599		
Total	31	1.92672			

Appendix AA: Analysis of variance for marketable roots (per plant) (Kg's) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.62009	0.20670	5.45	
Rep.*Units* stratum					
Prop	1	0.00486	0.00486	0.13	0.724
Var	3	0.78530	0.26177	6.91	0.002
Prop.Var	3	0.18148	0.06049	1.60	0.220
Residual	21	0.79587	0.03790		
Total	31	2.38759			

Appendix BB: Analysis of variance for Non-Marketable roots (per plant) (Kg's) during the full maturity phase (120 days after planting).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.0005691	0.0001897	0.33	
Rep.*Units* stratum					
Prop	1	0.0020360	0.0020360	3.54	0.074
Var	3	0.0795506	0.0265169	46.10	<.001
Prop.Var	3	0.0042384	0.0014128	2.46	0.091
Residual	21	0.0120800	0.0005752		
Total	31	0.0984741			

Appendix CC: Analysis of variance for Harvest Index (H.I) (120 days after planting)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	219.09	73.03	3.82	
Rep.*Units* stratum					
Prop	1	6.42	6.42	0.34	0.568
Var	3	2310.03	770.01	40.27	<.001
Prop.Var	3	68.05	22.68	1.19	0.339
Residual	21	401.54	19.12		
Total	31	3005.13			

Appendix DD: Weather data at Kaithinde in the 2012-2013 Agricultural Season

MONTH	RAIN DAYS	AMOUNT (mm)	TEMPERATURE	
			Max (^{O}C)	Min (^{O}C)
September, 2012	0	0		
October, 2012	1	1.7	33.9	18.2
November, 2012	4	20.7	33	18.6
December, 2012	11	106.4	31.2	18.9
TOTALS	16	127.8		
January, 2013	14	169.4	30.6	18.9
February, 2013	12	142.4	33	17
March, 2013	10	106.3	30	17.3
April, 2013	3	9.7	33.5	10.5
May, 2013	1	12	32	10.1
June, 2013	0	0	30.2	7
TOTALS	40	439.1		
TOTAL (Sept-June)	56	569.9		

Source: Meteorological Department, Lundazi District

Appendix EE: Results of Soil Analyses at Kaithinde

Measured parameter	**Result**	**Method**
Total Nitrogen (%)	0.18	Kjeldahl procedure
Phosphorous (mg/kg)	6.62	Bray and Kurtz
Potassium (mg/kg)	164.48	Atomic Absorption Spectrophotometry
Sodium (mg/kg)	10.80	Atomic Absorption Spectrophotometry
Calcium (mg/kg)	313.16	Atomic Absorption Spectrophotometry
Magnesium (mg/kg)	152.39	Atomic Absorption Spectrophotometry
pH ($CaCl_2$)	4.84	Glass electrode pH meter
Bulk density (g/cm^3)	1.59	Core ring
Organic matter (%)	1.33	Walkely Black