AGRONOMICAL AND PHYSIOLOGICAL FACTORS AFFECTING GROWTH, DEVELOPMENT AND YIELD OF SWEET POTATO IN ETHIOPIA

by

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ABSTRACT

Morphological and anatomical studies demonstrated the root formation characteristics of sweet potato. The presence and importance of preformed root primordia is recorded for the first time. On the vines root primordia are present in sets of four to ten adjacent to the leaf bases. These roots originate from the procambium on both sides of the leaf gap. Macroscopically the root tips of preformed root primordia protruding through the cortex and epidermis of the stems are prominent. The preformed root primordia produce adventitious roots, with pentarch, hexarch or septarch steles. Storage roots will under normal circumstances only originate from undamaged root primordia on the nodes of cuttings, or on nodes of newly formed vines, or from wound roots originating from the cut ends of the stem or leaf cuttings. Lateral roots originating from damaged root primordia, or directly from the adventitious roots, exhibit tetrarch steles and develop into fibrous roots without the potential to develop into storage roots. This understanding of the origin, anatomy and morphology of sweet potato roots should improve production practices, which will contribute to improved crop establishment and increased yield.

Differences in the contribution of individual subterranean nodes to storage root yield were studied. On average cuttings with three subterranean nodes produced 3.7 storage roots, with 33.2% on subterranean node 1, 30.0% on node 2 and 36.8% on node3. However, in terms of fresh mass of the storage roots node 1 contributed 45.4%, node 2 contributed 27.1% and node 3 contributed 27.4%.

The effect of temperature (20, 24, 28 and 32 ^{o}C constant), orientation of cuttings (vertical vs. horizontal) and size of cuttings (1 or 3 nodes) on the development of adventitious roots was observed in plant growth chambers. Twenty-one days after planting, the longest total root length of 4m per plant was recorded from the 24 ^{o} C growth chamber. The effect of soil moisture content on early root development was investigated by wetting and equilibrating sandy soil to 100, 80, 60 and 40% of field capacity. Although the 80% of field capacity treatment resulted in the best root development, differences among treatments were small, demonstrating the capacity of cuttings to successfully establish under a range of soil moisture contents.

Changes in dry mass of storage roots, stems, and leaves of three sweet potato cultivars (Awasa-83, Bareda and Falaha) were studied at Awasa and Melkassa. At the final sampling the early maturing cultivar Falaha had diverted a higher proportion of the total dry mass into storage roots at Melkassa because of the early initiation and growth of storage roots. The late maturing cultivar Awasa-83 had a smaller proportion of the total dry mass diverted into the storage roots at both locations because of late root initiation and growth. The high yielding cultivars Bareda at Melkassa, and Awasa-83 at Awasa, had higher crop growth rates and higher net assimilation rates than the other cultivars.

The effects of cultivar (Kudadie, Bareda and Awasa-83), planting position (horizontal and vertical), type of planting material (terminal cuttings with and without leaves) and cutting length (20, 25 and 30 cm) on the number and yield of storage roots were quantified in field trials at Awasa and Melkassa. Cultivar Kudadie produced the highest storage root yield at both locations. Horizontal planting of cuttings resulted in the highest total storage root yield at both locations. Cutting length did not affect storage root number and yield.

The effect of population density (50,000, 55,555, 75,000, and 100,000 cuttings per hectare) on the performance of the three Ethiopian sweet potato cultivars was studied at Awasa. The highest planting density consistently produced the best root yield, indicating the potential to increase yields with plant populations much higher than normally used. Early maturing cultivar Falaha produced more small and medium storage roots per plant, while the intermediate cultivar Bareda produced more large storage roots.

Key words: Adventitious root, cutting characteristics, dry matter partitioning, *Ipomoea batatas*, leaf gap, planting density, preformed root primordia, soil moisture, subterranean node, sweet potato, wound roots.

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CHAPTER 1

GENERAL INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.) belongs to the family Convolvulaceae. It is a herbaceous dicot widely grown throughout the tropics and warm temperate regions of the world between latitudes 40°N and S of the equator and between sea level and 2300 m altitude (Shukla, 1976; Hahn, 1977a; Bourke, 1982; Jana, 1982). Globally sweet potato is the seventh most important food crop after wheat, rice, maize, potato, barley, and cassava. Sweet potato is the second most important root and tuber crop in the world after potato (Horton, 1988). In Sub-Saharan Africa sweet potato is the third most important tuber crop after cassava (*Manihot esculenta*) and yam (*Dioscorea* spp.) (Ewell & Mutuura, 1994). More than 140 million tons of sweet potato is produced globally per year (FAO, 2000). The world average storage root yield of sweet potato has been estimated to be 14.8t ha^{-1} (FAO, 2000). Asia is the world's largest sweet potato producing continent, with 129 million tons annual production. China with 121 million tons accounts for 86% of world sweet potato production. Nearly half of the sweet potato produced in Asia is used for animal feed, the remaining primarily used for human consumption, either fresh or as processed products.

Although African farmers produce only about 9 million tons of sweet potato annually, most of the crop is cultivated for human consumption. African yields are quite low at 4 to 5 tons per hectare, about a third of the Asian yields, indicating huge potential for future growth. In Africa the crop is grown on small scale, primarily to help ensure food security of the rural households (Ewell & Mutuura, 1994).

Sweet potato is cultivated in Ethiopia mostly for human consumption and as animal feed. It ranks third after Enset (*Ensete ventricosum* (Welw.) Cheesman,) and potato *(Solanum* *tuberosum L.*) as the most important root crop produced in the country. Sweet potato is mainly grown by small scale, resource poor farmers. According to FAO (2000) the Ethiopian national average storage root yield of sweet potato is 8t ha^{-1}. Experimental storage root yields ranging between 30 and 73t ha^{-1} have been reported by Hossain *et al*., (1987), Siddique *et al*., (1988), Hall & Harmon, (1989), Bhagsari & Ashley, (1990) and Varma *et al*., (1994).

Yields obtained in Ethiopia are generally low, but there is good potential for the crop since climatic and soil factors are largely favourable. Ethiopia has an area of 1,122,000 km^2, 65% of the land is arable, with 15% presently cultivated. Ethiopia is in the tropical zone and has three climatic zones according to elevation. Tropical zone (Kwolla) is hot and humid, below 1830 masl and has an average annual temperature of 27^{o}C with annual rainfall of about 510 mm. Subtropical zone (Woina dega) is warm, and includes the highland areas of 1830 to 2440 masl and has an average annual temperature of about 22^{o}C, with annual rainfall between 510 and 1530 mm. Cool zone (Dega) is above 2440 masl with an average annual temperature of about 16^{o}C and annual rainfall between 1270 and 1280 mm. There are two seasons, the dry and rainy seasons. The dry season prevails from October to May. The rainy season is bimodal the short and the long rainy seasons the short rainy season is from February to April, while the long rainy season extends from June to September. Sweet potato is adapted to the tropical zone (Kwolla) and subtropical zone (Woina daga) areas of southern, southwestern and eastern parts of the country (http://www.ethiotreasures.plus.com/pages/climate.htm) (2002).

The crop has relatively few pests and diseases, and pesticides are rarely used. Sweet potato can be grown in poor soils with little or no fertilizers. Sweet potato grows best where average temperatures are 24^{o}C, the thermal optimum is reported to be about 24^{o}C (Kay, 1973). At temperatures below 10^{o}C growth is severely retarded. The crop is damaged by frost, and this fact restricts the cultivation of sweet potato in the temperate regions to areas with a minimum frost-free period of 4 to 6 months. Even where the frost-free period is sufficiently long, it is still essential that temperatures are relatively high during much of the growing period. In the tropics, yields decline with increasing altitude as do the number of storage roots and the proportion of roots that are marketable (Negeve *et al.*, 1992). Increasing altitude also delays maturity.

Growers of sweet potato in Ethiopia are faced with a number of problems in trying to improve the yield and quality of the crop. There are natural and technical limitations in the production of the crop. The natural limitations include drought, high temperature at low altitudes, frost at high altitudes, and lack of irrigation. Poor land preparation, lack of high yielding and adapted cultivars, lack of sufficient quantity of good quality cuttings, sub or supra-optimal plant population, improper method and depth of planting, careless harvesting, poor post-harvest handling, and lack of crop rotation are some of the factors that contribute to poor crop establishment and low yield.

Since sweet potato is the most important food crop in the densely populated areas of Ethiopia, and is also considered a potential cash crop for small-scale farmers, more information is needed on the yield physiology and management of the crop. Basic information on the origin and structure of sweet potato storage roots is still limited. Information on the contribution of individual nodes to total storage root mass and number is very limited. Such information will help to develop appropriate and affordable technologies to improve crop yield and quality in

Ethiopia. In this study the main objective was a better understanding of the yield physiology and agronomy of the crop in order to improve production in Ethiopia.

The approach was to:

1. Investigate the origin, structure and function of the adventitious roots (Chapter 3). Practically no information is available about the origin or the relationship between origin and structure.

2. Quantify the effect of temperature and soil water content on root and shoot growth in pot experiments (Chapter 4).

3. Establish the contribution of individual subterranean nodes from different types of planting material to storage root number and mass (Chapter 5).

4. Analyse dry matter production and partitioning of three sweet potato cultivars by means of standard growth analyses, specifically crop growth rate, tuber growth rate and net assimilation rate in field trials in Ethiopia (Chapter 6).

5. Determine effect of cutting characteristics on yield and yield components (Chapter 7).

6. Establish the effect of planting density and cultivar on yield and yield components by conducting field experiments (Chapter 8).

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CHAPTER 2

LITERATURE REVIEW

Sweet potato (*Ipomoea batatas* (L.) Lam.) is a member of the Convolvulaceae family (Purseglove, 1972). Approximately 900 different species of Convolvulaceae in 400 genera have been identified around the world. Yen (1974) and Austin (1978, 1988) recognized 11 species in the section batatas, which includes sweet potato. The closest relative of the sweet potato appears to be *Ipomoea trifida* that is found wild in Mexico, and *Ipomoea tabascana.* Sweet potato has a chromosome number of 2n = 90. Since the basic chromosome number for the genus *Ipomoea* is 15, sweet potato is considered to be a hexaploid. Most sweet potato cultivars are self-incompatible, which means that when self-pollinated, they cannot produce viable seed. It is accepted that cultivated sweet potato originated in Central America or tropical South America. Nishiyama (1971) and Martin & Jones (1972) suggested Mexico as a centre of diversity of the *batatas* section of *Ipomoea.*

2.1 CROP USES

Sweet potato is an important crop in many parts of the world. The storage roots of sweet potato serve as staple food, animal feed (Posas, 1989), and to a limited extent as a raw material for industrial purposes as a starch source and for alcohol production (Collins, 1984). In Japan dehydrated sweet potato is ground into flour, which is cooked for human consumption. Sweet potato starch is used for the manufacture of adhesives, textile and paper sizing and in the confectionery and baking industries. In most parts of the tropics, sweet potato is consumed boiled, baked, roasted or fried. Preparation practices vary according to the location. In Ethiopia, roots are boiled unpeeled or roasted unpeeled in the ash of a fire before being eaten, or less commonly, the sweet potato is boiled or fried with other vegetables or root crops. In Taiwan most sweet potatoes are eaten boiled or boiled and mixed with white rice. The fried chips are packaged and sold as a snack. For some areas in Asia, the snack types of sweet potato cultivars were bred for maximum yield and respond to high management inputs. The snack type of sweet potato used in Japan and Taiwan is also important, particularly in urban areas. The tender leaves are used as a vegetable in Africa, Indonesia and the Philippines. The vines are widely used as a fodder for livestock.

2.2 CROP DESCRIPTION

A. THE ROOT SYSTEM

When sweet potato is planted from stem cuttings, adventitious roots arise from the cutting in a day or two. These roots grow rapidly and form the root system of the plant. Research has shown that the roots of sweet potato can penetrate the soil to a depth of over 2m, the exact depth attained being dependent on the soil condition (Onwueme, 1978 and Kays, 1985). Based on its origin, the root system of sweet potato is divided into the adventitious roots arising from the subterranean nodes of a vine cutting and lateral roots arising from existing roots. Kays (1985) subdivided the adventitious roots into storage, fibrous and pencil roots. The lateral roots are subdivided into primary, secondary and tertiary roots. During the early ontogeny of young adventitious roots emerging from the stem, they are often separated into two classes namely thin and thick roots (Togari, 1950). According to Wilson (1982) and Kays (1985) thin roots are typically tetrarch in the arrangement of their primary vascular tissue, i.e., four xylem and phloem poles found within the vascular cylinder. The thick roots are pentarch or hexarch in structure. Under adverse conditions thick roots are reported to give rise to string roots (primary fibrous roots) and pencil roots depending on the primary cambial activity and the amount of lignification of cells of the stele (Hahn & Hozyo, 1984; Du Plooy, 1989). The most important functional differences between these root types are their capacity for storage root initiation in a specific region of the thick roots. Several factors such as exposure of potential storage roots to long photoperiod (Bonsi *et al.*, 1992), water logged soil conditions (Kays, 1985), high level of nitrogen supply (Wilson, 1973; Chua & Kays, 1981), gibberellic acid application (McDavid & Alamu, 1980), as well as exposing the plant to long days (McDavid & Alamu, 1980; Du Plooy, 1989) encourage lignification and inhibit storage root development. Alternatively high potassium supply (Tsuno, 1971; Hahn & Hozyo, 1984), the absence of light (Wilson, 1982), as well as well aerated soil conditions, low temperature and short days have been demonstrated to encourage storage root formation (Du Plooy, 1989).

a. *Storage Roots*

Storage roots arise from pentarch or hexarch thick young roots if the cells between the protoxylem points and the central metaxylem cell do not become lignified (Wilson & Lowe, 1973), or if only a slight proportion of these cells are lignified (Togari, 1950). The increase in storage root size is attributed to the activity of the vascular cambium as well as the activity of the anomalous cambia (Wilson, 1982). The initial sign of storage root formation is the accumulation of photosynthates consisting predominantly of starch (Chua & Kays, 1982). Storage root initiation is reported to occur between the period 35 to 60 days after planting (Enyi, 1977; Agata, 1982; Wilson, 1982). But the work of Du Plooy (1989) indicated that storage root initiation might occur as early as 7 days after planting. These conflicting results suggest the need for further research on the storage root formation in sweet potato.

Agata (1982) reported that storage root formation started about 30 to 35 days after planting and the root dry weight increased linearly until harvest. Wilson & Lowe (1973) reported that the number of storage roots formed reached a maximum between 49 and 56 days after planting but some cultivars may require up to 112 days after planting to form the maximum number of storage roots. The mean numbers of storage roots per plant at week 7 varied between 1.2 to 5.5 depending on cultivar.

b. *Pencil Roots*

Pencil roots are generally between 5 and 15 mm in diameter, they are the least well defined of the adventitious roots emerging from the subterranean node of the cutting. They develop mainly from young thick adventitious roots under conditions not conducive for the development of storage roots. In pencil roots lignification is not total, but result in uniform thickening of the entire root (Wilson & Lowe, 1973).

c. *Fibrous Roots*

According to Chua & Kays (1981) fibrous roots develop mainly from tetrarch, thin adventitious roots. The fibrous roots are generally less than 5 mm in diameter and are branched with lateral roots forming a dense network throughout the root zone constituting the water and nutrient absorbing system of the plant. Fibrous roots have heavily lignified steles and very low levels of vascular cambial activity. High nitrogen and low oxygen within the root zone favour their formation (Chua & Kays, 1981).

d. *Lateral Roots*

The lateral roots of sweet potato emerge from existing roots. Adventitious roots (storage, pencil and fibrous) have a profusion of lateral roots at varying densities along their axis. The primary lateral roots emerge from adventitious roots. Laterals emerging from the primary laterals are called secondary laterals, and those emerging from the secondary laterals are named tertiary laterals (Kays, 1985).

B. ABOVE GROUND PLANT ORGANS

a. *Vines*

Sweet potato has long thin stems that trail along the soil surface and can produce roots at the nodes. Sweet potato genotypes are classified as either erect, bushy, intermediate, or spreading, based on the length of their vines (Yen, 1974; Kays, 1985). Stem length varies with cultivar, and may range from about 1 m to over 6 m. Internode length is also highly variable, ranging from a few centimeters up to 10 cm in length. Planting density has a pronounced effect on the internode length as well as on vine length (Somda & Kays, 1990a). The stem is circular or slightly angular. Stem color is predominantly green, but purplish pigmentation is often present.

Branching is cultivar dependent (Yen, 1974) and branches vary in number and length. Normally, sweet potato plants produce three types of branches, primary, secondary and tertiary, at different periods of growth. The total number of branches varies between 3 and 20 among cultivars. Spacing, photoperiod, soil moisture and nutrient supply influence the branching intensity in sweet potato plant (Kays, 1985; Somda & Kays, 1990a; Sasaki *et al*., 1993).

b. *Leaf and Petiole*

The leaves of sweet potato occur spirally on the stem. The total number of leaves per plant varies from 60 to 300 (Somda *et al*., 1991). The number of leaves per plant increases with decreasing plant density (Somda & Kays, 1990b), increasing irrigation (Indira & Kabeerathumma, 1990; Holwerda & Ekanayake, 1991; Nair & Nair, 1995), and N application (Nair & Nair, 1995). Petiole length varies widely with genotypes and may range from approximately 9 to 33 cm (Yen, 1974). The petiole retains the ability to grow in a curved or twisted manner so as to expose the lamina to maximum light. In the early stages of development of the canopy petiole length is at its minimum, but towards the middle and latter part of the growing season petiole length increases substantially with an increase in canopy size. The petiole is swollen at its junction with the stem, and it bears two small nectaries at the junction. The lamina is extremely variable in size and shape, even for leaves on the same plant. The lamina is green in color, sometimes with purple coloration. Stomata are present on both the upper and the lower surface of the leaves. Stomatal density of sweet potato leaves varies between 47 and 155/mm^{-2} on the adaxial side and between 151 and 318/mm^{-2} on the abaxial side (Bhagsari, 1981; Bhagsari & Harmon, 1982; Bhagsari, 1990; Kubota *et al*., 1992). Kubota *et al*. (1993) found high yielding cultivars to have a greater number of stomata on the abaxial surface and a lower number on the adaxial surface than the low yielding cultivars, although this is probably not a universal phenomenon.

c. *Flower*

The flowers of sweet potato are born solitarily or on cymose inflorescences that grow vertically upward from the leaf axis (Purseglove, 1972; Onwueme, 1978). Each flower has five united sepals, and five petals joined together to form a funnel-shaped corolla tube. This tube is purplish in colour and is the most conspicuous part of the flower. The stamens are five in number and are attached to the base of the corolla tube. Stamens vary in height with respect to the length of the style. In most cultivars the two longest stamens are about the same length as the style. The filament is white and hairy; the anther is also white and contains numerous rounded pollen grains on the surface. The ovary consists of two carpels, each of which contains one locule. Each locule contains two ovules, so that there is a maximum of four ovules in each ovary (Onwueme, 1978).

Each flower opens before dawn on a particular day, stays open for a few hours, then closes and wilts before noon the same day. The length of time that the flower stays open is slightly longer if the weather is cool and cloudy. Pollination is by insects, particularly bees. The physiology of the sweet potato flower is complex. Firstly, the formation of the flower is subject to environmental control, especially photoperiodic control. Secondly, the flower is open and receptive for an extremely short period of time. Thirdly, incompatibility complexes exist. Fourthly, the existence of variation in stamen length with respect to the style introduces a further morphological complication into the pollination mechanism. All these features make seed production difficult (Onwueme, 1978).

d. *Fruit and Seed*

The sweet potato fruit is a capsule 5 to 8 mm in diameter. A false septum, formed during fruit development, may divide each of the two locules into two, thereby creating four chambers in the mature fruit. Each chamber may contain a seed, but usually only one or two chambers in each fruit contain any seed. The seed is black and about 3 mm long. It is flat on one side and convex on the other. The micropyle is located in a hollow on the flattened side. Endosperm is present in the seed in addition to cotyledons. The testa is very hard and almost impermeable to water or oxygen. For this reason the seeds germinates with difficulty. Germination can be improved by scarifying the seed either by mechanically clipping the testa, or by treating it with concentrated sulfuric acid for about 45 minutes. Freshly harvested seeds will germinate if scarified, since the only dormancy mechanism present is the impermeable testa (Purseglove, 1972 and Onwueme, 1978).

Germination of scarified seed occurs in 1 to 2 days. The radical is first to elongate, and develops into the primary root system. Germination is epigeal, since the cotyledons are carried above the soil level. After emergence, the bi-lobal cotyledons expand, develop chlorophyll, and become photosynthetic (Onwueme, 1978).

2.3 ENVIRONMENTAL CONDITIONS

Sweet potato is widely grown between latitudes 40^{o}N to 40^{o}S, and at altitudes as high as 2500 m at the equator (Hahn & Hozyo, 1984). They grow best where the average temperature is 24^{o}C, the thermal optimum is reported to be about 24^{o}C (Kay, 1973). At temperatures below 10^{o}C growth is severely retarded. The crop is damaged by frost, and this fact restricts the cultivation of sweet potato in the temperate regions to areas with a minimum frost-free period of 4 to 6 months. Even where the frost-free period is sufficiently long, it is still essential that temperatures should be relatively high during much of the growing period. In the tropics, yield declines with increasing altitude as do the number of roots and the proportion of roots that are marketable. Increasing altitude also delays maturity (Negeve *et al*., 1992).

Sekioka (1964) reported yields to be 5 to 6 times higher at 25/20°C than at 15/13°C (day/night), and higher at a soil temperature of 30°C than 15°C. On the other hand Young (1961) found that high night temperatures, by increasing carbon loss through respiration, are deleterious with yield substantially lower at 29/29°C than at 29/20°C. Seasonal plantings in northwestern Argentina suggest that flower and seed production are best with daily maximum temperatures between 23 to 24°C and minimum temperatures between 13 to 19°C (Folquer, 1974). In Puerto Rico flowering in a greenhouse did not occur above 27°C (Campbell *et al*. 1963).

Sweet potato performs best in regions with 750-1000 mm of rainfall per annum, with about 500 mm falling during the growing season. The timing and distribution of moisture supply as well as the amount affect yields. The crop is intolerant of water deficit during tuber initiation. Hahn & Hozyo (1984) suggest that at other times it may have tolerance to drought. Sweet potato is intolerant of water logging, particularly during tuber initiation (Wilson, 1982; Hahn & Hozyo, 1984). Sweet potato grows best on sandy-loam soils and does poorly on clay soils. Good drainage is essential since the crop cannot withstand water logging. Where the water table is high, the crop is planted on mounds or ridges. Soil with high bulk density or poor aeration tends to retard tuber formation and result in reduced yields (Watanabe *et al*., 1968). Wet soil conditions at harvest lead to an increase in tuber rot and adversely affect yields, storage life, nutritional and baking quality (Ton & Hernandez, 1978).

2.4 PRODUCTION ASPECTS

A. TILLAGE AND SEEDBED PREPARATION

The purpose of primary cultivation is to improve the infiltration of water, the penetration of roots and, to incorporate plant residues into the soil.

Root and tuber crops in general require a loose soil in which the tubers can grow with little hindrance. The reasons for this seem to lie in the manner in which the tuber form and penetrate the soil. Many tuber crops such as cassava, sweet potato, and Irish potato initially form relatively thin roots or stolons, which first penetrate the soil, and later enlarge to form the tuber.

On the basis of the type of the land tillage, three general methods of sweet potato planting exist. Planting on mounds, planting on ridges and planting on the flat. The first method is peculiar to traditional peasant sweet potato production, while the latter two are characteristics of partially mechanized and mechanized production.

a. *Mounding*

Planting of sweet potato on mounds is the most common practice in traditional agriculture. Essentially, the topsoil is gathered into more or less conical heaps at various points in the field. Hoes with wide blades are used for the mound making. The size of each mound, the mean distance between mounds, and the number of sweet potato cuttings planted on each mound vary from place to place. In general, the bigger the mound the greater the distance between the mounds, and the greater the number of the cuttings that may be planted on each.

According to Onwueme (1978) in some parts of southeastern Nigeria, mounds may attain heights of up to 1 m. The distances between the mounds can be as much as 3 m. On mounds of this size 6 to 10 cuttings can be planted at various points on the sloping side of the mound. In most sweet potato growing areas of Africa smaller mounds of 50 cm in height are more common, and only 5 or 6 cuttings are planted on each mound. There are several advantages of high mounds; they provide a favorable seedbed for tuber development, and the largest yield of tubers per plant and the most uniformly shaped tubers are often obtained from mound plantings. A second factor that may contribute to the high yield of mound grown plants is that the process of mound making collects the rich topsoil and the entire depth of the mound consists of the more fertile topsoil. A third advantage of mounding is that it facilitates harvesting. In soils where the water table is high, mounds also serve to keep most of the roots above the water table. Besides all its advantages mounding has the major disadvantage of not being mechanizable. Mound making is an extremely tedious and labour consuming operation, which is very difficult to mechanize (Onwueme, 1978). Planting on mounds is not common in Ethiopia.

b. *Ridging*

Planting on ridges is the most universally recommended method of growing sweet potato. It has been shown that the higher the ridges, the greater the yield up to a ridge height of 36 cm (Edmond & Ammerman, 1950). The optimum height of the ridge will depend on the soil type and the cultivar being grown. A high ridge provides ample depth of loose, fertile soil for root and tuber development and a high, broad ridge is less readily washed away by rain during the cropping season. After the ridges have been made, the actual planting of the cuttings on the ridge is done by opening up the soil at the crest of the ridge with a hoe.

Planting on ridges has several of the same advantages as planting on mounds. In addition, it has the added advantages that ridge making is completely mechanized, and that on the slopes, ridging along the contour can help in erosion control. The major disadvantage of ridge planting is that during the course of the season rains tend to wash soil away from the ridge-top, thereby decreasing the height of the ridges. The washing may progress to an extent where tubers growing within the soil become exposed. Such exposed tubers are generally unpalatable and are easily attacked by rodents and insects. Sometimes tubers of sweet potato growing on a ridge will penetrate downward through the loose soil until it encounters the harder soil at the base of the ridge. Further growth of the tuber will cause it not so much to penetrate the hard soil below, but to exert upward pressure ("heaving"). In such a situation, the top portion of the tuber may become exposed even if no appreciable soil wash has occurred. The consequences of such exposure are similar to those caused by soil wash (Onwueme, 1978).

c. *Flat Planting*

Ploughing and harrowing typically proceeds the planting of sweet potato on the flat. After that, the cuttings are planted in rows on the unridged land. If deep ploughed, planting on flat have several of the same advantages as planting on ridges. Compared to the mound and ridge methods the top soil may be shallow.

2.5 PLANTING MATERIAL

Sweet potato can be propagated by means of sprouts from tubers or by means of vine cuttings. Healthy tubers of 20 to 50 g should be planted 3 cm deep (Ikemoto, 1971). The use of sprouts derived from tubers for direct planting of sweet potato is, however, not recommended as a general practice, because it usually results in low yields compared to stem cuttings (Ikemoto, 1971).

Vine cuttings are the usual method of propagating sweet potato. It is better than using sprouts from tubers for several reasons. Firstly, plants derived from vine cuttings are free from soil-born diseases. Secondly, by propagating with vine cuttings, the entire tuber harvest can be saved for consumption or marketing instead of reserving some of it for planting purposes. Thirdly, vine cuttings yield better than sprouts, and produce tubers of more uniform size and shape. In the use of vine cuttings, apical cuttings are preferred to those from the middle and basal portion of the stem (Shanmugavelu *et al*., 1972). However, where the planting material is in short supply, middle and basal portion of the vine cuttings can be used with little decrease in expected yield. Onwueme (1978) indicated that tuber yield tend to increase with increase in the length of the vine cuttings used, and a length of about 30 cm is recommended. Cuttings of greater length than this tend to be wasteful of planting material, while shorter cuttings establish more slowly, and give poorer yields.

Various strategies can be adopted to ensure an adequate supply of cuttings at planting time, including nurseries, sprout from storage roots and successive planting.

A. NURSERY PLOTS

Nursery plots involves maintaining plots of sweet potato during the non-growing season. For most part of the tropics where the non-growing season corresponds to the dry season, the nursery plots are often established on stream banks. Nursery plots are commonly established at the time of harvest to utilize vine cuttings from the previous crop (Onwueme, 1978).

B. PRODUCTION OF SPROUTS FROM STORAGE ROOTS

Sprouts from storage roots is the standard method of producing planting material for the sub tropical and temperate regions. The method involves growing tubers in beds, of soil or sand. Tubers are spaced close together, covered shallowly with soil, and kept watered. Sprouts emerge after approximately two weeks and can be utilized for planting within few weeks after bedding. Sprouts can be pulled at weekly intervals. In order to maximize the production of sprouts, large tubers can be cut transversely into two or three pieces, so as to minimize proximal dominance. The tubers may also be treated with plant growth regulators, which have been reported to improve the production of sprouts. Such treatments include dipping in ethephon at 1500 ppm (Tompkins *et al*., 1973), dipping in 12% dimethyl sulphoxide (DMSO) for up to 20 minutes (Whatley, 1969), or treating with carbon dioxide at 30°C for three days before bedding (Su *et al*., 1965). Prior exposure of tubers to 43°C for 26 hours increased the number of sprouts (Welch & Little, 1966). It is also advantageous to disinfect the tubers before they are bedded. In temperate regions it may be essential that the sprouting beds be heated. Where controlled heating is practiced the beds are maintained at 28°C. At temperatures above 32°C the sprouts tend to be long, thin and weak (Welch & Little, 1966).

C. SUCCESSIVE PLANTING

A strategy sometimes adopted to cope with a shortage of vines is to plant only a portion of the field with the available vines. When these plants are well established, vine cuttings are taken from them and used to plant the next portion. This procedure is repeated until the entire field has been planted. This strategy can be combined with either the nursery plot or the storage root sprouting methods. The main disadvantage of successive planting is that the plants in the field may mature at different times. In traditional production of sweet potato, this disadvantage is inconsequential, since the crop is in any case harvested over an extended period of time (Onwueme, 1978).

2.6 PLANTING, WEEDING AND FERTILIZATION

A. PLANTING

Vine cuttings are generally planted vertically at an angle or horizontal to the surface with three to four nodes in the soil. Chen *et al*., (1982) reported on the modification of a mechanical planter that permits sweet potato cuttings to be planted horizontally, thus resulting in a greater yield. At planting, the vine is inserted into the soil so that one-half to two third of its length is beneath the soil surface. The placement of the vine or sprout is done by hand in most parts of the tropics; but single row or multiple row planters, which can plant cuttings are available. Most of these transplanters have devices which water the plants or provide them with nutrient solutions as they are operating in the field. It is, therefore, possible even to plant during a dry spell in anticipation of the rains. The vines are normally planted 25 to 30 cm apart on ridges that are 60 to 75 cm apart which requires 44,000 to 67,000 cuttings ha $^{-1}$ (Onwueme, 1978). Cultivars with trailing stems are planted wider apart than those with semi trailing stems. Sweet potato is able to compensate to some extent for variation in planting density. As plant population per hectare increases the number of tubers per plant decreases, the mean weight per tuber decreases, and the yield per plant decreases. It is best to plant sweet potato early in the season so that the entire rainy season can be utilized. Where the rainy season is very long planting may be delayed and timed such that the crop matures as rainfall begins to decline. In the sub tropical and warm temperate regions, sweet potato is planted in the spring as soon as the soil has warmed up sufficiently and the danger of frost is past.

WEED CONTROL

Weeds are a problem in sweet potato only during the first two months of the growth. Sweet potato vines grow quickly and may reach full canopy in six weeks (Onwueme, 1978). Vigorous growth of the vines causes rapid and effective coverage of the ground surface and smothers the weeds. Harris (1958) reported that a crop of sweet potato would practically eliminate an infestation of nutsedge *Cyprus rotundus*. For this reason, most traditional farmers do not bother to weed sweet potato plots at all. Alternatively, a single hoe weeding is done about four weeks after planting. The use of herbicides to control weeds in sweet potato is widely practiced in various parts of the world. Several herbicides are commonly used in the U.S. Diphenamide (2.7-4.4 kg. ha^{-1}) or Chloramben (3.3 kg. ha^{-1}) applied on newly planted plots, or Vernolate (3.3 kg. ha^{-1}) incorporated into the soil just before planting, are among the recommended herbicides in the U.S.A. (Talbert, 1967). Herbicides have been found not to affect the storage root quality or processing quality (Hernandez *et al*., 1969; Constantin *et al*., 1975; Hammett & Monaco, 1982). Weeds are not a serious problem in sweet potato fields in southern Ethiopia and are typically controlled by hand weeding.

C. FERTILIZERS

Sweet potato is often considered as a crop associated with poor soils. This is probably because it is well suited to sandy soils that are often infertile, and because tuber yields are sometimes depressed in very fertile or heavily fertilized soils. Nevertheless, good yields can be obtained only under conditions of high, but balanced, nutrition.

As with most root crops, sweet potato has a high requirement for potassium relative to nitrogen. A crop yielding 30 t/ha of top growth and 22 t/ha of storage roots takes up 80 kg N, 29 kg P and 185 kg K per hectare (AVRDC, 1975).

Sweet potato farmers generally would not apply fertilizers in Ethiopia for two reasons. Firstly the response of sweet potato cultivars to different fertilizers has not been clearly established. Secondly the crop is often not paying the cost of the fertilizers.

a. Nitrogen

The contribution of nitrogen to storage root and above ground biomass yield is still not fully understood. Nitrogen fertilizer responses are variable (Talleyrand & Lugo-Lopez, 1976; Bourke, 1985). High nitrogen rates may result in yield decline, e.g. beyond 56 kg N ha^{-1} in India (Nandpuri *et al*., 1971) and beyond 94 kg N ha^{-1} in Puerto Rico (Landrau & Samuels, 1951). Some sweet potato cultivars are capable of producing high tuber yield (21 to 38t ha $^{-1}$) in low nitrogen soils apparently because of nitrogen fixation by organisms in the root environment (Hill *et al*., 1990). Inocculation of roots with nitrogen fixing *Azospirillum* may increase storage roots yield by 22% (Mortley & Hill, 1990). Bourke (1977) found that sweet potato planted after forest clearing in lowland Papua New Guinea required no fertilizer, whereas crops planted after grassland required 150 kg N per hectare.

b. Phosphorus

Sweet potato seldom responds to phosphorus fertilizer. This is because the crop, like cassava and yam, is well adapted to soils with low phosphorus availability, and is capable of 70% of its maximum yield at a soil solution concentration as low as 0.003 ppm P_2O_5 (Nishimoto *et al*., 1977).

c. Potassium

According to Tsuno & Fujise (1965a and b) potassium is important to the development of storage roots, because high concentrations in leaves (above 4% K) promote translocation of photosynthates from leaves to storage roots. High photosynthate concentrates in leaves are inhibitory to photosynthesis. Gollifer (1972) obtained storage root yield increases of up to 86% with 112 kg potassium ha^{-1} in the Solomon Islands.

High nitrogen fertilizer encourages vine growth, thereby reducing potassium concentration. This is in agreement with the finding that greater storage root enlargement occurs when the nitrogen: potassium ratio is low. AVRDC (1975) recommended a ratio of 1:3.

2.7 CROPPING SYSTEMS

Sweet potato is mostly cultivated as a sole crop. Being a short duration crop it often fits well into farming systems such as relay cropping, inter cropping and rotation with other crops (Wan, 1982; Moreno, 1982; Sannamarappa & Shivashankar, 1988; Caradong & Curayag, 1989; Shinohara *et al*., 1989; Ghosh, 1991).

Sweet potato is grown in various rotation systems around the world. In Zanzibar, the rice crop has been found to do well after sweet potato. In Sierra Leone, it is often alternated with swamp rice or hungry rice (*Digitaria*) (Onwueme, 1978). A major advantage of sweet potato in rotation is its ability to smother and control weeds. In the southeastern U.S.A., growing of sweet potato can effectively control nutgrass (*Cyperus rotundus*) (Harris, 1958). The ability of sweet potato to control weeds is due to the vigorous, almost aggressive growth of the vines.

In many parts of the humid tropics it is possible to grow two crops of sweet potato a year. In the drier areas, as well as in the temperate zones, only one crop per year is possible. Sweet potato can be grown in various cropping systems in most sweet potato growing areas of Ethiopia. It is possible to grow two crops of sweet potato a year, but in the drier areas only one crop per year is grown. In Wolaita area of Ethiopia for example sweet potato is grown in the two cropping seasons called Belg and Meher. Belg is the short rainy season, while Meher is the long rainy season. The major crops grown in the Meher season are faba bean, ginger and cotton, while those of the Belg season are maize, sorghum and cassava (Getahun, 1993).

2.8. GROWTH ANALYSES

A. PLANT GROWTH MEASURMENTS

The total dry matter production by crops depends on the size of the leaf canopy, the rate at which the leaf functions (efficiency) and the length of time the canopy persists (duration). Leaf area has been studied on the basis of (a) the individual plant leaf area (LA), (b) leaf area index (LAI) and (c) leaf area duration (LAD).

a. Leaf area

Leaf area is a function of the total number of leaves and the size of the leaves per plant. Kays (1985) reported that the mean number of leaves on plants of the cultivar Jewel at the end of the growing season ranged from 373 at a wide spacing (45 x 96 cm) to 117 at a close spacing (15x 96 cm). The mean area per leaf varied from 73 cm $^{-2}$ at the widest spacing to 66 cm $^{-2}$ at the closest spacing. According to Kays (1985) differences in leaf size arises due to effects on cell division and expansion.

b. Leaf area index

Leaf area index (LAI) expresses the ratio of leaf surface (one side only) to the ground area occupied by the crop (Gardner *et al.*, 1994). Leaf area index varies widely among sweet potato cultivars, and at different growth periods, depending on the number of leaves retained on the stem and their size. Shorter photoperiod (McDavid & Alamu, 1980), increasing N application (Patil *et al.*, 1990), and decreasing plant density (Somda & Kays, 1990a) increase leaf area of individual leaves and leaf area per plant. Changes in leaf area index during growth occur in three phases, LAI steadily increases in the first phase, then reaches a maximum (between the eighth and sixteenth week after planting) in the second phase, and decline during the third phase. Maximum leaf area indices of between 2 and 11 have been reported (Yu, 1981; Agata, 1982; Bourke, 1985; Li & Kao, 1985).

c. Leaf area duration

Leaf area duration (LAD) expresses the magnitude and persistence of leaf area or longevity of the photosynthetic surface of the plant during the period of crop growth (Gardner *et al.*, 1994). Leaf area duration values of up to 88 weeks have been reported (Enyi, 1977). The leaf area duration varies substantially among cultivars grown under similar conditions. For example, the cultivar Fadenawena had leaf area duration of 36.4 weeks while for Laloki No. 2 it was 87.9 weeks (Enyi, 1977). The leaf area duration also varies widely from year to year for the same cultivars. Differences of up to 45% between years for the same cultivar have been reported (Enyi, 1977).

B.YIELD

The yield of a crop depends on the production of assimilates by the leaves (source) and the extent to which they can be accumulated in the sink represented by the organs that are harvested (Hahn, 1977a). Storage root yield of sweet potato is determined primarily by sink capacity rather than source potential (Hozyo, 1970; Hozyo, 1977; Wilson, 1977). However, both source potential and sink capacity can be factors limiting storage root yield (Hahn, 1977b). The relative contribution of source potential and sink capacity to storage root yield differs during the crop growth period among cultivars (Li & Kao, 1985; Bouwkamp & Hassan, 1988). The source potential is more limiting than the sink during the early growth period, but they are equally important in determining the storage root yield after the formation of the storage roots (Li & Kao, 1985; Li & Kao, 1990). More research is needed for a better understanding of the source and sink relationship in sweet potato.

Sweet potato cultivars vary widely in their yield potential (Wilson & Lowe, 1973). The main components of yield in root and tuber crops are the number and mean weight of storage roots or tubers (Wilson & Lowe, 1973). Average fresh storage root yields of 10 to 25t ha $^{-1}$ in 16 to 20 weeks has been obtained for sweet potato in many countries (Bhagsari & Harmon, 1982; Li & Kao, 1985; Bhagsari, 1990; Sen *et al*., 1990). The world average yield of sweet potato has been estimated to be 15t ha $^{-1}$ (FAO 2000). However, experimental storage root yields ranging between 30 and 73t ha $^{-1}$ have been reported (Bhagsari & Ashley, 1990). Fresh vine yields between 11 and 46t ha $^{-1}$ has been recorded (Singh & Mandal, 1976; Li & Kao, 1985; Sen *et al*., 1990).

Wide variability in storage root yield among sweet potato cultivars, and among individual plants of the same cultivar, has been attributed to genotype, propagation material, environment, and soil factors. Genetic, environmental and edaphic factors that influence leaf production and abscission, leaf area, leaf photosynthetic rate, storage root formation and development, total dry matter production and dry matter partitioning determine sweet potato yield (Lowe & Wilson, 1975).

Total dry matter production and efficiency of dry matter allocation to storage roots are important factors determining storage root yield. The increase in total dry matter yield as well as storage root dry mass follows a sigmoid pattern (Huett & O'Neill, 1976; Enyi, 1977; Kays, 1985; Li & Kao, 1985; Li & Yen, 1988). Some reports indicate a linear increase in total and storage root dry matter (Nair & Nair, 1995). The ratio between the storage root dry mass and the total dry mass, or harvest index, indicates dry matter partitioning efficiency to storage roots. Huett (1976) reported that the harvest index ranged from 9.5 to 66.3% for 16 cultivars evaluated in subtropical Australia. Several authors confirmed that the harvest index among sweet potato cultivars varies between 11 and 85% when harvested after 12 to 24 weeks (Enyi, 1977; Bhagsari & Harmon, 1982; Kays, 1985; Bhagsari & Ashley, 1990).

C. GROWTH RATE MEASUREMENTS

The integration of weight and leaf area measurement over time provides values that are highly useful for studying the growth of crops. Three of the more valuable growth analysis functions are the crop growth rate, the relative growth rate and the net assimilation rate. Relative growth rate (RGR) is the rate of increase in plant dry weight relative to the total dry weight of the plant. Crop growth rate (CGR) is the gain in weight of a community of plants on a unit of land in a unit of time. Net assimilation rate (NAR), or unit leaf rate, is the net gain of assimilates per unit of leaf area and time. Growth of plant organs can be similarly defined. For example tuber growth rate (TGR) is a measure of the increase in storage root weight per unit area per unit time (Kays, 1985; Gardner *et al.*, 1994).

a. Crop Growth Rate

The crop growth rate (CGR) is a measure of how fast dry matter is accumulated in a crop stand. The rate at which dry matter is accumulated by sweet potato is considerably lower than those of many crops. For example, reported values of maize (245 g m^{-2} week $^{-1}$), sugar beet (230 g m^{-2} week $^{-1}$), paddy rice (220 g m^{-2} week $^{-1}$), and soybean (160 g m^{-2} week $^{-1}$) are all substantially higher than for sweet potato (120 g m^{-2} week $^{-1}$) (Tsuno, 1971). Bourke (1985) found one cultivar of sweet potato in Papua New Guinea to exhibit a CGR of 112 g m $^{-2}$ week $^{-1}$ during the period 7 to 10 weeks after planting. Kato *et al*. (1979) found for a cultivar grown in Japan a highest CGR of 150 g m $^{-2}$ week $^{-1}$ during the period 10 to 14 weeks after planting. Early in the season the CGR is relatively low. Since rate of growth of the plant is, in part, a function of the leaf area available for photosynthesis, Tsuno (1971) determined the relationship between the leaf area and growth rate. Maximum growth rates occurred when the leaf area index was 3.2. As the leaf area index increased or decreased from this point the crop growth rate declined. The length of time the plant maintains a high crop growth rate is also an important factor in determining the final yield. Compared to paddy rice which has a maximum crop growth rate substantially higher than the sweet potato, but with similar yields per unit area, Tsuno (1971) found that sweet potato compensated for its lower rate by functioning at the maximum rate for a longer period of time.

b. ***Relative Growth Rate***

Relative growth rate (RGR) expresses the dry weight increase in a time interval in relation to the initial weight (Gardner *et al.*, 1994). Most analyses of the relative growth of sweet potato have focused on the harvested yield components of the plant (yield growth rate) rather than the total plant dry weight. Occasionally yield growth rate (YGR) is referred to as relative growth rate (Kays, 1985). Early in the season the plants are seen to partition the bulk of their dry mass into structures other than storage roots (Agata & Takeda, 1982). As the season progresses, the fraction partitioned into the storage roots increased and reached a peak value of approximately 23 g m $^{-2}$ day $^{-1}$. At the latest sampling date, the yield growth rate actually superseded the crop growth rate indicating that there was a transport of carbon into the storage roots from other plant parts (Kays, 1985).

c. Net Assimilation Rate

Net assimilation rate (NAR), or unit leaf rate, is the net gain of assimilates, per unit of leaf area and time (Gardner *et al.*, 1994). Tsuno & Fujise (1965a) found that there was a linear relationship between leaf area and net assimilation. As the leaf area of the plant increased the overall net assimilation rate decreased.

2.9 DISEASES AND PESTS

A. FUNGAL DISEASES

a. *Black rot*

Black rot is caused by *Ceratocystis fimbriata*. The disease has been reported in many countries. Black rot is the most significant disease of sweet potato. The disease can cause severe losses both in the field prior to harvest or on roots in storage. The pathogen not only reduces the yield and quality of the tuber but also imparts a bitter taste that extends beyond the lesions. In the field it causes young plants to turn yellow and the under ground stem portion to blacken. On the storage roots, dark circular depressions develop, and the rot may spread through the entire tuber. Infected storage roots produce ipomeamarone and ipomeamaronol, which are toxins that cannot be removed by boiling or baking of the storage roots (Wilson *et al*., 1970). Infected storage roots used for the production of sprouts for the next crop becomes a major source of primary inoculum (Daines, 1962).

Successful control measures of black rot have relied on the following practices (Cheo, 1953):

- The use of resistant varieties;
- Use of disease-free planting material;
- Planting vine cuttings instead of tuber-pieces or sprouts;
- Crop rotation. Since the fungus attack only sweet potato it should not be planted in the same field more than once in three or four years;
- General sanitation in the field and in the store, which includes washing the tubers, machines, and storage crates or storage structures with effective fungicides.

b. *Scurf*

Scurf is caused by *Monilochaetes infuscans*, and is only known to infect sweet potato and related species (Clark & Watson, 1983). It is a very slow growing fungus, and has been reported in Brazil, USA, Japan, and Australia (Onwueme, 1978). It causes brownish blotches on the tubers and other subterranean parts of the plant. It does not directly affect the cortex or under lying tissues of the storage root. Successful control measures of the scurf disease are:

- Only scurf free plants should be used as planting material;
- Treating infected planting material with hot water, at 49°C for 10 minutes; or
- Treating infected planting material with effective fungicides.

c. *Fusarium wilt*

Fusarium wilt or stem rot caused by *Fusarium oxysporum* f. *batatis* has been reported in the USA, and Japan (Onwueme, 1978). It enters the plant mostly through wounds, and attacks the vascular tissue, especially the xylem. Growth of the plant is stunted, and leaves are wrinkled and yellowish in colour. Nielsen & Johnson (1974) found that extreme post harvest temperatures prior to curing reduced wound healing of storage roots and increased the incidence of surface- rot. Control measures include:

- The use of resistant varieties;
- Dipping propagating material in fungicides before planting;
- Planting only disease-free planting material; and
- Burning of all infected crop residues.

d. *Soft rot*

Soft rot is commonly called *Rhizopus* soft rot. It is caused by *Rhizopus stolonifer*. It is a serious post-harvest disease of sweet potato. Most prevalent in temperate and sub-tropical growing regions, but also common in tropical growing regions. The fungus is unable to penetrate through the intact periderm of the tuber; it normally gains access through wounds. The disease causes a general rotting of the tuber during storage (Moyer, 1981). Control of this disease consists of the following practices:

- Avoid tuber wounding during harvesting;
- Ensure proper curing of the tubers before they are stored; wound healing and reinforcement of the periderm during curing help to create a barrier to the entry of the fungus;
- Treat the harvested tubers with effective fungicides; and
- Destroy the infected tubers.

B. VIRUS DISEASES

a. *Mosaic*

This virus was first isolated in Argentina (Nome, 1973). Mosaic is a serious virus disease of sweet potato in the USA, and becoming increasingly serious in Africa (Onwueme, 1978). It is caused by a strain of the tobacco mosaic virus. Infected plants have small, mottled, malformed leaves and yield little or no tubers. Normally only a few plants are infected in any given field, and it appears that the disease does not spread readily from plant to plant. A simple control measure, therefore, is to rogue and burn the infected plants.

b. *Feathery mottle complex*

Sweet potato feathery mottle virus was first isolated from sweet potato and purified by Moyer & Kennedy, (1978). Sweet potato feathery mottle virus (SPFMV) is found nearly everywhere sweet potatoes are grown. A complex of viruses; the internal cork virus, the leaf spot virus, and the white fly transmitted yellow dwarf virus apparently cause the feathery mottle complex. The white flies concerned are *Bemisia* and *Trialeurodes*. These three viruses, when present together, causes severe symptoms which none-of them individually can cause. Feathery mottle disease is characterized by dwarfing of the plants, yellowing of the veins in the younger leaves, and yellowish spotting in older leaves. Internodes are short and tubers are small. Strains of this virus have been shown to be the causal agents to several of the virus diseases of sweet potato (Campbell, *et al*., 1974; Cadena-Hinojosa & Campbell, 1981; Cali & Moyer, 1981). Control is by removal and burning of the infected plants, and by using insecticides to control white fly.

c. *Internal cork*

A virus or complex of viruses causes internal cork. It is characterized by the development of corky areas within the flesh of the tuber. These areas remain distinct during cooking and are bitter to the taste. Infected tubers appear normal externally, and the symptoms can only be seen when the tuber is cut. Symptoms on the growing plant include chlorotic leaf spotting, vein clearing and purple ring spotting of the foliage. Various aphids, including the cotton aphid transmit the internal cork virus. Control of the disease is by using resistant cultivars and by crop rotation. Some of the resistant cultivars are symptomless carriers of the virus, and may spread the disease to susceptible cultivars if they are grown close together (Onwueme, 1978).

Other viruses of sweet potato include leaf spot, sweet potato vein mosaic virus, sweet potato mild mottle virus, sweet potato latent virus and sweet potato yellow dwarf virus.

In Ethiopia several diseases have been identified on sweet potato the most important among these are stem blight, leaf blight, stem lesion and tuber rot. Stem blight is the most common one. Biological studies, varietal screening and chemical control studies have been attempted. Sweet potato and tomato have been identified as the only hosts of the fungus. Among the varieties tested, Koka 9 was the most susceptible, and Koka 12 was found less infected by the pathogen.

Benomyl in hot water solution has been found effective in the control of stem blight (unpub. data).

C. NEMATODES

Many genera of plant parasitic nematodes are associated with sweet potatoes in the field, but only three are important. The three major types of nematodes attacking the crop are the sting nematode (*Belonolaimus gracilis*), the root lesion nematode (*Pratylenchus*), and the root knot nematode (*Meloidogyne*) which is the widest spread of the three. Nematode attack causes poor growth, low yield, and cracked tubers (Giamalva *et al*., 1963). A nematicide (aldicarb 350 g/100 m planting furrow) was found an effective chemical control method (National Department of Agriculture (RSA), 1999). Other control measures are:

- Immersing the planting material in hot water at 47°C for 65 minutes. This is only necessary for tubers that are to be used to produce sprouts for planting;
- The use of resistant varieties;
- Crop rotation.

D. INSECTS

a. *Sweet potato weevil*

The sweet potato weevil is one of the major pests of sweet potato worldwide. Three species have been identified in Africa: *Cylas formicarius* (F.), *Cylas puncticollis* Boheman and *Cylas brunneus* (Olivier). Their distribution in Africa has been surveyed, and it appears that all the three species have a similar life history, making all of them difficult targets for conventional pest control measures (Allard & Rangi, 1990). *Cylas puncticollis* only occurs in Africa; being recorded from Burundi, Cameroon, Chad, Congo, Ethiopia, Guinea, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Tanzania, and Uganda (Hill & Waller, 1988). *Cylas formicarius* is pan tropical, from west Africa, through to east Africa, southern Africa, Madagascar, Mauritius, Seychelles, India, Bangladesh, Sri Lanka, south east Asia, China, Philippines, Indonesia, USA, West Indies, Mexico, northern South America, and several other locations around the world (Hill & Waller, 1988).

The adult females lay their eggs in small pockets, at the base of the stem and in the tuber. The larvae cause considerable damage to the tuber by feeding on it and burrowing extensively through it. The ability of the adult to fly is very limited, so that flying is only a minor mode of distribution of the weevil. Crawling is probably more important.

Infestation by the weevil varies with season. In the tropics they are more numerous on sweet potato grown during the dry season. In sub-tropical and warm temperate regions, the cold temperature late in the season markedly limits the egg laying ability of the adult female. At temperatures between 21 and 15.5^{o}C egg laying is slow; below 15.5^{o}C egg laying stops completely. Temperatures at or below freezing can kill the adult in seven days, the larvae in 15 days, and the pupae in 21 days (Onwueme, 1978).

Deltamethrin (50 ml per 100 liter water), gamma-BHC (20 to 30 kg ha $^{-1}$) and tralomethrin (40 ml per 100 liter water) were reported effective in controlling sweet potato weevil (National Department of Agriculture, RSA 1999). It appears that the deeper the tubers lie within the soil, the less likely that the weevil will infest it. It has been found that earthing-up around the tuber results in a lower degree of infestation (IITA, 1975). Sweet potato weevil control measures are the following:

- Effective quarantine systems to reduce the spread of sweet potato weevil to uninfected areas;
- The use of insecticides;
- Crop rotation. All sweet potato residues must be eradicated when the rotation crops are being grown;
- Prompt harvesting. It appears that the weevils are most serious if harvesting of the tubers is delayed. Harvesting early may help to avoid infestation;
- Cultural practices such as earthing up to prevent tuber exposure on the field, and planting of weevil-free material.

b. *Sweet potato butterfly*

Sweet potato butterfly *Acraea acerata* (Hew.) is a common and serious insect pest of sweet potato. It has been reported to cause extensive damage in eastern Africa. The larvae feed on the leaves of sweet potato, and heavy attacks can result in complete defoliation of the vines.

Defoliation in young plants causes crop retardation and large reductions in yield. The eggs are laid in batches of 100 to 150 on both surfaces of the leaves, and hatching takes about seven days. The larvae are greenish-black and covered with fleshy, branching spines. For the first two weeks of their life the larvae are gregarious, feeding on the upper leaf surface under the protective webbing. For the final week of the larvae life cycle the caterpillar become solitary and nocturnal and eats the whole leaf lamina. This insect is distributed over the whole of eastern Africa and the Congo (Hill & Waller, 1988). It can only be effectively controlled by the use of insecticide sprays.

According to a survey made in southern Ethiopia between 1986 and 1990 sweet potato weevil (*Cylas puncticollis*) and sweet potato butterfly (*Acraea acerata*) are the major insect pests of sweet potato (Emana & Adhanom 1989). Emana (1990) reported that prompt harvesting, earthing up, crop rotation and the use of weevil free planting materials are important in preventing sweet potato weevil damage. Foliar spray of endosulfan was reported to control sweet potato weevil. Attempts were also made to screen insecticides against sweet potato butterfly, and the result indicated that carbaryl 85% WP gave good level of control (IAR, 1992).

2.10. HARVESTING, CURING AND STORAGE

A. HARVESTING

The exact duration of the growth period varies with cultivars and with the environmental conditions under which the crop is grown. Depending on the growing conditions and cultivars, the crop growth period varies between 12 and 35 weeks (Chen & Xu, 1982; Hahn & Hozyo, 1984), whereas a duration of 25 to 50 weeks has been reported for some cultivars (Huett, 1976; Huett & O' Neill, 1976). However, most of the cultivars attain maximum storage root yield in 12 to 22 weeks after planting (Steinbauer & Kushman, 1971; Huett, 1976; Gupta & Ray, 1979; Indira & Lakshmi, 1984; Nair & Nair, 1985; Sen *et al.*, 1990).

Yellowing of the leaves may indicate readiness of the crop for harvesting. In other instances there is no externally visible signs of readiness for harvesting. If harvesting is done too early, yields are low, but if the crop is left in the ground too long, the tubers become fibrous, unpalatable, and are prone to attack by the sweet potato weevil and various rots. Mature tubers can be recognized by the fact that the sap exuded by them when they are cut does not readily darken. Most frequently, all the storage roots on a given plant do not reach maturity at the same time, so that harvesting is done at a time when a reasonable number are mature. This could be determined by harvesting a few representative plants and judging whether or not the entire field is ready for harvesting or not. In cases where the vines have been earthed-up and tubers have also been formed on the stems, the disparity in maturity between the tubers is even greater. In much traditional sweet potato cultivation harvesting is done as the food is needed.

B. CURING AND STORAGE

After harvesting, the storage roots are subjected to curing in order to promote rapid healing of wounds inflicted during harvesting, and to increase the strength of the periderm of the storage root. Curing is necessary to minimize infection by microorganisms during storage, and to make the root more resistant to wounding during subsequent handling. Curing must be done immediately after harvesting. In most parts of the humid tropics, prevailing temperature and humidity conditions are favourable for curing, and curing occurs naturally. Storage roots should be allowed to cure for 4 to 5 days before they are stored.

Most sweet potato producers in the tropics do not store their crop under controlled conditions. Some farmers avoid the need for storage by leaving the crop in the ground and harvesting only as needed. Others store the crop in underground pits covered with grass. Tubers may also be kept on platforms or stored in baskets. In general, sprouting and spoilage are common with these methods of storage, and the tubers cannot be kept in a satisfactory condition for more than one or two months.

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CHAPTER 3

THE ORIGIN AND STRUCTURE OF ADVENTITIOUS ROOTS IN SWEET POTATO (*Ipomoea batatas* (L.) Lam.)

3.1 ABSTRACT

Morphological and anatomical studies demonstrated the root formation characteristics of sweet potato. In this study the presence and importance of preformed root primordia is recorded for the first time. On the vines preformed root primordia are present in sets of four to ten adjacent to the leaf bases. These roots originate from the procambium on both sides of the leaf gap. Macroscopically the root tips of preformed root primordia protruding through the cortex and epidermis of the stems are prominent. The preformed root primordia produce adventitious roots, which typically exhibit pentarch, hexarch or septarch steles. These nodal adventitious roots can develop into fibrous roots, pencil roots or storage roots. It is postulated that storage roots will under normal circumstances only originate from undamaged preformed root primordia on the nodes of cuttings, or on nodes of newly formed vines. “Secondary” adventitious wound origin roots with similar anatomical characteristics to the nodal adventitious roots can, however, originate in the absence of preformed root primordia. Such “secondary” adventitious roots with the potential to develop into strorage roots can be initiated from callus tissue at the cut end of the cutting; from nodes where preformed root primordia were excised or damaged; or on leaf petioles. Lateral roots originating from damaged root primordia, or directly from the adventitious roots, or from callus tissue, exhibit tetrarch steles and develop into fibrous roots without the potential to develop into storage roots. This understanding of the origin, anatomy and

morphology of sweet potato roots should improve production practices, which will contribute to improved crop establishment and increased yield.

3.2 INTRODUCTION

Sweet potato roots develop as adventitious roots (Togari, 1950). They normally arise from the under ground stem portion of a vine cutting used as planting material. Based on their external morphology Togari (1950) and Kays (1985) subdivided adventitious roots into “thick” and “thin” roots and also stated that adventitious roots on cuttings may differentiate into fibrous roots, pencil roots or storage roots. Kays (1985) indicated that if the environment is conducive “thick” roots develop into storage roots. Thickening growth of the storage roots occurs by the activity of the vascular cambium as well as anomalous primary and secondary cambial segments (Wilson, 1970 & 1982). Activity of all cambia results in the formation of thin-walled, starch storing parenchyma cells. The contribution of different cambia in the production of storage parenchyma varies among cultivars and appears to be a cultivar related characteristic. A high yielding cultivar will show extensive anomalous cambial activity compared to low yielding cultivars with limited anomalous thickening growth (Wilson & Lowe, 1973a). The proximal end of the storage root does not take part in the formation of the storage root and forms the storage rootstalk. The length of the stalk appears to be cultivar dependent. It is generally accepted in literature on this topic that “thin” adventitious roots develop into either fibrous roots which are generally less than 5 mm in diameter, or in some cases into pencil roots which are generally between 5 and 15 mm diameter. Based on their external morphology Lowe & Wilson (1974) sub-divided sweet potato adventitious roots into ‘thick’ pigmented storage roots, ‘thick’ pigmented pencil roots that do not form storage roots, and ‘thin’, white fibrous roots. All three types give rise to lateral fibrous roots. Pigmented roots were defined as roots distinguishable from white fibrous roots by the development of surface pigmentation (cream colored, pink or red) similar to those later occurring on tuberous roots (Lowe & Wilson, 1974). Apart from adventitious roots arising from the nodal part of the stem, wound roots develop from the callus tissue in response to the wounding effect after the cutting is made (Hartman et al., 2002). Spence & Humphries (1971) reported that leaves of sweet potato cut at the base of the petiole formed roots when planted in sand moistened with a dilute nutrient solution and kept in subdued light in the glasshouse.

Air and soil temperature, physical characters of the soil, and soil fertility influence sweet potato storage root formation and growth (Ravi & Indira, 1999). Night air temperatures seem to be the most critical factor for storage root growth, presumably due to greater translocation of sugar from the shoot to the roots at lower temperatures. Plants grown for 81 days with 2.5% oxygen in the root zone, produced more fibrous, non-storage roots (88.7% of the total dry mass) than the plants grown in a 21% oxygen root zone with only 10.9% (dry mass) non-storage fibrous roots (Chua & Kays 1981). Dry and compact soil hampered storage root formation (Watanabe *et al.*, 1968a, and 1968b; Sajjapongse & Roan 1982).

The factors determining whether adventitious roots will remain unthickened, develop into pencil roots, or develop into storage roots, remain unclear. Wilson (1973a & 1973b) conducted experiments using roots up to 3 cm long emerged from petioles. These rooted leaves were grown in a sand culture for ten to twelve days. Rooted leaves were then treated with four levels of nitrate-nitrogen (21, 42, 105, and 210 ppm). After eight weeks of growth in a greenhouse individual rooted leaves were scored for number of adventitious shoots, tubers and uniformly thickened tuberous roots. Those grown at 21 ppm NO_3-N produced tubers and uniformly thickened roots but no adventitious shoots. Rooted leaves grown at 42 and 105 ppm NO_3-N developed tubers on which single adventitious shoots were formed as well as uniformly thickened roots. Only a few adventitious shoots developed on the uniformly thickened roots in these plants. With the leaves grown at 210 ppm NO_3-N, very few tubers were produced, while adventitious shoots were formed in clusters of up to four on the uniformly thickened roots. This negative effect of high nitrogen levels on storage root development may be comparable to the negative effect of high nitrogen levels on tuberization in potato, which has been linked to the effect of nitrogen on levels of endogenous gibberellins (Hammes & Beyers, 1973).

According to Artschwager (1924) and Togari (1950) storage roots usually develop from thick roots with pentarch or hexarch steles and enlarged apical meristems. Roots which did not develop into storage roots included thin adventitious roots containing tetrarch steles with a central core of metaxylem elements and no pith (Artschwager, 1924) and a small apical meristem (Togari, 1950).

Although existing literature provide a reasonable amount of information on the classification and structure of sweet potato adventitious roots, some issues remain unclear. No information is available about the origin or the relationship between origin, structure and function of these roots. The objectives of the study were to:

- investigate the origin of adventitious roots of sweet potato;
- provide additional information on the structure of sweet potato roots; and
- find possible relationships between origin, structure and function of the roots.

3.3 MATERIALS AND METHODS

Mother plants of the cultivar Atacama were grown on the Experimental Farm of the University of Pretoria to provide stem cuttings for the observations on the origin and anatomy of the roots. The investigation consisted of three parts.

1. Observations were made on the undamaged root primordia on freshly cut vines. Transverse and longitudinal sections, using a sliding microtome with freezing equipment, were prepared for microscopic observations.

2. Terminal and middle parts of the vines were used to obtain adventitious roots. Freshly cut vines were placed in polyethylene bags and incubated at 20° C. Roots obtained in this way were sampled regularly from day three to day 14. This technique ensured that the roots were free of sand or other substrate particles. In addition, pencil roots and storage roots from more mature plants in a greenhouse were also sampled for microscopic observation.

3. Leaf cuttings, and stem cuttings with the preformed root primordia removed, were planted in containers with sand. The containers were placed on a mist bed

for two weeks. Roots obtained from these cuttings were anatomically characterised.

For all the anatomical observations root segments were fixed in F.A.A., dehydrated in increasing ethanol concentrations and embedded in wax after substituting the alcohol with xylene (O'Brien & Mc Cully, 1981). Sections of 7 to 10 μ m, in thickness were made with a rotating microtome and stained in Safranin 0, counter stained in Fast Green, and mounted in Clearmount (O' Brien & Mc Cully, 1981).

3.4 RESULTS AND DISCUSSION

Preformed root primordia

Macroscopic longitudinal rows of small white protruberances are present on both sides of the leaf bases on the vines, even on young nodes close to the vine apex (Figures 3.1A & 3.1B). These protuberances occurred in sets of four to ten per node. It was confirmed microscopically that the protuberances were in fact root tips of preformed roots, protruding through the cortex and epidermis of the stem (Figures 3.1C & 3.1D). From the micrographs it is clear that the roots originate from the procambium on both sides of the leaf gap. Despite the macroscopic prominence of the preformed root primordia no reference to it could be found in the literature. The presence of the preformed root primordia is probably recorded for the first time. Hartman *et al*., (2002) reported the origin of preformed roots in a number of woody and herbaceous plant species, but sweet potato is not included. As in other plant species an outstanding feature of the preformed root primordia of sweet potato is that they will remain dormant until suitable growing conditions occur. Root primordia on older nodes on sweet potato vines are exposed to damage over a longer period of time, and necrotic root primordia can often be observed. Even the vines from plants produced in a glasshouse under favorable conditions exhibited preformed root primordia with necrotic tips as can be seen in Figure 3.1B. Microscopically there were indications that some root tips were actually aborted. In contrast with this the preformed root primordia on younger nodes near the vine apex are typically sound and healthy. This may partly explain the phenomenon that terminal cuttings tend to be more vigorous and productive than basal cuttings (Onwueme, 1978).

Root development from preformed root primordia

The root primordia of vines exposed to a humid atmosphere in polyethylene bags sprouted and produced clean white roots within 24 hours as illustrated in Figures 3.2A & 3.2B. This proved to be a valuable technique to obtain root material free from soil and ideal for microtome slides. The number of adventitious roots per node are determined by the number of performed root primordia per node, and the extent of damage and degeneration suffered by root primordia. The emerging adventitious roots were all more or less of the same diameter as illustrated in Figure 3.2, and lateral roots developing from the basal part of the adventitious roots can be confused with adventitious roots. In Figure 3.2C two lateral roots can be seen developing from the base of one of the adventitious roots. Adventitious roots can only emerge from healthy undamaged preformed root primordia, damaged preformed root primordia can not develop into adventitious roots as illustrated in Figure 3.2D. The presence of preformed root primordia and their ability to start growing within hours of being exposed to favorable conditions, explains the remarkable capacity of sweet potato cuttings to establish successfully in a short period of time.

Wound induced roots

Cuttings with wounds inflicted during the removal of preformed root primordia, as well as leaf cuttings, produced wound roots within two weeks as illustrated in Figure 3.3. Wound induced adventitious roots developing from the cut ends of the cuttings (Figure 3.3B) and from the cut ends of leaf petioles (Figures 3.3C & 3.3D) were found to be similar to the wound roots produced on the nodes where preformed root primordia were removed (Figure 3.3A). It is clear from the photographs that all wound roots were morphologically similar in appearance and originated from the callus tissue or directly adjacent to the callus. The development of wound roots on nodes with the preformed root primordia removed is probably reported for the first time. No reference to the capability of sweet potato cuttings to produce adventitious roots when the preformed root primordia are removed or damaged could be found. All adventitious roots have the potential to develop into pencil or storage roots. Some will remain without thickening throughout the plant's growth period. The latter form of adventitious root was identified as thick roots by most authors, including Wilson & Lowe (1973a), Du Plooy (1989).

The typical root system of a sweet potato plant originating from a stem cutting is illustrated in Figure 3.4A, where the different types of adventitious roots, namely unthickend roots, a pencil root and a storage root are visible. Lateral roots develop on all the adventitious roots and even from the base of damaged preformed root primordia. Lateral roots of first, second and higher orders will develop to form the fibrous root system for absorbing and transporting water and nutrients.

In cultivars with pigmented storage roots, pigmentation of the root epidermis starts after approximately three weeks, with the result that in mature plants all the adventitious roots are pigmented, while lateral roots remain unpigmented.

Anatomical structure of sweet potato roots

It was observed from micrographs of transverse sections of adventitious roots and wound roots that storage roots and pencil roots arise from roots with poly-arch steles while the fibrous roots arise from lateral roots with tetrarch or pentarch steles. In Figure 3.4B a lateral root with central metaxylem element, typically pentarch in arrangement of the primary vascular tissue, is illustrated. The five xylem and phloem poles within the vascular cylinder can be seen. This arrangement of the vascular tissues and the beginning of a lignified stele indicate no potential to develop into a storage root. In the formation of the fibrous roots none or little normal secondary thickening growth with no anomalous secondary thickening growth with extensive lignification, occurs.

In this investigation it was clearly observed that all lateral roots developed from existing roots and were usually thin with tetrarch and infrequently pentarch steles. The primary laterals grew profusely downwards into the soil forming secondary laterals. In some cases tertiary laterals emerged from secondary laterals. These lateral roots of sweet potato form the water and nutrient absorbing system of the plant and are often referred to as the fibrous roots.

In Figure 3.4C an adventitious root, typically hexarch in the arrangement of the primary vascular tissues, (that is six xylem and phloem poles found within the vascular cylinder) and without the central metaxylem element, is illustrated. This anatomically structure is characteristic of roots with the potential to develop into storage roots. Adventitious roots, which is septarch in the arrangement of the primary vascular tissues (seven xylem and phloem poles found within the vascular cylinder), without the central metaxylem element, as illustrated in Figure 3.4D, also have the potential to develop into storage roots. In storage root development the cells between the protoxylem points and the central metaxylem cell do not become lignified, or only a small portion of these cells are lignified, as illustrated in Figure 3.5A. In storage roots, storage tissue formation occurs by normal secondary thickening growth, as well as anomalous secondary thickening growth, with little lignification. The development of storage roots from thick adventitious roots with poly-arch steles reported by Wilson & Lowe (1973a) is similar to the observations reported here. Wound roots with hexarch steles and with large central metaxylem elements is illustrated in Figure 3.5B. This is a typical structure indicating that the lignification of steles is not total and the root may develop into a pencil root. It was observed in this study that storage and pencil roots develop from both adventitious and wound roots with poly-arch steles. The development of adventitious roots from leaf cuttings reported by Spence & Humphries (1971) was also confirmed in this study. Pencil roots, as they were named by Wilson & Lowe (1973a), are derived from adventitious roots, with poly-arch steles.

According to Wilson & Lowe (1973a) thick roots are either pentarch, hexarch or septarch at the base and tetrarch nearer to the apical meristem, and contain a central pith with or without central metaxylem cells. However, in this study the number of xylem strands in the roots was found not to differ throughout the length of the root (Figure 3.5.C).

The morphological and anatomical observations in Chapter 3 emphasized the potential of sweet potato cuttings to quickly activate root formation, the literature revealed a gap of information on the rooting of cuttings, and factors affecting root establishment. The aspect of environmental factors such as temperature and soil moisture content on cutting establishment will be dealt with in Chapter 4.

3.5 CONCLUSION

Observations on the origin of sweet potato roots, their morphology and anatomy, indicated that adventitious roots normally develop from preformed root primordia on the nodes. Adventitious roots can also develop from wound callus on stems or petioles. All adventitious roots have poly-arch steles and can develop into pencil roots or storage roots. Lateral roots develop on unthickened adventitious roots, pencil roots and storage roots, mainly have tetrarch steles and comprises the fibrous roots. It is suggested that the confusing terminology in the literature referring to thick and thin roots resulted from superficial observations, with the “thin” roots being either lateral roots from the base of preformed root primordia, or young adventitious roots. Only by correctly identifying the origin of the root, or by considering the stele characteristics (tetrarch or poly-arch), can the young roots be identified as either adventitious roots (potential storage roots) or lateral roots (fibrous roots). More research is required to identify the factors determining whether an adventitious root will remain as it is, thickened into a pencil root, or develop into a storage root.

An understanding of the origin and nature of the sweet potato root system not only contributes towards scientific clarity, but should also assists agronomists to improve production practices. Thus the existence of preformed root primordia and their ability to produce adventitious roots within hours after exposure to favorable circumstances partly explains the remarkable capacity of cuttings to quickly establish even under less favorable circumstances. It also emphasises the advantage of using relatively young cuttings with undamaged root primordia as planting material. The optimum number of subterranean nodes when cuttings are planted will be affected by the number of undamaged preformed root primordia per node. With this new perspective on the origin of storage roots from preformed root primordia, basic studies to obtain more potential storage root sites by production practices like ridging, may yield interesting results.

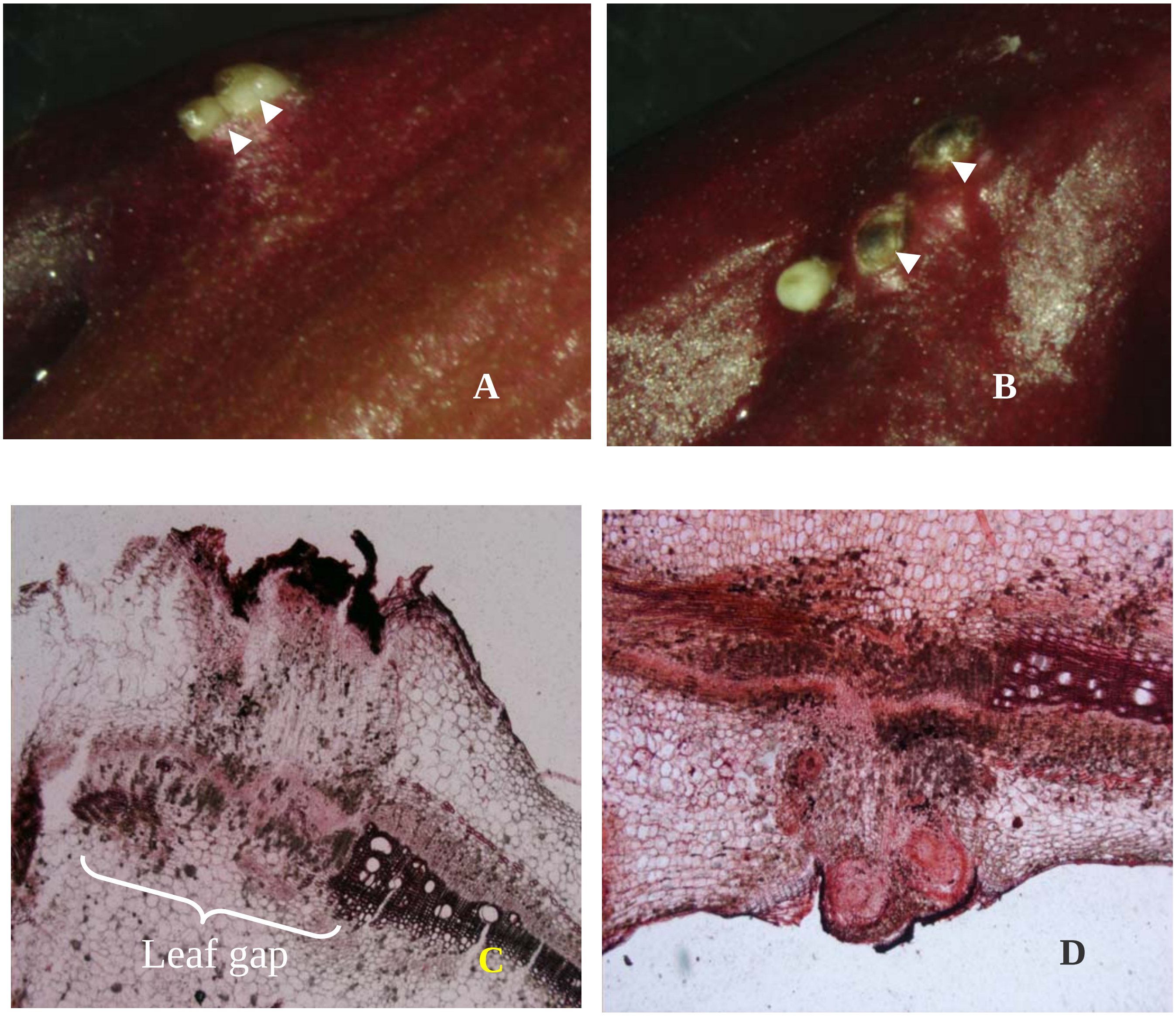

Figure 3.1. Nodal part of sweet potato vines showing preformed root primordia

A. Primordia on a young node close to the shoot apex.
B. Primordia on an older node near the base of the vine.
C & D Sections of nodes illustrating root tips of preformed root primordia protruding through the cortex and epidermis.

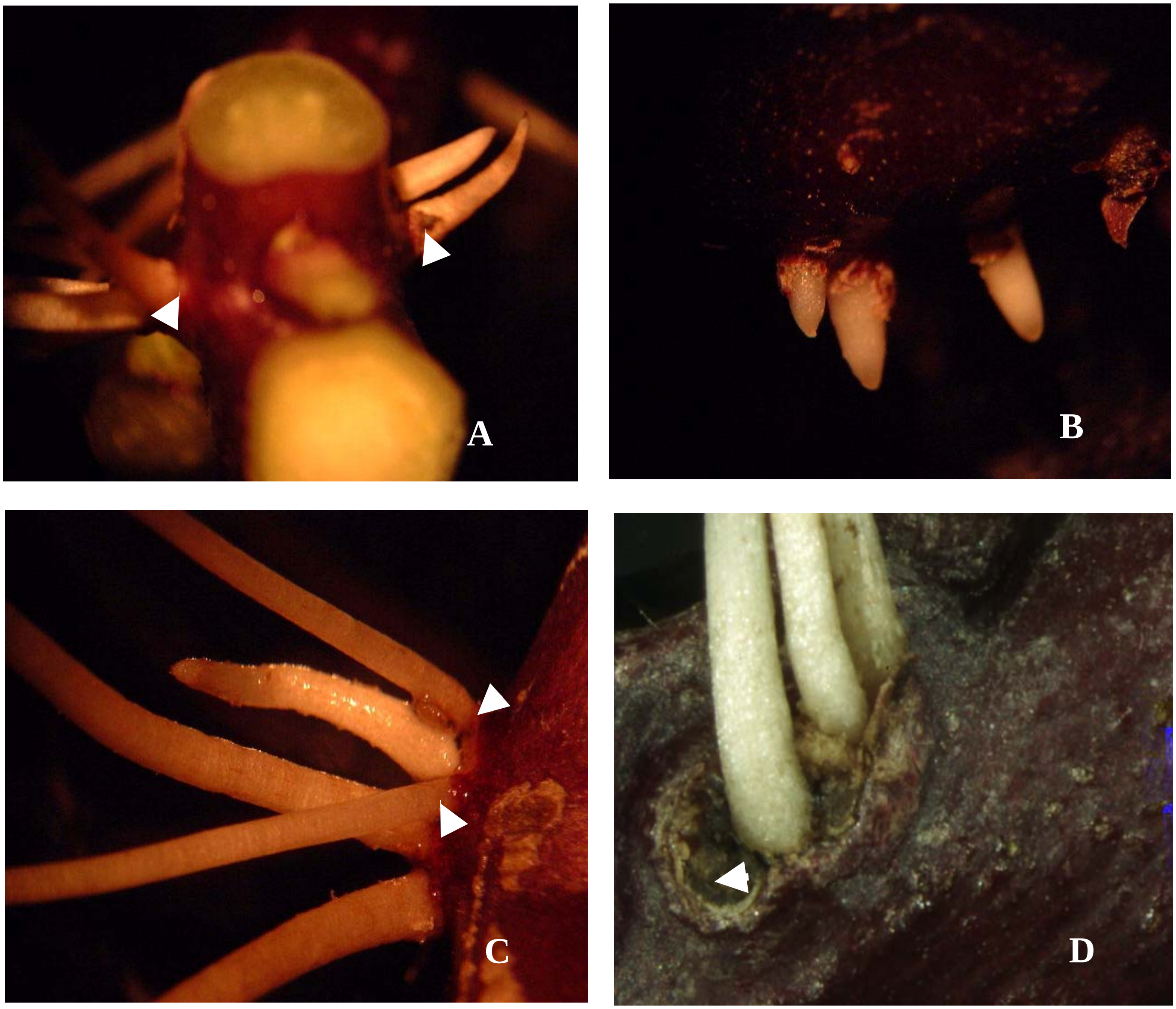

Figure 3.2 Root development from preformed root primordia

A & B. Exposed to a humid atmosphere in a polyethylene bag adventitious roots developed within 24 hours.

C. Three adventitious roots with two lateral roots growing from the base of an adventitious root after 72 hours in a moist atmosphere.

D. Three adventitious roots from undamaged primordia, and a damaged unsprouted primordium.

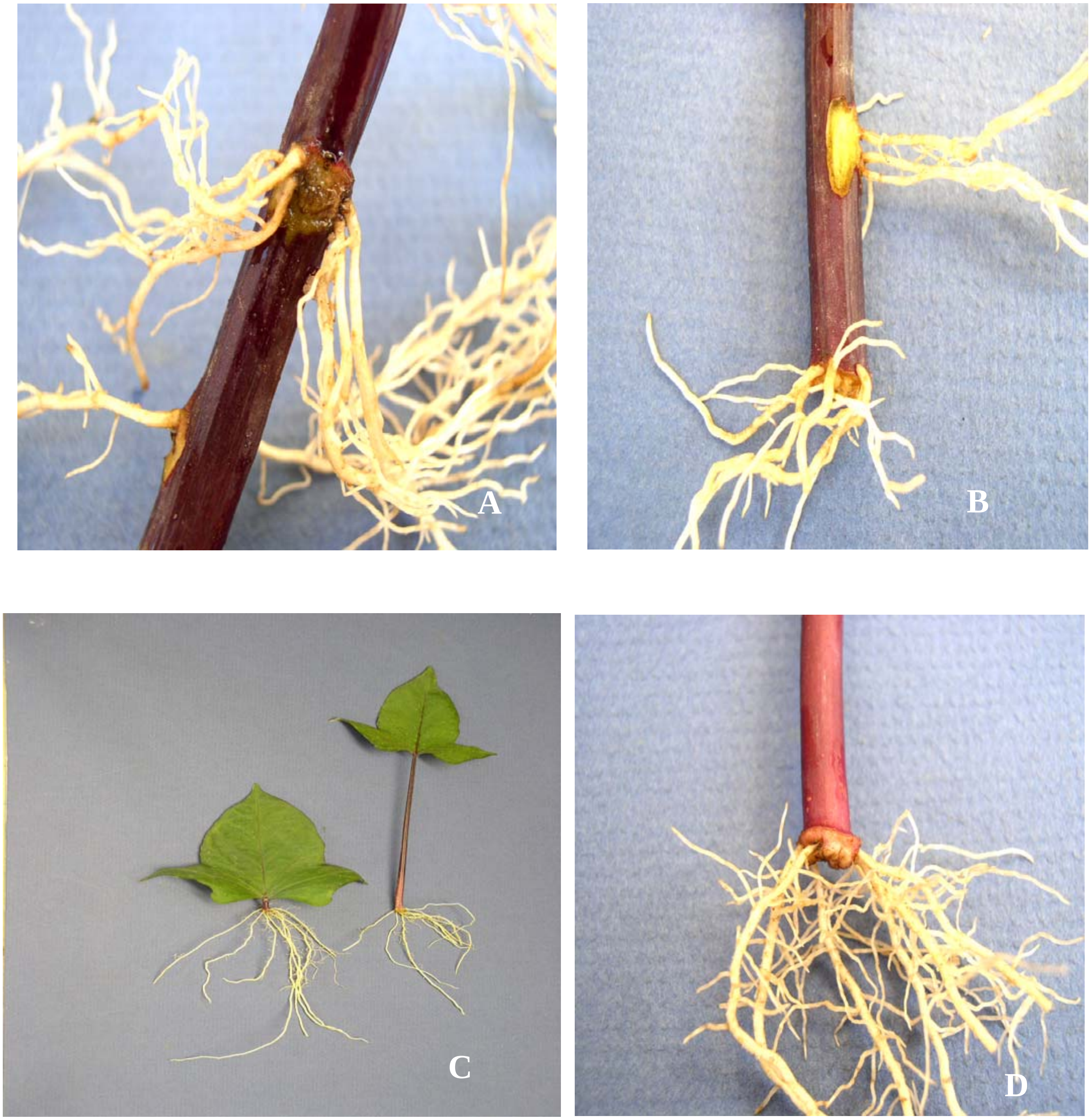

Figure 3.3. Cuttings of sweet potato showing wound induced adventitious roots

A. Adventitious wound roots where preformed root primordia were excised from cutting

B. Adventitious wound roots where the stem was cut (bottom).

C & D. Adventitious wound roots on leaf petioles

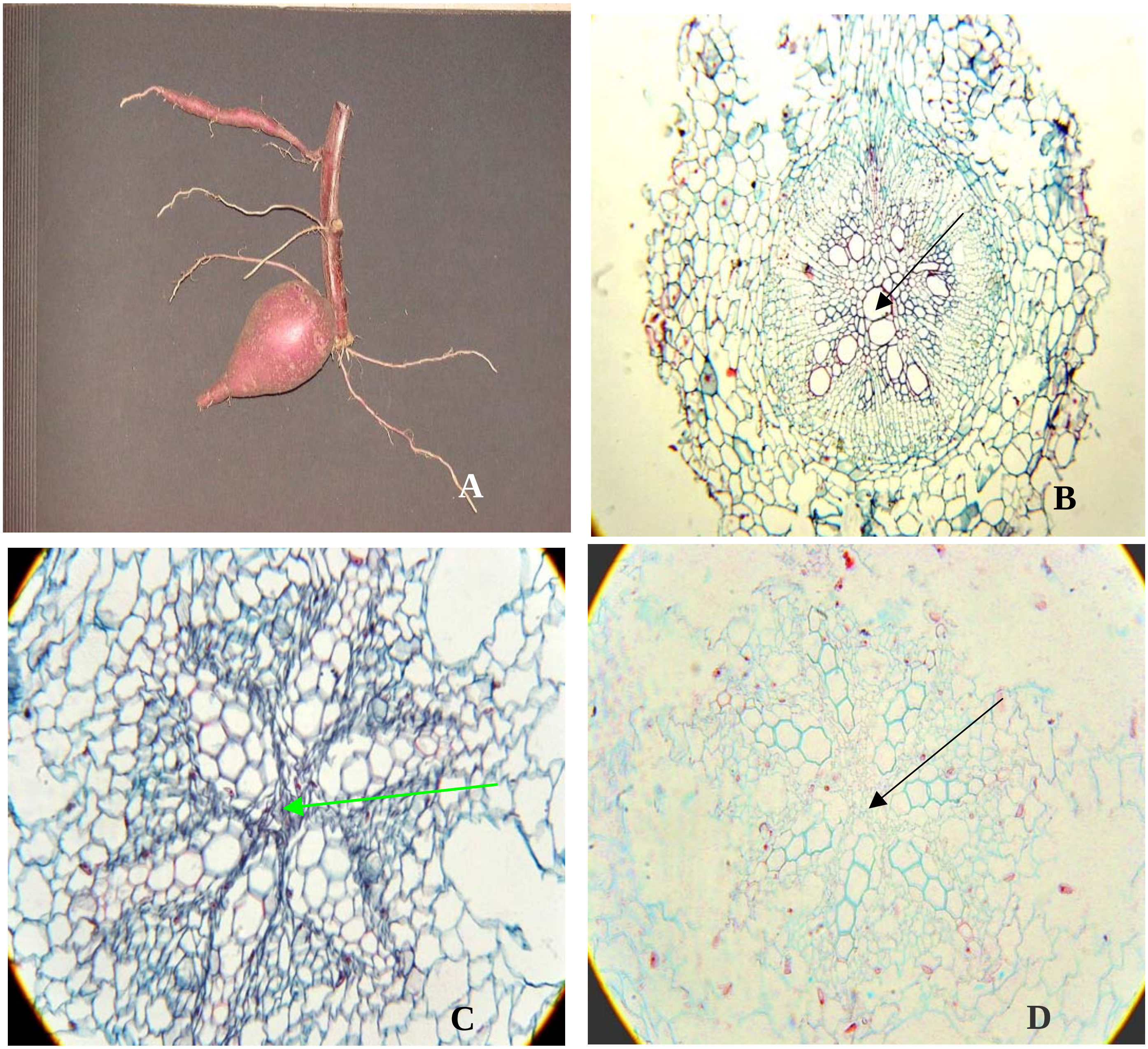

Figure 3.4. Illustration of the morphology and anatomy of the sweet potato root system

A. The general morphology of the roots. The root system of sweet potato consists of unthickened adventitious roots, pencil roots, and storage roots, all with lateral roots.
B. Micrograph of transverse section of a root with a pentarch stele and central metaxylem cell, indicating the beginning of a lignified stele. This is a typical structure of roots without the potential to develop into storage roots.
C. Micrograph of transverse section of a root with a hexarch stele without the central metaxylem. This is a typical structure indicating a root without potential to develop into a storage root.
D. Micrograph of transverse section of a root with septarch stele without the central metaxylem. Roots with this structure have the potential to develop into storage roots.

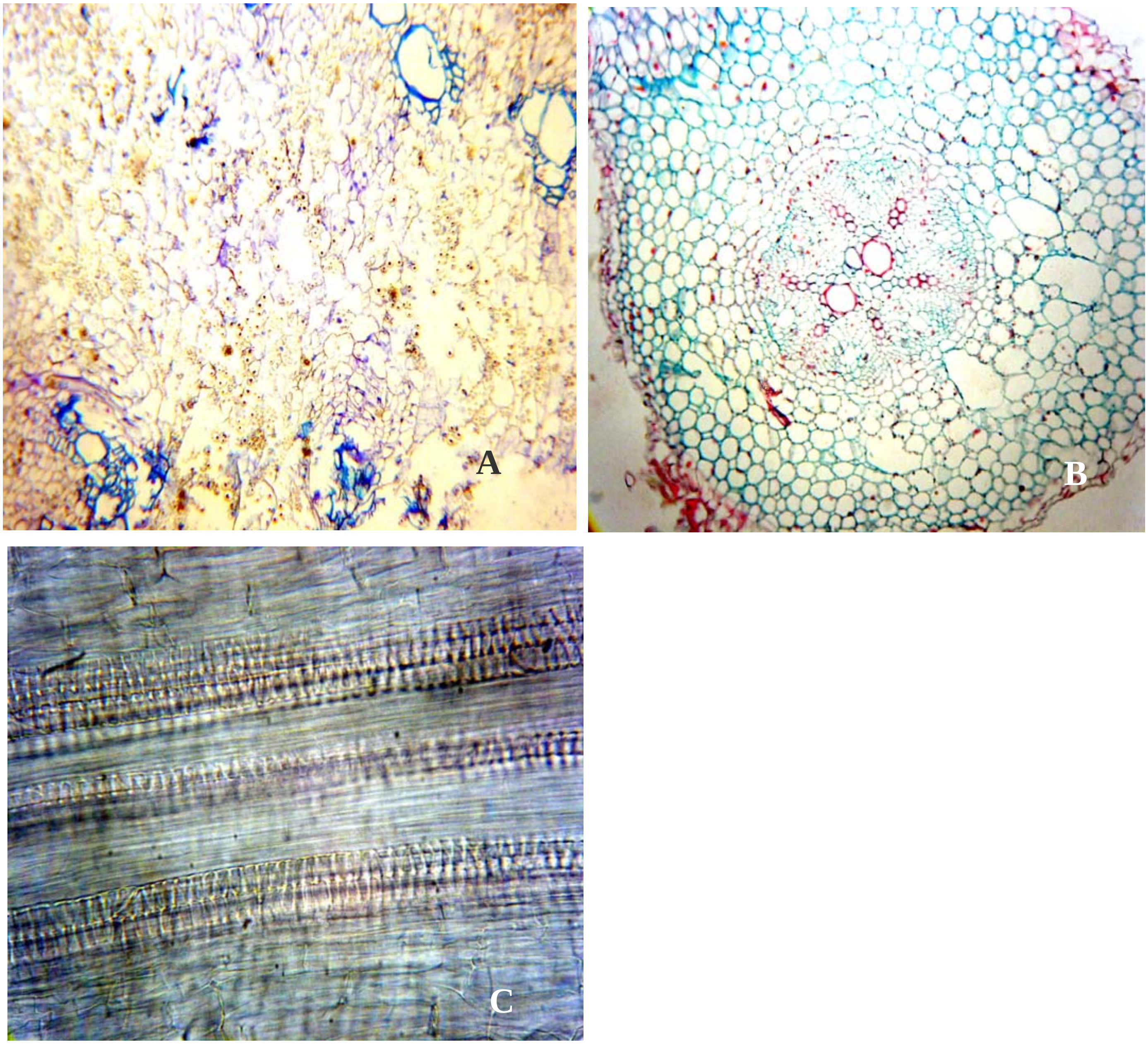

Figure 3.5. Micrographs of transverse sections of a young storage root, a wound root, and a longitudinal whole mount of a root

A. Magnified micrograph of transverse section of a young storage root illustrating storage tissue formation in the centre of the root
B. Micrograph of transverse section of a wound root with large central metaxylem elements and hexarch stele. Roots with this structure have the potential to develop into pencil roots
C. Micrograph showing portion of a clear whole mount of a longitudinal section root with three primary xylem strands parallel to each other. It was observed that the number of xylem strands remain unchanged throughout the length of the roots.

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CHAPTER 4

EFFECT OF TEMPERATURE AND SOIL MOISTURE CONTENT ON CUTTING ESTABLISHMENT

4.1 ABSTRACT

Effective rooting is essential for successful crop establishment from cuttings. The objective of this study was to determine the effect of temperature and soil water content on root and shoot growth during the early establishment of sweet potato cuttings. Root growth and development were examined in a phytotron at four temperatures (20, 24, 28 and 32 °C constant) and with four types of cuttings (3 node cutting vertically planted, 3 node cutting planted upside down, 3 node cutting horizontally planted and 1 node cutting planted horizontally). The cuttings were allowed to establish and grow for three weeks. The highest total root length (3.59m per plant) was recorded in the 24 °C growth chamber, significantly longer than the roots in the other temperature treatments. The highest root dry mass (0.22 g per plant), shoot dry mass (1.7 g per plant), leaf area (578 cm^2) and total dry mass (2.0 g per plant) were also obtained from the 24 °C growth chamber. The three node cuttings planted vertically produced the longest total root length of 3.66 m per plant, significantly longer than those of the other cutting types. The highest root dry mass, shoot dry mass, leaf area, vine length, leaf number, and total dry mass were also obtained from the vertically planted three node cuttings.

A pot experiment was conducted with cuttings sealed in plastic bags containing sandy soil at 100, 80, 60 and 40% of field water capacity. The cuttings were allowed to establish and grow in a plant growth chamber at 28 °C and harvested after 12 and 20 days. The 80% of field capacity moisture regime was found to be the optimum soil moisture content for sweet potato root growth.

With the soil water content at field capacity and at 40% of field capacity root development was somewhat suppressed. The results illustrated the capacity of sweet potato cuttings to establish successfully under a range of ambient temperatures and soil moisture contents.

4.2 INTRODUCTION

Establishment of sweet potato cuttings can be quite variable depending on environmental conditions. Although sweet potato is grown in the tropical, sub tropical and warm temperate regions of the world, it is essentially a warm weather crop (Onwueme, 1978). The thermal optimum is reported to be above 24 °C, compared to 25-30 °C for cassava and yam (Kay, 1973). Differences in thermal responsiveness would be expected among the wide range of sweet potato genotypes. Being a tropical crop, sweet potato is sensitive to low temperatures. Harter & Whitney (1962) reported that sweet potato could not survive temperatures of less than 12 °C, at 15 °C the plants were able to survive but did not grow, above 15 °C growth increased with increasing temperature up to 35 °C, and at 38 °C growth was somewhat depressed. Sark (1978) reported that sweet potato grown in a 10 to 15 °C greenhouse had much reduced vine growth compared to those grown in temperatures of 21 to 25 °C.

Gomes & Carr (2003) studied the effect of water availability and vine harvesting frequency on the productivity of sweet potato in Mozambique, and suggested that the water requirement over the growing season is between 360 and 800 mm. Sweet potato is normally propagated from vine cuttings, and the development of adventitious roots is expected to be sensitive to soil moisture deficits immediately after planting. An adequate moisture supply is probably essential for promoting rapid and uniform root development and good stand establishment. During vegetative development of plants even minor stresses can reduce the rate of leaf expansion and the leaf area at later stages of development. Although no published information on the effect of soil moisture content on cutting establishment could be found, various publications refer to the negative effect of water stress on growth and yield of sweet potato. During vegetative development the leaf area index increases with increase in soil moisture (Enyi, 1977; Indira & Ramanujam, 1985; Chowdhury & Ravi, 1988). The storage root initiation period is the most sensitive to moisture deficit due to its effect on storage root number (Indira & Kabeerathumma, 1988; Nair & Nair, 1995; Ravi & Indira, 1996). Moisture deficits during the storage root initiation period induce lignification of adventitious root and hampers growth (Ravi & Indira, 1996).

Considering the scarcity of information on factors affecting early root growth and cutting establishment, two experiments were conducted to establish to what extent root and shoot growth of newly planted cuttings is affected by ambient temperature and soil moisture. The objective of this study was to determine the effect of temperature and soil water content on the root and shoot growth during the establishment of cuttings.

4.3 MATERIALS AND METHODS

Temperature Experiment

A pot experiment with four temperature treatments and four types of cuttings was conducted during 2000 in the phytotron on the Experimental Farm of the University of Pretoria. Leaves were removed from the cuttings before planting. The experiment was carried out in four plant growth chambers. The growth chambers were regulated to constant temperatures of 20 ^{o}C, 24 ^{o}C, 28 ^{o}C, and 32 °C. The photoperiod was 12hr with an abrupt light/dark change. The four types of cuttings were:

N1. Three-node cuttings vertically planted with one node under the soil surface.
N2. Three-node cuttings planted upside down with one node under the soil surface.
N3. Three-node cuttings horizontally planted with all the nodes 5-7 cm under the soil surface.
N4. One-node cuttings planted horizontally.

Pots were filled with fine sifted, heat-sterilized sand and cuttings were planted on 24 October 2000. There were five replications (pots) of each treatment combination. Within the growth chambers the pots were arranged randomly and watered once a day. All pots were harvested three weeks after planting. The stem length, leaf number and leaf area were determined. The roots were carefully removed from the sand by submerging the pot in water to loosen the sand and minimize root breakage. After uprooting the roots were washed to remove the remaining sand. Images of the roots were obtained by scanning the roots with an image analyzing computer programme. The root length was measured using the “GS Root” programme. Roots and shoots were dried in a forced-ventilation oven at 60 °C for 48 hours. Dry matter partitioning was determined from the total dry mass of the shoots and the roots.

Treatments were arranged in a randomized complete block design. The experimental data were subjected to standard analyses of variance using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1989) to determine the effect of main factors and the interaction between them. Differences at the $P \leq 0.05$ level were used as a test of significance and means were separated using Tukey's t-test.

Moisture Experiment

A pot experiment with four-soil water content levels was conducted. The four moisture levels were field capacity (FC), 80% of field capacity, 60% of field capacity, and 40% of field capacity. The four moisture regimes were obtained by adding 70 ml, 56 ml, 42 ml, and 28 ml water respectively to 2 kg dry sand in plastic bags. After adding the water the sand in each bag was thoroughly mixed to achieve an even distribution of moisture, and sealed in polyethylene bags to come to equilibrium. After two days three cuttings of identical fresh mass and length were planted vertically through small slits in each bag on 6 September 2000. After planting the containers were placed in a growth chamber at a constant temperature of 28 ^{o}C and a photoperiod of 12 hours.

Two harvests were made, the first harvest was 12 days after planting (12DAP) and the second one 20 days after planting (20DAP). At the first harvest three replicates of each treatment were sampled, while at the second harvest there were four replications. The harvesting procedure, data recorded and statistical procedures were similar to those described for the temperature experiment.

4.4 RESULTS

Temperature experiment

Effect of temperature

Root lengths and root dry mass results are presented in Table 4.1. An increase in temperature from 20 ^oC to 24 ^oC increased the root length and root dry mass per plant. The highest total root length of 3.95 m per plant was obtained from plants exposed to a 24 ^oC growing temperature. As the temperature increased from 24 to 32 ^oC the root length decreased to 1.62 m per plant. The highest root dry mass was obtained from the plants exposed to 24 ^oC growing temperature and the lowest from the plants exposed to 20 ^oC. The largest proportion (13.6%) of the total biomass was partitioned to roots in the 32 ^oC treatment and the lowest (9.5%) at 28 ^oC.

The effect of temperature on shoot growth is presented in Table 4.2. In general shoot characteristics did not differ significantly between the 24^oC and 28^oC temperatures, but exposure to 20^o C or 32^o C affected shoot growth negatively. The highest vine length of 26.7 cm per plant was obtained from the plants exposed to 28 ^oC growing temperature, and the shortest vine length of 14.1 cm per plant was obtained from plants exposed to 20 ^oC. The highest leaf number (14) per plant was obtained from the plants grown at 28 ^oC, and the lowest temperature of 20 ^oC produced the smallest number of leaves (7) per plant. The highest shoot dry mass of 1.8 g per plant was obtained from the plants exposed to 24 ^oC and the lowest shoot dry mass (0.6 g per plant) was from the plants grown at 20 ^oC. The largest leaf area of 578 cm^2 was attained by plants grown in the 24 ^oC growth chamber and the smallest leaf area (188 cm^2) was obtained from plants grown at 20 ^oC.

Effect of type of cutting

Results of the effect of type of cutting on root length, root dry mass and fraction of the mass partitioned to roots are presented in Table 4.1. The highest root length of 3.66 m per plant was obtained from the three node cuttings oriented vertically, and the shortest (2.16 m) from the one node cutting oriented horizontally. The three node cuttings planted vertically produced the highest root dry mass of 0.22 g per plant, and the one node cutting planted horizontally produced the lowest (0.08 g per plant). The three node cuttings planted horizontally partitioned the highest fraction of dry mass (12.3%) to the roots while the three-node cuttings planted upside down partitioned the lowest.

Results of the effect of type of cutting on vine length, leaf number, shoot dry mass production and partitioning and leaf area are presented in Table 4.2. The vine length, leaf number and shoot dry mass from the three node cuttings were similar, whether planted vertically, horizontally or even up side down. The leaf area from the three node cuttings was similar, whether planted horizontally or vertically. It is interesting that even when planted upside down sweet potato cuttings retain the ability to establish vigorous root and shoot growth.

Temperature x type of cutting interactions

The temperature x type of cutting interactions were only significant for root length and leaf area. Vertically oriented three node cuttings exposed to 24 ^{o}C growing temperature resulted in a much longer root length (6.4 m) than any of the other treatment combinations (Figure 4.1). The one node cutting produced less root growth (1.2 m) than the other cuttings at 28 ^{o}C, but had similar root growth at 20, 24 and 32 ^{o}C. In Figure 4.2 the temperature x type of cutting interaction for leaf area shows that vertically planted three node cuttings had a larger leaf area (877 cm^2) at 24 ^oC than the other cuttings, while at 20^o, 28^o and 32 ^oC the leaf areas were similar except for the small leaf area of the one node cuttings at 20 ^oC. Similarity between Figures 4.1 and 4.2 is interesting and may be an indication of the reliability of the data, but an explanation for the interactions is not obvious.

Moisture experiment

The effect of soil water content 12 days after planting on root development is summarized in Table 4.3. The longest total root length (3.46 m) was obtained from cuttings grown in soils at 80% of field capacity. As the soil water content decreased from 80 to 40% of field capacity the root length decreased to 1.5 m per plant. Differences in shoot and total dry mass per plant and percentage dry matter partitioned to the shoot were significant. The largest proportion (86.5%) of the total biomass was partitioned to stems, the highest shoot dry mass of 0.09 gram per plant, and the highest total dry mass of 0.11 gram per plant were recorded from plants grown at 80% of field capacity, and the lowest at 40% of field capacity.

Results of the effect of soil water content 20 days after planting on root development is summarized in Table 4.4. Differences in root length and root dry mass were not statistically significant, although roots in the 80% of field capacity treatment tended to be the longest. Differences in shoot dry mass per plant were not significant, but the soil moisture regimes showed significant differences in dry matter partitioned to the shoots and total dry mass produced per plant. The largest proportion (90.9%) of the total biomass was partitioned to the stems, and a highest total dry mass of 0.146 g per plant, was recorded from plants grown at 80% of field capacity.

In this study the 80% of field capacity moisture regime was found to be the optimum soil moisture content for root and shoot development. Lower or higher moisture regimes resulted in less root growth, but it is interesting to note that even at an initial moisture content of 40% of field capacity, substantial root development occurred. This is an indication that soil water content is not critical during the establishment of cuttings, provided that the soil is neither too wet nor too dry.

4.5 DISCUSSION AND CONCLUSION

The increase in root length and root dry mass per plant with increasing temperature from 20 to 24 ^{o}C, and a decrease in root length and root dry mass with increase in temperature from 28 to 32 ^{o}C suggests that 24 ^{o}C was the optimum temperature for root growth and development. The increase in leaf number and vine length per plant with increasing temperature from 20 to 28 ^{o}C, and decrease in vine length and leaf number with increase in temperature from 28 to 32 ^{o}C, indicate that the optimum temperature for shoot growth was approximately 28 ^{o}C. The results suggest that temperature ranging from 24 to 28 °C is the most suitable for early root and shoot growth. According to Spence & Humphries (1971) leaf cuttings planted in sand and exposed to root temperatures of 35, 30, 25, 15, and 10 ^{o}C indicated that at 15 ^{o}C no roots developed into storage roots but there were more fibrous roots than at 25 and 30 ^{o}C.

Despite the relative large coefficient of variation a reasonably clear picture emerged from the experiments regarding the effect of temperature and soil moisture content on early root development. Better root growth was achieved 12 and 20 days after planting from cuttings planted at 80% of field capacity. Lower or higher moisture regimes resulted in less root growth, but it is interesting to note that even at an initial moisture content of 40% of field capacity, substantial root development occurred. This is an indication that soil water content is not critical during the establishment of cuttings, provided that the soil is not too wet (field capacity or wetter) nor too dry (less than 40% of field capacity). Using two sweet potato cultivars Bok (1998) conducted a pot experiment where cuttings were planted in soil at 100%, 70%, 50%, and 30% of field capacity. He reported that the cultivars performed similarly under different soil water regimes, with respect to root length and root dry mass production. The 70% of field capacity moisture regime was found to be the optimum for root development of the cultivars. This result is similar to my data, which indicated that the 80% of field capacity moisture regime was the most favorable for root development. An explanation for the somewhat depressed root growth at field capacity reported by Bok (1998), and observed in this experiment, is not clear. The possibility of partly anaerobic conditions in the polyethylene bags containing the sandy substrate cannot be excluded, and should be investigated.

The results confirm the capacity of sweet potato cuttings to successfully establish under a range of soil moisture conditions and ambient temperatures. This is one of the features of sweet potato cuttings contributing to its suitability as propagating material, even under relatively unfavorable environmental conditions.

Table 4.1 Effect of temperature and orientation of cuttings on sweet potato root development

Treatment		Per plant		
		Root length (m)	Root dry mass (g)	% dry mass partitioned to root
Temperature	**20 °C**	2.51	0.08	10.9
	24 °C	3.95	0.22	11.0
	28 °C	2.92	0.17	9.5
	32 °C	1.62	0.15	13.6
	LSD$_T$	0.75	0.05	1.6
Cutting type	**N1**	3.66	0.22	12.0
	N2	2.32	0.13	9.7
	N3	2.86	0.18	12.3
	N4	2.16	0.08	11.0
	LSD$_T$	0.75	0.05	1.6
Mean		2.75	0.16	11.3
CV%		43.2	55.0	22.2

Table 4.2 Effect of temperature and orientation of cuttings on sweet potato shoot development

Treatment		Vine length cm	Leaf number	Leaf area cm^2	Shoot dry mass g/plt	Total dry mass g/plt
Temperature	**20 °C**	14.1	7.2	187.5	0.61	0.7
	24 °C	25.6	13.7	578.2	1.75	2.0
	28 °C	26.7	14.4	519.0	1.50	1.7
	32 °C	20.9	11.7	246.5	1.00	1.1
	LSD$_T$	3.2	2.3	107.3	0.4	0.4
Cutting type	**N1**	24.1	13.8	510.4	1.59	1.8
	N2	22.7	12.7	375.8	1.21	1.3
	N3	22.9	12.8	425.3	1.34	1.5
	N4	17.6	7.7	219.7	0.70	0.8
	LSD$_T$	3.2	2.3	107.3	0.4	0.4
Mean		21.8	11.8	382.8	1.21	1.35
CV%		23.1	30.6	44.3	47.6	47.8

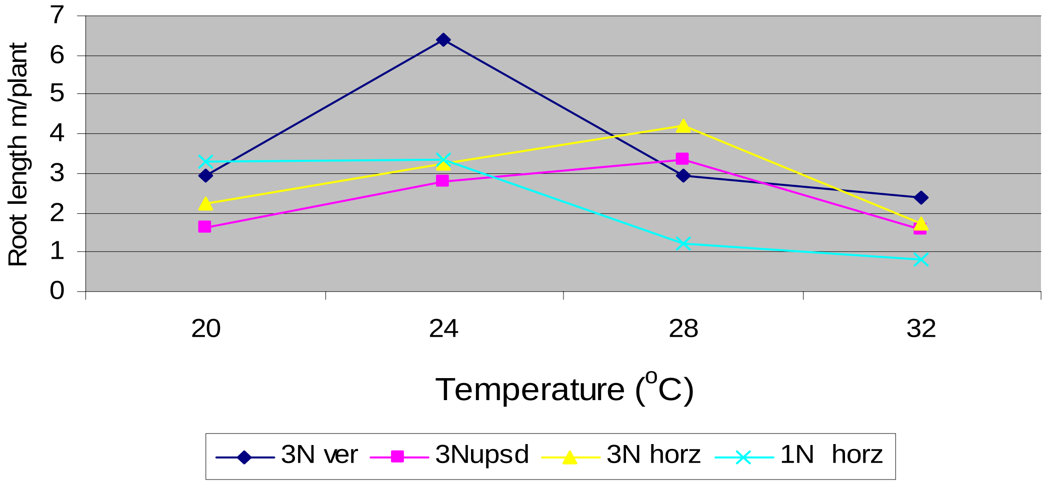

Figure 4.1 Interaction between temperature and orientation of cutting on root length

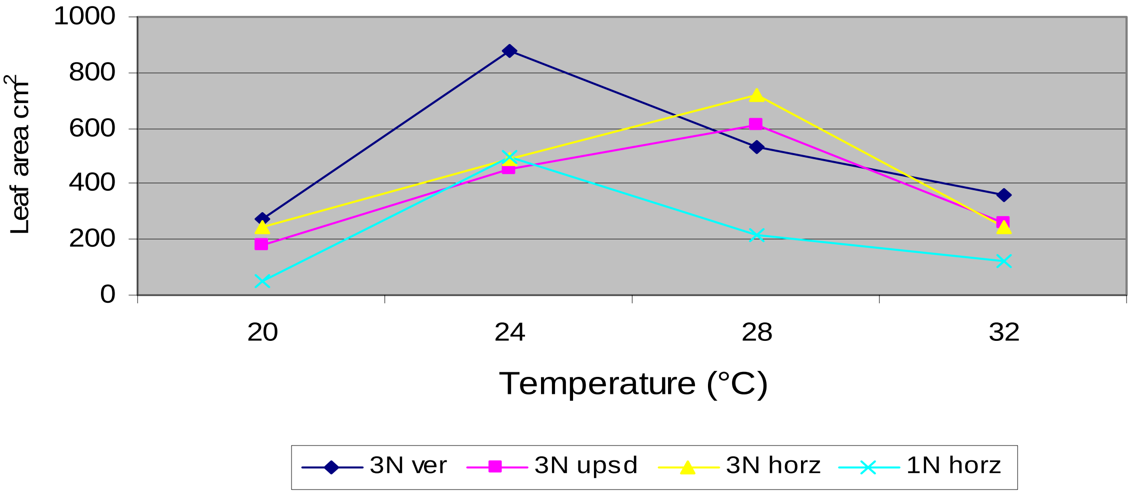

Figure 4.2 Interaction between temperature and orientation of cutting on leaf area per plant

Table 4.3 Effect of soil water content on the shoot and root growth of sweet potato 12 days after planting

Soil water content (%FC)	Root length in (m)	Root dry mass g/plant	Shoot dry mass g/plant	Total dry mass g/plant	% DM partitioned to shoot
100	2.10	0.011	0.067	0.078	85.47
80	3.46	0.015	0.093	0.108	86.53
60	2.46	0.013	0.050	0.063	78.26
40	1.53	0.010	0.034	0.044	75.35
LSD_T	1.86	0.010	0.044	0.053	10.51
Mean	2.39	0.0123	0.061	0.073	81.40
C.V. (%)	41.37	41.53	38.31	38.10	6.86

Table 4.4 Effect of soil water content on the shoot and root growth of sweet potato 20 days after planting

Soil water content (%FC)	Root length in (m)	Root dry mass g/plant.	Shoot dry mass g/plant	Total dry mass g/plant	%DM partitioned to shoot
100	2.40	0.009	0.086	0.095	90.26
80	3.80	0.012	0.118	0.146	90.92
60	3.21	0.010	0.094	0.103	90.83
40	3.02	0.015	0.083	0.098	85.27
LSD_T	1.66	0.006	0.040	0.039	3.72
Mean	3.11	0.012	0.095	0.111	89.32
C.V. (%)	37.72	32.61	27.24	23.10	2.70

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CHAPTER 5

INFLUENCE OF CUTTING CHARACTERISTICS ON STORAGE ROOT FORMATION AT INDIVIDUAL NODES

5.1 ABSTRACT

Little information is available on the contribution of individual subterranean nodes to storage root production. As this may affect productivity it was investigated in three pot experiments conducted on the Experimental Farm of the University of Pretoria. The objective was to determine the contribution of individual subterranean nodes to storage root formation on terminal, middle and basal vine cuttings, planted with three nodes below the soil surface. In Experiment 1 two types of stem cuttings (terminal and basal) with two orientations of planting (vertical and horizontal) were planted. In Experiment 2 two types of stem cutting (terminal and middle) with different numbers of leaves (0, 0.5, 1 and 2) were planted. In Experiment 3 three types of cuttings (terminal, middle and basal) with two orientations of planting (vertical and horizontal) were planted. Terminal cuttings were more productive than basal cuttings, and horizontal planting produced a higher storage root yield than vertical planting, but these treatments did not have a clear effect on the distribution of storage roots on the subterranean nodes.

Morphologically, the number of preformed root primordia, and thus the potential to produce storage roots, are similar for all nodes of a cutting. This was reflected in the results, and on average 3.7 storage roots were produced per cutting, with 33.2% of the storage roots formed on subterranean node 1, 30.0% on node 2 and 36.8% on node 3. However, in terms of fresh mass of

the storage roots node 1 contributed 45.4%, node 2 contributed 27.1% and node 3 contributed 27.4%. This distribution pattern may reflect the relative proximity of the nodes to the source of assimilates from the leaves.

5.2 INTRODUCTION

Cuttings from the shoot apex are often regarded as better planting material than basal or middle vine cuttings (Eronico *et al*., 1981; Choudhury *et al.*, 1986; Villamayor Jr & Perez, 1988; Schultheis *et al*., 1994). Apical cuttings may ensure better rooting and establishment and faster shoot growth and therefore early canopy closure for weed suppression (Eronico *et al*., 1981; Hall, 1987). The age of the source plant from which the cuttings are taken is important. Yield is significantly reduced when cuttings from older plants are used (Martin, 1984). Villamayor Jr & Perez (1988) reported that the basal cuttings of young sweet potato plants (2.5 months) produced a 19% lower storage root yield than the terminal cuttings. On the other hand, the basal cuttings from older sweet potato plants (4 months) produced a 56% lower root yield than the terminal cuttings of the same plants. The storage root mass obtained from the individual subterranean nodes of the cuttings, however, was not reported. The presence of leaves on vine cuttings greatly increased adventitious root production, presumably due to the presence of active endogenous root promoting substances (Fadl *et al*., 1977; Fadl *et al*., 1978). Ravindran & Mohankumar (1982, 1989) reported that storage root yield was significantly higher in plants from vine cuttings with foliage than in plants from cuttings without foliage. Contrary to this Villamayor Jr (1986) reported that the presence of leaves on vine cuttings did not influence storage root number and storage root mass.

The number of nodes on cuttings used as planting material may be an important aspect of yield variability. Lowe & Wilson (1975) reported that 80 to 100 % of the yield is produced at the first four nodes below the soil surface. An increase in the length of cuttings was reported to increase sweet potato yield (Jimenez-Tiamo, 1983). Choudhury *et al.* (1986) reported that the highest storage root yield of 63.5t ha^{-1} was achieved from 12-node cuttings when two types of vine cuttings (apical and middle) were planted. This was followed in decreasing order by cuttings having 9, 6 and 3 nodes respectively. However, none of the quoted sources reported on the contribution of the individual subterranean nodes to storage root yield. Du Plooy *et al.* (1992) conducted experiments to investigate storage root formation at individual nodes. They reported that the number of storage roots did not differ as they differentiated at lower nodes in vertically planted cuttings with three subterranean nodes. For the five subterranean nodes the first two produced more storage roots than the lower three. The results showed that the highest storage root mass was achieved from node 1. This was followed in decreasing order by the lower nodes.

Considering the importance of sweet potato as a food crop in many of the developing countries, the lack of knowledge on storage root formation is surprising. It is not clear whether storage root initiation differs among nodes, nor whether nodes differ as preferred assimilate sinks. Such information can affect production practices like length of cuttings, planting depth and ridging.

The objectives of this study were:

- to determine the contribution made by individual subterranean nodes of terminal, middle, and basal cuttings to storage root formation; and

- to determine the influence of cutting orientation, and presence or absence of leaves on the cuttings, on storage root formation at individual nodes.

5.3 MATERIALS AND METHODS

Three greenhouse experiments were conducted during 2002 on the Experimental Farm of the University of Pretoria, using the cultivar Atacama. Uniform terminal, middle and basal cuttings of 20 cm length and containing six nodes were obtained from plants grown in a greenhouse. Four cuttings per pot were planted with three nodes below the soil surface. For horizontally planted cuttings the three nodes were placed 5 cm below the soil surface with the top part of the cutting above the soil surface. The subterranean node closest to the soil surface was identified as node 1. The plastic pots (25 cm in diameter spaced 20 cm apart) filled with sandy soil were irrigated daily with a commercial nutrient solution. All three experiments were conducted under similar conditions during the autumn and winter of 2002. Plants were harvested ninety days after planting. Each plant was carefully uprooted from the sandy soil by submerging the pot in water to loosen the sand and minimize storage root breakage from the nodes. The roots were washed to remove the remaining sand. Only roots that could clearly be identified as storage roots were counted and weighed separately from each of the three nodes.

The experimental data were subjected to standard analyses of variance using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, Institute Inc. Cary, NC, USA 1989) to determine the effect of main factors and the interaction between them. Differences at the $P \leq 0.05$ level were used as a test of significance and means were separated using Tukey's t-test.

In **Experiment 1** two types of stem cuttings (terminal and basal) with two orientations of planting (horizontal and vertical) were planted. The experiment was a 2 x 2 factorial in a completely randomized design with ten replications.

In **Experiment 2** two types of stem cuttings (terminal and middle) with different numbers of leaves on the cuttings (0, 0.5, 1 or 2) were planted in a vertical position. The experiment was a 2 x 4 factorial in a completely randomized design with four replications.

In **Experiment 3** terminal, middle and basal cuttings with two orientations of planting (horizontal and vertical) were planted. The experiment was a 3 x 2 factorial in a completely randomized design with four replications.

5.4 RESULTS

Experiment 1

The total number and fresh mass of storage roots per plant obtained from terminal and basal cuttings planted in vertical and horizontal positions, and the contribution of individual nodes to storage root number and fresh mass are presented in Table 5.1. Due to the relatively high coefficient of variation only the main trends are discussed.

Terminal cuttings produced significantly more storage roots (2.75 per cutting) than basal cuttings (1.55). Vertical or horizontal planting of the cuttings did not affect the number of storage roots. Over all the treatment combinations on average 37.5% of the storage roots were formed on node 1, with 25.4% on node 2 and 37.2% on node three, indicating no clear node preference in the initiation of storage roots.

The terminal cuttings produced a larger mass of storage roots (151 g) than the basal cuttings (77 g). The orientation of the cuttings did not affect the storage root yield, although vertically planted cuttings tended to have higher yields than those planted horizontally. On average over the treatment combinations node 1 contributed 50.6% to the storage root mass, node 2 21.5% and node 3 27.9%.

None of the type x orientation of cutting interactions were statistically significant, indicating that for all the parameters evaluated the types of planting material reacted similarly to changes in the orientation of planting.

Table 5.1 Storage root number and yield produced per plant and per node from terminal and basal cuttings planted vertically and horizontally: Experiment 1

Treatment	Total	Node Position		
		Node 1	Node 2	Node 3
Storage root numbers				
Type of cutting				
Terminal	2.75 (100%)	1.20 (43.6%)	0.75 (27.3%)	0.80 (29.1%)
Basal	1.55 (100%)	0.45 (29.0%)	0.35 (22.6%)	0.75 (48.4%)
LSD_T	0.84	0.54	0.50	0.55
Orientation of cutting				
Vertical	2.3 (100%)	0.80 (34.8%)	0.55 (24.0%)	0.95 (41.3%)
Horizontal	2.0 (100%)	0.85 (42.5%)	0.55 (27.5%)	0.60 (30%)
LSD_T	0.84	0.54	0.50	0.56
Mean	2.15 (100%)	0.83 (37.5%)	0.55 (25.4%)	0.77 (37.2%)
CV%	60.0			
Storage root yield (g)				
Type of cutting				
Terminal	151 (100%)	91.7 (60.8%)	39.9 (26.4%)	19.3 (12.8%)
Basal	77.3 (100%)	28.4 (36.7%)	10.9 (14.1%)	38.1 (49.0%)
LSD_T	55.17	46.12	27.27	32.10
Orientation of cutting				
Vertical	122 (100%)	66.6 (54.5%)	21.1 (17.3%)	34.4 (28.2%)
Horizontal	106 (100%)	53.5 (50.4%)	29.7 (28.0%)	22.9 (21.6%)
LSD_T	55.2	46.12	27.27	32.10
Mean	114 (100%)	60.0 (50.6%)	25.4 (21.5%)	28.7 (27.9%)
CV%	75.0			

Experiment 2

The contribution of individual nodes to total number and fresh mass of storage roots obtained from terminal and middle cuttings with and without leaves are presented in Table 5.2. Due to the relatively high coefficient of variation only the main trends are discussed. There was no difference in the number of storage roots produced by terminal and middle cuttings. However, the presence or absence of leaves on the cuttings affected storage root number, with significantly less storage roots (3.6) formed on cuttings without leaves, compared to approximately 5.4 on cuttings with leaves. The number of leaves present on a cutting did not have an effect on storage root numbers. On average over the treatment combinations the contribution of individual nodes to storage root numbers was similar, with node 1 bearing 34%, node 2 35%, and node 3 31% of the storage roots.

The terminal cuttings produced a larger mass of storage roots (250 g per plant) than did the middle cuttings (197 g). The presence or the absence of leaves on the original cutting did not affect storage root mass. On average over the treatment combinations the contribution of individual nodes to storage root mass decreased from 103 g (47%) on node 1 to 69 g (31%) on node 2 and to 50 g (22%) on node 3.

The type of cutting x presence or absence of leaves on cutting interactions were statistically significant for storage root number at node 1 (Figure 5.1) and at node 2 (Figure 5.2). Middle cuttings with one leaf produced more storage roots on node 1 and 2 than terminal cuttings with one leaf. With 0, 0.5 or 2 leaves per cutting there were no differences between terminal and middle cuttings. No physiological explanation for this phenomenon can be offered.

Table 5.2 Storage root number and yield produced per plant and per node from terminal and middle cuttings planted with and without leaves: Experiment 2

Treatment	Total	Node Position		
		Node 1	Node 2	Node 3
Storage root numbers				
Type of cutting				
Terminal	4.66 (100%)	1.50 (32.2%)	1.72 (37.0%)	1.44 (30.9%)
Middle	5.25 (100%)	1.84 (35.1%)	1.75 (33.3%)	1.66 (31.6%)
LSD_T	1.02	0.44	0.56	0.54
Leaf number				
0	3.62 (100%)	1.31 (36.2%)	1.25 (34.5%)	1.06 (29.3%)
½	5.50 (100%)	1.81 (32.9%)	1.94 (35.3%)	1.75 (31.8%)
1	5.37 (100%)	2.12 (39.5%)	1.69 (31.5%)	1.56 (29.0%)
2	5.31 (100%)	1.44 (27.1%)	2.06 (38.8%)	1.81 (34.1%)
LSD_T	1.44	0.63	0.79	0.76
Mean	4.95 (100%)	1.67 (33.8%)	1.73 (35.0%)	1.55 (31.1%)
CV%	28			
Storage root yield (g)				
Type of cutting				
Terminal	250 (100%)	115 (46.0%)	82.8 (33.2%)	52.0 (20.8%)
Middle	197 (100%)	92.4 (46.9%)	55.7 (28.3%)	48.8 (24.8%)
LSD_T	45.27	32.71	33.7	31.1
Leaf number				
0	207 (100%)	104 (50.1%)	67.5 (32.6%)	35.8 (17.3%)
½	199 (100%)	106 (53.0%)	56.5 (28.3%)	37.1 (18.6%)
1	251 (100%)	111 (44.3%)	78.4 (31.2%)	61.5 (24.5%)
2	235 (100%)	93.3(39.7%)	74.5 (31.7%)	67.2 (28.6%)
LSD_T	64.02	46.26	47.7	44.03
Mean	223 (100%)	103 (46.7%)	69.2 (30.9%)	50.4 (22.4%)
CV%	27.8			

Figure 5.1 Interaction between type of planting material and number of leaves on cuttings on storage root number at node 1 Experiment 2

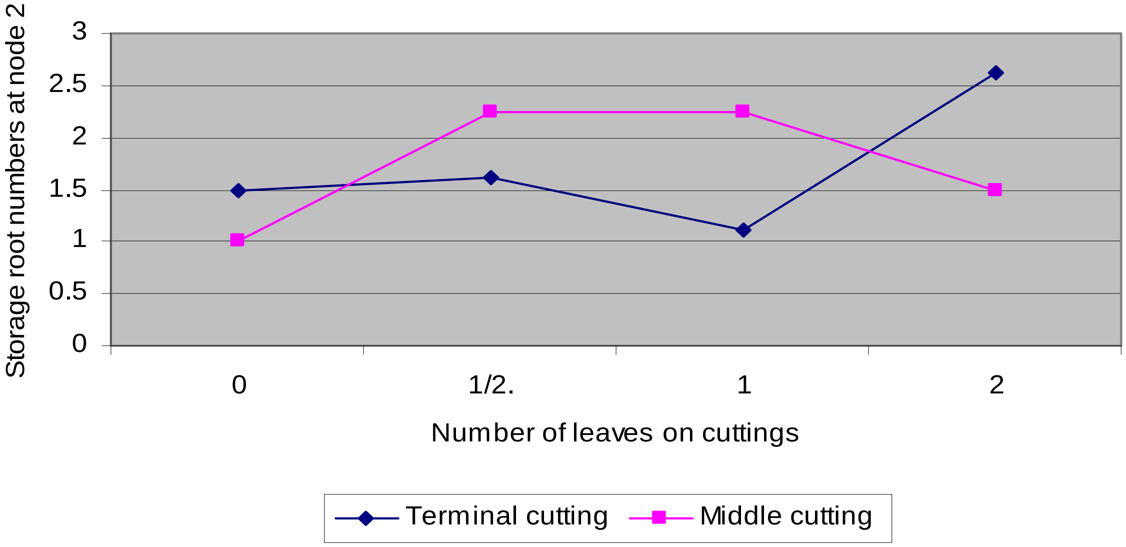

Figure 5.2 Interaction between type of planting material and number of leaves on cuttings on storage root number at node 2 Experiment 2

Experiment 3

The total number and fresh mass of storage roots per plant obtained from terminal, middle and basal cuttings planted in vertical and horizontal positions, and the contribution of individual nodes to storage root number and fresh mass are presented in Table 5.3. Considering the relatively high coefficient of variation only the main trends are discussed. Terminal cuttings produced significantly more storage roots (4.8 per cutting) than middle cuttings (3.4). Vertical or horizontal planting of the cuttings did not affect the number of storage roots produced. On average over all the treatment combinations 31.6% of the storage roots were formed on node 1, 30.5% on node 2 and 37.8% on node three.

The terminal and middle cuttings produced a larger mass of storage roots (184 g and 186 g per plant respectively) than the basal cuttings (71 g). Horizontal planting of the cuttings resulted in a larger total storage root yield than vertical planting. On average over all the treatment combinations 43.5% of the storage root fresh mass was formed on node 1, 29.3% on node 2 and 27.1% on node three.

None of the type x orientation of cutting interactions were statistically significant indicating that for all the parameters evaluated the three types of cutting reacted similarly to changes in planting orientation.

Table 5.3 Storage root number and yield produced per plant and per node from terminal middle and basal cuttings planted vertically and horizontally: Experiment 3

Treatment	Total	Node Position		
		Node 1	Node 2	Node 3
Storage root numbers				
Type of cutting				
Terminal	4.8 (100%)	1.6 (32.2)	1.5 (31.4)	1.8 (36.2)
Middle	3.4 (100%)	1.3 (38.9)	1.0 (29.7)	1.1 (31.5)
Basal	4.1 (100%)	1.0 (24.3)	1.3 (30.3)	1.9 (45.4)
LSD_T	1.07	0.60	0.49	0.94
Orientation of cutting				
Vertical	4.0 (100%)	1.3 (31.6)	1.2 (29.4)	1.5 (39.0)
Horizontal	4.3 (100%)	1.3 (31.2)	1.4 (31.9)	1.6 (37.0)
LSD_T	0.87	0.49	0.40	0.77
Mean	4.1 (100%)	1.3 (31.6)	1.3 (30.5)	1.6 (37.8)
CV%	24.8			
Storage root yield (g)				
Type of cutting				
Terminal	184 (100%)	82.0 (44.6)	57.6 (31.3)	44.2 (24.0)
Middle	186 (100%)	100 (54.0)	51.1 (27.5)	34.4 (18.5)
Basal	71 (100%)	19.0 (26.9)	21.0 (29.8)	30.6 (43.3)
LSD_T	49.94	41.22	28.01	25.00
Orientation of cutting				
Vertical	124 (100%)	59.4 (48.1)	31.8 (25.8)	32.3 (26.1)
Horizontal	170 (100%)	74.9 (44.0)	54.7 (32.1)	40.5 (23.8)
LSD_T	40.78	33.66	22.87	20.41
Mean	146.8 (100%)	67.2 (43.5)	43.2 (29.3)	36.4 (27.1)
CV%	32.4			

5.5 DISCUSSIONS AND CONCLUSION

Number of storage roots

The three experiments resulted in a clear picture regarding the contribution of individual nodes to storage root production. The mean number of storage roots produced by the three types of cuttings was similar. On average over the three experiments 3.7 storage roots were produced per cutting, with 33.2% of the storage roots formed on subterranean node 1, 29.9% on node 2 and 36.8% on node 3, indicating no clear node differences (Table 5.4). It should be noted that on average only 1.27 storage roots were actually initiated per node, although typically four or more preformed root primordial (potential storage roots) are present on each node. Contrary to this Du Plooy *et al.* (1992) observed that with three subterranean nodes the number of storage roots did not differ significantly, but tended to decrease from 2.6 roots at node 1, to 2.4 roots at node 2 and to 2.2 roots at node 3. For the five subterranean nodes the storage roots decreased significantly from 2.1 roots at node 1, to 1.9 roots at node 2, to 1.4 roots at node 3, to 1.1 roots at node 4, to 0.9 roots at node 5. The three subterranean nodes produced a total of 7.2 storage roots per cutting while the five subterranean nodes produced 7.4, compared to the 3.7 storage roots per cuttings obtained in our experiments. Lowe & Wilson (1975) reported that node 1 contributed 27%, node 2 contributed 30%, node 3 contributed 24% and node 4 contributed 18% of the total number of storage roots per cutting.

Preformed root primordia on the basal part of the vine are more aged and exposed to damage over a longer period than primordia on the terminal part of the vine. This may partly explain the phenomenon that terminal cuttings are more productive than the basal cuttings. The extent of damage to root primordia can affect the results obtained from experiments to determine the contribution of individual subterranean nodes to storage root formation. It is important that cuttings should be handled properly to avoid possible damage to preformed root primordia.

Fresh mass of storage roots

On average over the three experiments node 1 contributed 45.4%, node 2 contributed 27.1% and node 3 contributed 27.4% of the storage root fresh mass (Table 5.5). This distribution pattern probably reflects the relative proximity of the nodes to the source of assimilates from the leaves. The results corroborate those of Du Plooy *et al*., (1992) who reported that node 1 of three subterranean nodes contributed the highest storage root mass of 140 g, node 2 contributed 90 g and node 3 contributed 41 g. With five subterranean nodes, node 1 contributed the highest storage root mass of 136 g, node 2 contributed 92 g, node 3 51 g, node 4 35 g and node 5 28 g. Lowe & Wilson (1975) observed that the mean storage root yield of node 1 was 85 g, node 2 116 g, node 3 64 g and node 4 54 g for six cultivars. The explanation for the differences between the results of Du Plooy *et al* (1992), Lowe & Wilson (1975) and the experiments conducted at University of Pretoria is not clear, but it reflects the high degree of variability in sweet potato research pointed by Lowe & Wilson (1975).

No clear information yet exists on the contribution of individual subterranean nodes to the number and mass of storage roots produced. This is the subject which deserves more research attention. The pot experiments reported here contribute towards a better understanding of this topic and clearly indicated that a similar number of storage roots formed at each of the three subterranean nodes, reflecting the fact that the number of preformed root primordia (potential storage root) was the same for all the nodes (Chapter 3). Only a few of the adventitious roots developing from preformed root primordia actually develop into storage roots. Factors determining whether a potential storage root develops into storage root remain unclear and deserve more attention.

Table 5.4 Mean storage root number per node of the three experiments

Type of	Storage root number (Percentage contribution in bracket)			
cutting	Total	Node 1	Node 2	Node 3
Terminal	4.08	1.42 (36.0)	1.33 (31.9)	1.33 (32.0)
Middle	4.31	1.57 (37.0)	1.37 (31.5)	1.36 (31.5)
Basal	2.83	0.72 (26.7)	0.80 (26.5)	1.31 (46.9)
Mean	3.74	1.24 (33.2)	1.17 (29.9)	1.33 (36.8)

Table 5.5 Mean storage root mass per node of the three experiments

Type of	Storage root mass (Percentage contribution in bracket)			
cutting	Total	Node 1	Node 2	Node 3
Terminal	194.75	96.2 (48.1)	60.1 (29.4)	38.50 (22.4)
Middle	191.48	96.5 (50.5)	53.4 (27.8)	41.61 (21.6)
Basal	73.98	23.7 (37.7)	16.0 (24.2)	34.31 (38.1)
Mean	153.40	72.1 (45.4)	43.2 (27.1)	38.14 (27.4)

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CHAPTER 6

EFFECT OF CUTTING CHARACTERISTICS ON YIELD AND YIELD COMPONENTS OF SWEET POTATO

6.1 ABSTRACT

Appropriate plant establishment techniques are essential for successful crop growth and yield. Cutting characteristics are important factors that may affect yield and yield components. Effect of cultivar (Kudadie, Bareda and Awasa-83), planting position (horizontal and vertical), type of planting material (terminal vine cuttings with and without leaves) and cutting length (20, 25 and 30 cm) on the number and yield of storage roots were studied in Ethiopia at Awasa and Melkassa. The objective of the study was to identify cutting characteristics for better plant establishment and consequently for higher storage root yields. Cultivar Kudadie had the highest total and marketable storage root yield and cultivar Awasa-83 the lowest, at both locations.

The horizontal method of planting resulted in the highest total and marketable storage root yield at both locations. The planting position x type of planting material interaction was highly significant for total storage root number. The combination of horizontal planting and cuttings with leaves gave the highest total number of storage roots.

The cutting length (20, 25 and 30 cm) did not affect storage root number and yield, except for the number and yield of small storage roots. The 30 cm vine cuttings produced the highest number of small storage roots per unit area and the highest small storage root yield at both locations.

Generally storage root numbers tended to increase when the leaves were retained on the cuttings. Cuttings with leaves also produced the highest total and marketable storage root yield at Awasa. At Melkassa only the yield of small storage roots were higher when cuttings with leaves were planted.

6.2 INTRODUCTION

Sweet potato is one of the most important carbohydrate staples in Ethiopia. According to a survey by the Ministry of Agriculture Southern Regional Bureau (1999) a significant segment of the population depend primarily on sweet potato for their food supply. Its cultivation is estimated to cover an area of about 52,000 hectares in the southern region. In traditional farming systems, sweet potato planting material can be difficult and costly to obtain during the dry season. In general, the crop is planted using vine cuttings. Utilizing the vines as planting material give the farmers the opportunity to use all storage roots for consumption or for sale.

The terminal portion of sweet potato vine is reputed to be superior to the middle and basal portions for plant establishment and root yield. The majority of sweet potato farmers use cuttings with leaves. In Ethiopia sweet potato farmers using oxen to prepare the land prefer horizontal planting to vertical planting of cuttings. However, other resource poor farmers who are cultivating their crop manually prefer planting at an angle of 45°. The length of the vine cuttings varies from farmer to farmer and from location to location. There is no clear evidence whether the presence of leaves on the cuttings affects crop establishment and yield. Furthermore it needs to be established whether different cultivars require different lengths of cuttings and different positions of planting for best results.

There have been attempts to increase yield of sweet potato through modifications in cutting characteristics. Various propagation materials can be used to establish the crop. Sweet potato is normally propagated vegetatively by vine cuttings. However, in areas where production can not be carried on continuously and vines are unavailable for planting, root sprouts and storage root pieces are used for propagation. Vigorous and healthy storage roots from the previous crop are bedded and the sprouts are used as propagating material. Ikemoto (1971) reported that tubers for bedding should weigh from 20 to 50 g, and should be planted 3 cm deep. This method is generally used in temperate and subtropical regions (Steinbauer & Kushman, 1971 and Edmond & Ammerman, 1971).

Vine cuttings are better planting material in tropical regions than sprouts from tubers for several reasons. Firstly, plants derived from vine cuttings are free from soil-born diseases (Onwueme, 1978; Phills & Hill, 1984). Secondly, by propagating with vine cuttings the entire tuber harvest can be saved for consumption or marketing instead of reserving some of it for planting purposes. Thirdly, vine cuttings yield better than sprouts, and produce roots of more uniform size and shape. Cuttings from the shoot apex are considered better planting material than basal and middle vine cuttings (Shanmugavelu *et al*., 1972; Godfrey-Sam-Aggrey, 1974; Eronico *et al*., 1981; Villanueva, Jr., 1985; Choudhury *et al*., 1986; Villamayor, Jr & Perez, 1988; Balasurya, 1991; Schultheis & Cantliffe, 1994). Compared to cuttings from middle and basal portions, apical shoot cuttings grow more vigorously and produce larger storage root yields. Where the planting material is in short supply, middle and basal portions of the vine cuttings can be used, but with a decrease in expected yield (Degras, 1969).

There are conflicting results regarding the optimum length of vine cuttings. Onwueme (1978) indicated that tuber yield tend to increase with increase in the length of the vine cuttings used, and recommended a length of about 30 cm. Cuttings longer than 30 cm tend to be wasteful of planting material, while much shorter cuttings established slower, and gave poorer yields. Godfrey-Sam-Aggrey (1974), Shanmugavelu *et al.* (1972), Tanaka & Sekioka (1976), Ravindran & Mohankumar (1982) and Bautista & Vega (1991) also recommended that 20 to 40 cm long vine cuttings should be used for better storage root yield. Hall (1986) found that 40 to 45 cm cuttings produced higher total marketable root yield than 20 to 25 cm cuttings.

Chen & Allison (1982) reported that horizontal planting increased sweet potato yield. Storage root yield was significantly higher in plants from vine cuttings with leaves than in plants from cuttings without leaves (Ravindran & Mohankumar, 1982, 1989).

Information regarding cutting characteristics for the establishment of sweet potato in Ethiopia is scarce. Therefore experiments were conducted in two locations (Melkassa and Awasa) to compare and quantify the effects of cultivar, planting material, planting position and cutting length on the storage root yield. The objectives of the study were:

- to better understand cutting characteristics required for successful crop establishment and crop productivity in Ethiopia;
- to determine whether cultivars differ in terms of the required cutting characteristics;
- to identify the best cutting characteristic combinations for optimum storage root yield; and

- to identify differences in storage root yield using different cultivars and cutting characteristics at different locations.

6.3 MATERIALS AND METHODS

Soil and climate: Melkassa

Melkassa Research Centre, Ethiopia, is located at Lat. 8^{o} 24’ N and Long. 39^{o} 12’ E, at an altitude of 1550 masl, on the flat plains. The Centre is in a drought-prone cropping area. The monthly rainfall, evaporation and mean daily minimum and maximum temperatures for the year 2001 are shown in Figure 6.1a. The long term (1977 to 2001) meteorological data of the Centre indicates that the mean maximum temperature is 28.6° C and the mean minimum temperature is 13.8° C. The long-term average annual rainfall is 811 mm (March to October). May is the month with the highest average maximum temperature (30.9°C), whilst October is the month with the lowest average minimum temperature (11.8°C). Temperatures for the 2001 cropping season at Melkassa were similar to the 25-year trend, but rainfall was higher than normal. During the five months of the growing season (April to August 2001) precipitation totaled 648 mm, compared to the 25-year average of 537 mm for the same period. (Appendix, Table A6.1).

The pre-experimental soil chemical and physical characteristics are presented in Table 6.1. The soil is volcanic in origin. The texture is mainly silt clay loam with 40% silt, 32% sand and 28% clay. The pH is in the range of 7.3. Accordingly, the soil can be characterized as alkaline. The organic carbon content of 1.29% and the total nitrogen content of 1.08% are rated as moderately low and low in tropical soil standards. The available P is generally too low to afford sustainable crop production. Cation exchange capacity (CEC) determined by NH_4OAC solution at pH 7 is relatively high, ranging from 25.2 to 28.4 c mol kg^{-1}. The dominant exchange cations present are calcium and magnesium.

Table 6.1 Soil chemical and physical properties at Melkassa and Awasa experimental sites

	Melkassa	Awasa
pH (in H_2O 1:2.5)	7.3	6.62
Organic Carbon %	1.29	2.32
Total N %	0.15	0.22
CEC (cmol kg^{-1})	25.2-28.4	25.5-26.3
P (ppm)	7.06	35.80
Ca (m.e./100g)	17.52	20.19
Mg (m.e./100g)	3.33	4.32
K (m.e./100g)	2.00	3.75
Na (m.e./100g)	0.67	1.35
Sand (%)	32.0	28.5
Silt (%)	40.0	43.5
Clay (%)	28.0	28.0
Texture class	Silt Clay Loam	Silt Clay Loam

* Source: Eylachew Zewdie Ethiopian Agricultural Research Organization, National Soils Laboratory Research Center, Addis Ababa, Ethiopia. (This table is from this source)

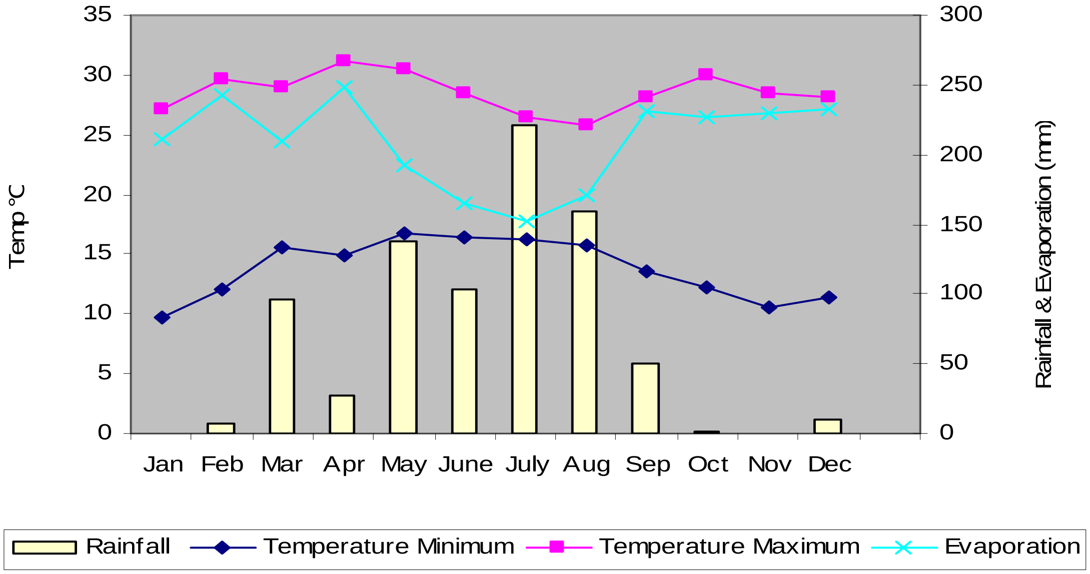

Figure 6.1a Meteorological data for Melkassa Research Centre showing daily mean maximum and minimum temperatures, evaporation and rainfall in 2001.

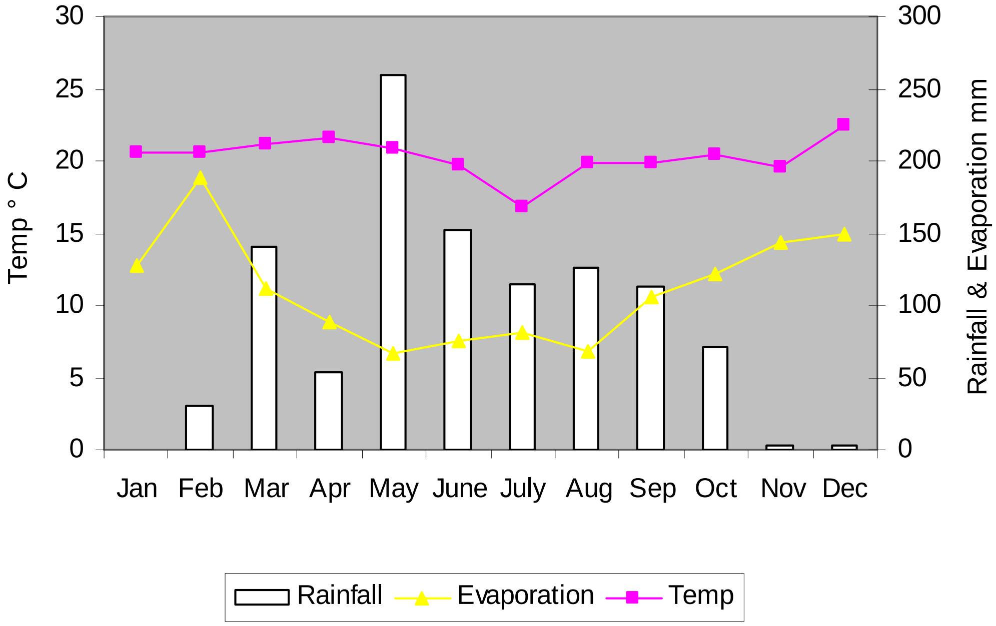

Figure 6.1b Metereological data for Awasa Research Centre showing daily mean temperatures, evaporation and rainfall in 2001

Soil and climate: Awasa

Awasa Research Centre, Ethiopia, is located at Lat. 07^o 04’ N and Long. 38^o 31’ E, at an altitude of 1700 masl, in the middle of the Rift Valley. The monthly rainfall, evaporation and mean daily temperature for the year 2001 are shown in Figure 6.1b. According to the long-term (1972 to 2001) meteorological data of the Centre, the mean maximum temperature is 26.6° C and the mean minimum temperature is 12.5° C. The long-term average annual rainfall is 1055 mm, fairly evenly distributed throughout the rainy season (May to October). May is the month with the highest average daily temperature (26.5° C), whilst July is the month with the lowest mean daily temperature (16.8° C). Temperature and rainfall for the 2001 cropping season at Awasa were similar to the 30-year trend. During the five months of the growing season (June to October 2001), precipitation totaled 577mm, which is the same as the 30-year average (Appendix, Table A6.2).

The pre-experimental soil chemical and physical characteristics are presented in Table 6.1. The soil is volcanic in origin. The texture is mainly silt clay loam with 43.5%, silt, 28.5% sand and 28% clay. The pH is in the range of 6.62 to 6.64. Accordingly the soil can be characterized as slightly acidic (Asefa Zeleke, Kelsa Kena & Desta Goshu, unpublished data, 1995*). The organic carbon content of 2.32% and total nitrogen content of 0.22% both can be rated as moderately low. The available P is moderately high for sustaining crop production. The cation exchange capacity (CEC) determined by NH_4OAC at pH 7 is relatively high at 26.3 meq/100g soil. The dominant exchange cations present are calcium and magnesium.

* Southern Agricultural Research Institute. Awasa Agricultural Research Center, Natural Resource Section, Awasa, Ethiopia.

Experimental design and treatments

At both Melkassa and Awasa, a 3x2x2x3 factorial experiment in a randomized complete block design with four replications was planted. Treatments applied were three cultivars (Awasa-83, Bareda and Kudadie), two types of planting material (terminal vine cuttings with and without leaves), two types of orientation of cuttings (vertical and horizontal) and three cutting length (20, 25 and 30 cm). For both vertical and horizontal planting two thirds of the cutting length were planted under the soil surface while the remaining one third was left above the soil. The 20 cm cuttings of Awasa-83 consisted of 6 nodes, Bareda of 4 nodes, and Kudadie of 8 nodes. The 25 cm cuttings of Awasa-83 consisted of 7 nodes, Bareda 5 nodes, and Kudadie 9 nodes. The 30 cm cuttings of Awasa-83 consisted of 9 nodes, Bareda 6 nodes, and Kudadie 11 nodes. Planting depth for vertically oriented cuttings ranged from 13cm for the 20 cm cuttings to 20cm for the 30 cm cuttings. In the case of the horizontal planting cuttings were placed 7 to 10 cm below the soil surface with the top one-third above the soil surface. The cultivars represented different maturity groups. Awasa-83 is a late maturing white-fleshed cultivar with a recommended growing period of more than 150 days. Bareda is an intermediate maturing cream-fleshed cultivar with a recommended growing period ranging from 120 to 135, days and Kudadie is an early maturing carrot-fleshed cultivar with a recommended growing period ranging from 90 to 105 days. All three cultivars are nationally released in Ethiopia.

The experiments were planted on 30 March 2001 at Melkassa and 31 May 2001 at Awasa. At Awasa the experiment was conducted under rain-fed conditions. At Melkassa the rain was supplemented by furrow irrigation. At each site there were 144 plots, each plot consisting of five rows of 3 m with 0.6 m between rows. Each row contained 10 cuttings spaced 0.3 m apart.

In the case of the 30 cm cuttings this arrangement resulted in the cuttings being placed end to end for the horizontal planting position. The planting density was 55,555 cuttings per hectare. The two border rows were disregarded and the three central rows were harvested. This resulted in a net plot size of 4.32 m^2.

Data recorded

The experiments were harvested 150 days after planting and the tubers were separated into the standard sizes of small, medium and large (marketable yield) and total yield. Tubers with a weight of less than 100g were grouped as undersize, with a weight ranging between 100g to 200g as small, with a weight ranging between 200g to 350g as medium, with a weight ranging between 350g to 500g as large and with a weight of greater than 500g as oversize. The undersize and the oversize tubers were categorized as unmarketable.

The experimental data were subjected to standard analyses of variance using the General Linear Model (GLM) procedure in the Statistical Analysis System (SAS, 1989) programme to determine the effect of main factors and the interaction between them. Differences at the $P \leq 0.05$ level were used as a test of significance and means were separated using Tukey's t-test. The trials at the two sites were analysed separately.

6.4 RESULTS AND DISCUSSION

Melkassa experiment

Tuber numbers

The mean number of small, medium, large, (marketable), undersize, oversize and total storage roots of the three cultivars at Melkassa is presented in Table 6.2. Cultivar Kudadie produced the highest number of total, marketable, small, medium, large, undersize, and oversize storage roots, and Awasa-83 the lowest. The small storage roots accounted for 19.6% of the total number of storage roots per unit area, medium storage roots for 15.8%, large storage roots for 15.5%, undersize storage roots for 42.6% and oversize storage roots for 6.3%. The highest proportion of the total root number was obtained from undersize storage roots.

The two planting positions (vertical and horizontal) differed significantly in number of medium, large, and oversize storage roots. The storage root numbers of all grades tended to increase with horizontally planted vine cuttings compared to a vertical planting position. Planting the cuttings in a horizontal position increased the number of medium storage roots by 17% and the number of large storage roots by 39%.

The two types of planting material (terminal cuttings with and without leaves) differed in the number of small, undersize and total storage roots produced. Vine cuttings with leaves significantly increased the number of small storage roots by 36% and the number of undersize storage roots by 18%.

The three vine cutting lengths did not differ in number of medium, large, undersize, oversize and total storage roots per unit area. The 30 cm cuttings produced significantly more small storage roots than the 20 cm cuttings.

A number of significant interactions were observed. The cultivar x type of planting material interaction on total root number is illustrated in Figure 6.2, showing differences in total storage root number of the cultivars when the vines were planted with and without leaves. Cuttings of cultivar Kudadie with leaves resulted in a higher number of storage roots than cuttings without leaves. In the case of cultivars Bareda and Awasa-83 the number of roots were not affected by the presence or absence of leaves. This conflicting result between cultivars may be indicating that the effect of presence or absence of leaves on storage root number is cultivar dependent. It is interesting to note that the presence of leaves on the cuttings resulted in the formation of even more storage roots in the prolific tuberizing Kudadie, but the presence of leaves had no effect on the storage roots of Awasa-83 and Bareda. The exact scientific explanation for this phenomenon remains unclear.

The type of planting material x planting position interaction on total storage root number is illustrated in Figure 6.3. Horizontally planted cuttings with leaves produced more roots than the horizontally planted cuttings without leaves, In the case of vertically planted cuttings the number of roots were not affected by the presence or absence of leaves.

A number of significant higher order interactions were observed. The cultivar x cutting length x type of planting material x orientation of cutting interaction on medium and large roots was significant. The 25 cm cuttings with leaves planted horizontally was found the best combination for Kudadie to produce the highest number of storage roots (85.6 m $^{-2}$). For Bareda the combination that produced the highest number (39.5 roots m $^{-2}$) was 30 cm cutting planted horizontally without leaves. In the case of Awasa-83 to produce the highest number (17.6 roots m $^{-2}$) the best combination was found to be both 20 and 25 cm cuttings with leaves planted horizontally (Appendix Table A6.3).

Table 6.2 Effect of cultivar, position of planting, type of planting material and length of cuttings on storage root numbers m^{-2} at Melkassa

		Storage root number m $^{-2}$						
Treatment		**Total**	**Marketable**	**Small**	**Medium**	**Large**	**Undersize**	**Oversize**
Cultivar	**Awasa-83**	14.8	9.1	3.2	3.0	2.9	4.5	1.1
	Bareda	24.6	12.2	4.2	3.8	4.2	9.6	2.3
	Kudadie	56.0	27.1	11.2	8.3	7.6	26.4	2.6
	LSD$_T$	4.54	2.44	1.28	0.94	0.92	2.30	0.63
Planting position	**Vertical**	33.5	14.8	6.1	4.6	4.1	13.4	1.6
	Horizontal	29.8	17.5	6.4	5.4	5.7	13.6	2.4
	LSD$_T$	3.7	1.99	1.05	0.77	0.75	1.88	0.52
Terminal cuttings	**without leaves**	29.5	15.0	5.3	4.8	5.0	12.4	2.0
	with leaves	33.8	17.3	7.2	5.2	4.9	14.6	1.98
	LSD$_T$	3.7	1.99	1.05	0.80	0.75	1.88	0.52
Cutting length	**20cm**	29.7	14.6	5.0	4.9	4.7	12.9	2.3
	25cm	32.3	16.8	6.3	5.2	5.3	13.7	1.8
	30cm	32.9	16.9	7.3	4.9	4.8	14.0	2.0
	LSD$_T$	4.50	2.44	1.54	0.94	0.92	2.30	0.76
MEAN		31.7	16.14	6.2	5.0	4.9	13.5	2.0
CV%		35.4	37.3	51.1	46.3	46.4	42.1	77.5

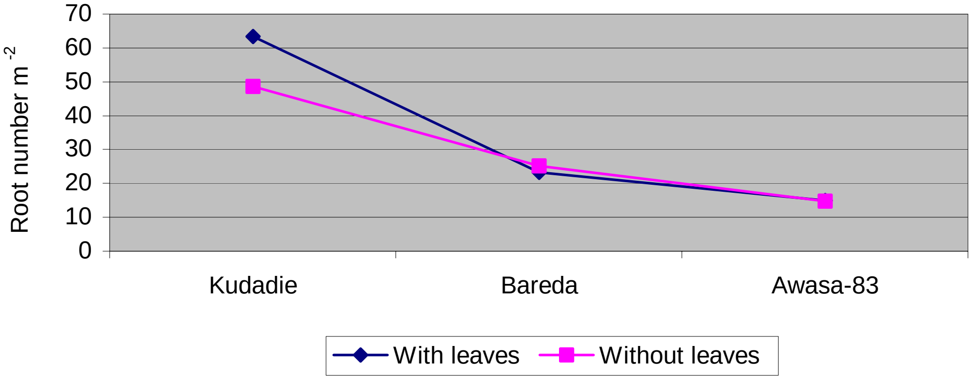

Figure 6. 2 Interaction between cultivar and type of planting material on total storage root number at Melkassa

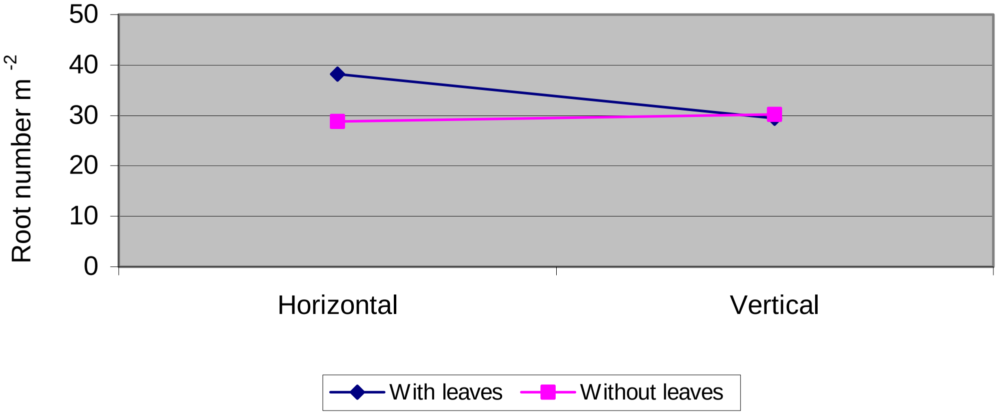

Figure 6.3 Interaction between type of planting material and planting position on total storage root number at Melkassa

Storage root yield

The mean yield of small, medium, large, and total storage roots of the three cultivars at Melkassa is presented in Table 6.3.

The three sweet potato cultivars differed significantly in total, small, medium and large fresh root yields. Cultivar Kudadie produced the highest total root yield (138.7t ha $^{-1}$) and Awasa-83 (49.5t ha $^{-1}$) the lowest. On average small storage roots accounted for 10% of the total storage root yield per hectare, medium storage roots for 16%, and large storage roots for 32% of the total storage root yield. The highest portion of the marketable yield of the three cultivars was obtained from the large storage roots and the lowest from the small roots.

The two planting positions (vertical and horizontal) differed in total, medium, large and marketable storage root yield. Horizontal planting produced the highest root yield (111.3t ha $^{-1}$) and vertical planting (77.4t ha $^{-1}$) the lowest. Planting cuttings in a horizontal position increased total storage root yield by 44%, small storage root yield by 11%, medium storage root yield by 25%, large storage root yield by 37%, and marketable storage root yield by 29% compared to the vertical planting position. Hall (1986) reported that U.S. # 1 root yield from 20 to 25 cm ‘Red Jewel’ cuttings was increased when they were oriented vertically compared to cuttings oriented horizontally. Orientation did not influence the U.S. # 1 root yield from 40 to 45 cm ‘Red Jewel” cuttings. Allison & Chen (1980) and Chen & Allison (1982) reported that horizontal planting increased sweet potato yield compared to vertical planting. Contradictory to this Du Plooy, (1989) reported no significant differences in yield between vertical and horizontal orientation of cuttings of three cultivars using cuttings of 30 cm length, planted with either three or five nodes underground. Malcolm (1992) also reported no significant differences in yield between the vertically and horizontally planted cuttings using two cultivars and four cutting lengths.

The two types of planting material (terminal cuttings with and without leaves) did not differ in fresh storage root yield except for the small storage roots. The cuttings with leaves increased the yield of small storage root by 24%. Ravindran & Mohankumar (1982, 1989) reported that storage root yield was higher in plants from cuttings with foliage compared to plants from cuttings without foliage.

The three cutting lengths (20, 25 and 30 cm) did not differ in the yield of medium, large and marketable storage roots. The 30 cm cuttings resulted in a higher yield of small storage roots than the 20 cm cuttings. There were no significant yield differences between the 25 cm and the 30 cm cuttings. Using cuttings of 23, 31, 46, and 61 cm lengths folded into two equal parts with 5 cm of the blind ends inserted in the soil Godfrey-Sam-Aggrey (1974), reported that 46 and 61 cm long cuttings produced significantly better yields. Hall (1986) also reported that total marketable root yield of cultivar "Red Jewel" was significantly greater with 40 to 45 cm than 20 to 25 cm cuttings. Other authors (Shanmugavelu *et al.*, 1972; Tanaka & Sekioka, 1976; Chen & Allison, 1982; Ravindran & Mohankumar, 1982; Sanchez *et al.*, 1982; Bautista & Vega, 1991) reported that cuttings of intermediate lengths (40 cm) produced better storage root yields than longer cuttings. The literature reflects contradicting results on the effect of length of sweet potato cuttings on yield. It should be noted that longer cuttings are more difficult to handle, transport and plant. Cuttings of greater length than 30 cm tend to be wasteful of planting material, while much shorter cuttings establish more slowly and result in lower yields. In general it can be concluded that cutting length do not affect storage root yield much, and therefore farmers can follow local practices.

Two of the first order interactions were significant, namely the cultivar x planting material interaction and the planting material x planting position interaction. The cultivar x planting material interaction on total fresh root yield is illustrated in Figure 6.4, showing differences in total root yield of cultivars when the cuttings were planted with and without leaves. Cuttings of cultivars Kudadie and Bareda with leaves resulted in a higher total root yield than the cuttings without leaves, while for Awasa-83 the presence or absence of leaves on the cutting had no effect on total root yield.

The type of planting material x planting position interaction on large storage root yield is illustrated in Figure 6.5 showing differences in large storage root yield of horizontally planted cuttings with and without leaves. Horizontally planted cuttings with leaves resulted in higher large storage root yield than the horizontally planted cuttings without leaves, while for vertically planted cuttings the presence or absence of leaves on the cutting had no effect on large storage root yield.

A significant higher order interaction was observed. The cultivar x cutting length x type of planting material x orientation of cutting interaction on small storage root yield was significant. For Kudadie the 30 cm cuttings with leaves, planted horizontally, was found to be the combination to produce the highest yield of 223.4t ha $^{-1}$ (Appendix Table A6.4). For Bareda the highest yield of 189t ha $^{-1}$ was obtained from 20 cm cutting without leaves planted horizontally. In the case of Awasa-83 the 25 cm cuttings without leaves, planted horizontally, produced the highest (67t ha $^{-1}$) storage root yield (Appendix Table A6.4).

Table 6.3 Effect of cultivar, position of planting, type of planting material and length of cuttings on storage root yield at Melkassa

Treatment		Storage root yield t/ha						
		Total	Marketable	Small	Medium	Large	Undersize	Oversize
Cultivar	**Awasa-83**	49.5	32.6	4.9	9.2	18.5	2.2	14.6
	Bareda	94.9	46.1	5.7	11.1	29.3	3.7	44.7
	Kudadie	138.7	85.0	16.4	25.3	43.2	11.4	42.1
	LSD$_T$	22.2	10.5	2.5	3.3	7.6	1.13	12.7
Planting position	**Vertical**	77.4	47.7	8.6	13.5	25.6	5.6	24.0
	Horizontal	111.3	61.4	9.5	16.9	35.0	5.9	43.7
	LSD$_T$	15.1	7.1	1.7	2.2	5.2	0.92	10.39
Terminal cuttings	**without leaves**	95.3	55.3	8.1	15.0	32.2	5.6	34.2
	with leaves	93.4	53.8	10.0	15.4	28.4	6.0	33.4
	LSD$_T$	15.1	7.1	1.7	2.2	5.2	0.92	10.39
Cutting length	**20cm**	97.8	53.7	8.3	14.9	30.4	6.1	37.6
	25cm	86.2	52.8	8.4	15.4	29.1	5.2	28.5
	30cm	99.1	57.1	10.5	15.3	31.4	6.1	35.4
	LSD$_T$	22.2	10.5	2.1	3.3	7.6	1.13	12.73
MEAN		94.4	54.6	9.0	15.2	30.3	5.79	33.82
CV%		48.5	39.5	57.4	44.4	51.6	48.3	57.33

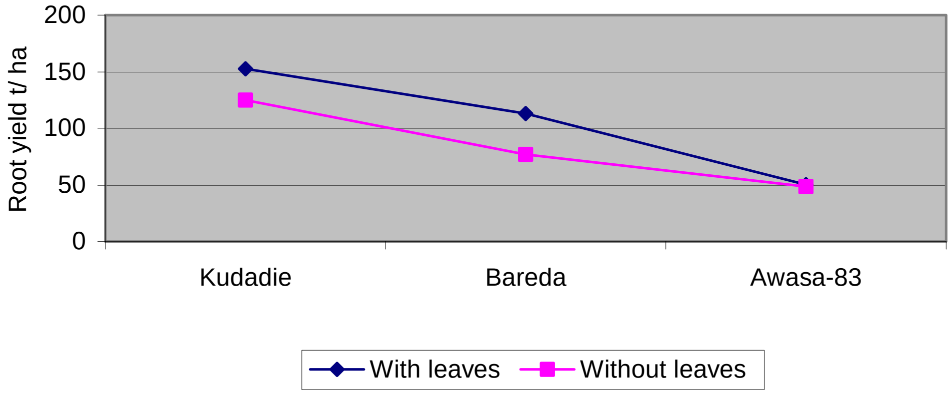

Figure 6.4 Interaction between cultivar and type of planting material on total root yield at Melkassa

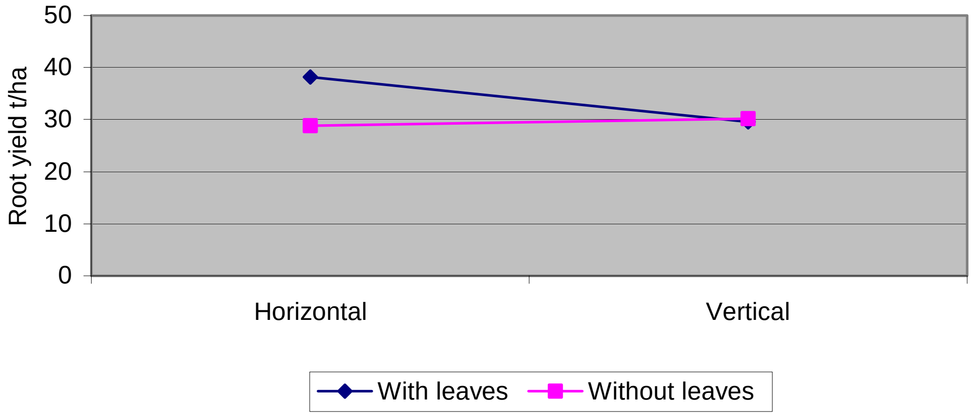

Figure 6.5 Interaction between planting position and type of planting material on large storage root yield at Melkassa

Awasa experiment

Tuber numbers

The number of marketable, small, medium, large, undersize, oversize and total storage roots of the three cultivars at Awasa is presented in Table 6.4. The three cultivars Awasa-83, Bareda and Kudadie differed significantly in number of small, medium, large, undersize, oversize and total storage roots. At Awasa, as at Melkassa, cultivar Kudadie had the highest number of small, medium, large, marketable, undersize, and total storage roots, and Awasa-83 the lowest. The small and medium storage roots each accounted for 20.9% of the total number of storage roots per unit area, large storage roots 28%, undersize 26% and oversize 4%. The marketable storage roots (small, medium and large storage roots) accounted for 69% of the total storage root number. The highest proportion of the marketable root number was obtained from large storage roots (41%).

Generally the storage root number tended to increase with the horizontal method of planting compared to a vertical planting position, but only the number of large and marketable storage roots increased significantly. The number of large roots was increased by 35% and the marketable roots by 13%.

The terminal cuttings with and without leaves differed in number of storage roots. Cuttings with leaves increased the total number of storage roots by 16%, marketable storage roots by 23%, small storage roots by 46% and medium storage roots by 21%.

The three cutting lengths did not differ in number of storage roots produced per unit area, except for the 30 cm cuttings resulting in significantly more small storage roots than the 25 cm cuttings.

There were significant interactions between cultivar x type of planting material, cultivar x orientation of planting, cutting length x type of planting material, and type of planting material x orientation of planting. The type of planting material x orientation of planting interaction on total root number is illustrated in Figure 6.6. Horizontally planted cuttings with leaves produced more roots than the horizontally planted cuttings without leaves, In the case of vertically planted cuttings the number of roots were not affected by the presence or absence of leaves. It is interesting to note that this interaction is almost identical to the interaction observed at Melkassa (Figure 6.3).

The type of planting material x cutting length interaction on total fresh root number is illustrated in Figure 6.7. Cuttings of 30 cm length with leaves produced more storage roots than the 30 cm cuttings without leaves. In the case of the 20 cm cutting the number of roots were not affected by the presence or absence of leaves. The 30 cm cutting with leaves produced more roots than the 25 cm cuttings with leaves.

A number of significant higher order interactions were observed. The cultivar x type of planting material x orientation of cutting interaction on total storage root number was significant. Cuttings of 20 cm with leaves and vertical planting were found the best combination for Kudadie to produce the highest number (36 m $^{-2}$) of storage roots. For Bareda the treatment combination to produce the highest number (30.7 m^{-2}) was found to be the 30 cm cuttings without leaves and planted horizontally. In the case of Awasa-83 the combination to produce the highest number (26 roots m^{-2}) was found to be the 30 cm cuttings without leaves and planted horizontally (Appendix Table A6.5).

Table 6.4 Effect of cultivar, position of planting, type of planting material and length of cuttings on storage roots number m^{-2} at Awasa

Treatment		Storage root number m^{-2}						
		Total	Marketable	Small	Medium	Large	Undersize	Oversize
Cultivar	**Aw-83**	18.2	13.5	4.9	4.5	4.1	4.3	0.4
	Bareda	19.6	13.5	3.2	3.9	6.4	5.0	1.1
	Kudadie	28.1	18.9	5.6	5.5	7.8	8.2	1.0
	LSD_T	2.16	1.50	0.81	0.77	1.05	1.32	0.30
Planting position	**Vertical**	21.4	14.3	4.7	4.5	5.2	6.4	0.7
	Horizontal	22.5	16.2	4.4	4.8	7.0	5.3	1.0
	LSD_T	1.76	1.22	0.66	0.63	0.86	1.08	0.25
Terminal cutting	**Without leaves**	20.3	13.7	3.7	4.2	5.8	5.7	0.9
	With leaves	23.6	16.8	5.4	5.1	6.3	6.0	0.7
	LSD_T	1.76	1.22	5.68	0.63	0.86	1.08	0.25
Vine lengths	**20 cm**	21.2	14.6	4.4	4.3	5.9	5.7	0.9
	25 cm	21.3	15.1	4.1	4.5	6.4	5.3	0.9
	30 cm	23.4	16.1	5.2	5.0	5.9	6.6	0.7
	LSD_T	2.16	1.50	0.81	0.77	1.05	1.32	0.30
MEAN		22.0	15.3	4.6	4.6	6.1	5.9	0.8
CV%		24.3	24.2	44.0	41.2	42.7	55.8	91.0

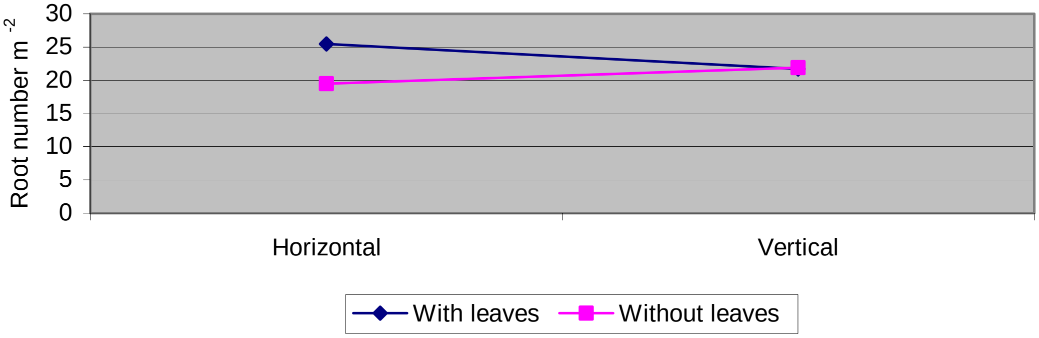

Figure 6.6 Interaction between type of planting material and planting position on total root number at Awasa

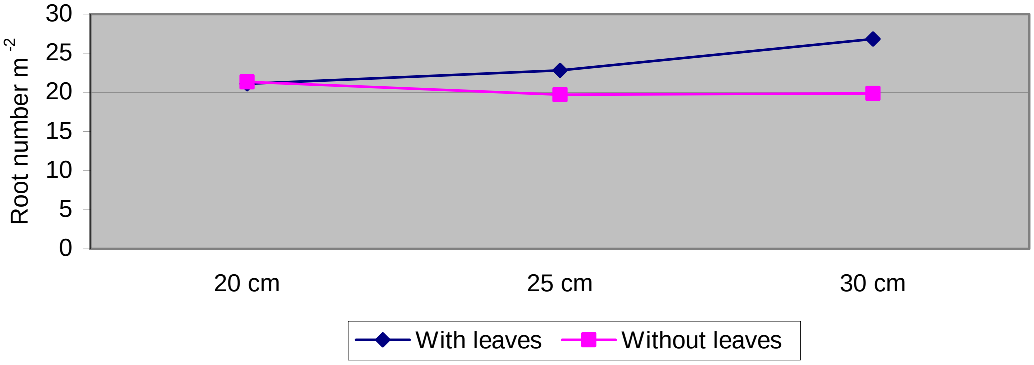

Figure 6.7 Interaction between type of planting material and cutting length on total root number at Awasa

Storage root yield

The yield of total and marketable storage roots of the three sweet potato cultivars at Awasa is presented in Table 6.5. The three cultivars Awasa-83, Bareda and Kudadie differed significantly in total and marketable root yield. Similar to the results of the Melkassa experiment, cultivar Kudadie produced the highest total (76.6t ha $^{-1}$), marketable (60.8t ha $^{-1}$), small, medium, large, and undersize fresh root yield, and cultivar Awasa-83 the lowest yield. On average small storage roots accounted for 10% of the total storage root yield per hectare, medium storage roots for 22%, large storage roots for 44%, and marketable storage roots for 77% of the total storage root yield. The highest proportion of both total and marketable storage root yields was obtained from the large storage roots.

The two types of planting positions (vertical and horizontal) differed in total, marketable, large, and oversize storage root yields. Horizontal planting resulted in the highest total, marketable, large and oversize root yields. Planting the cuttings in a horizontal position increased total storage root yield by 27%, marketable storage root yield by 23%, large storage root yield by 34% and oversize storage root yield by 55%, compared to a vertical planting position. Hall (1986) reported that root yield from 20 to 25 cm cuttings was increased when they were oriented vertically compared to the cuttings oriented horizontally. Du Plooy (1989) and Malcolm (1992) found no significant differences in yield between vertical and horizontal orientation of cuttings. Allison & Chen (1980) and Chen &Allison (1982) reported that horizontal planting increased sweet potato yield compared to vertical planting.

The two types of planting material (terminal cuttings with and without leaves) differed in storage root yield. The terminal cuttings planted with leaves produced significantly higher yields of total, marketable, small and medium storage roots per hectare. Planting terminal cuttings with leaves increased the total storage root yield by 12%, marketable storage root yield by 20%, small storage root yield by 52% and medium storage root yield by 22.8% compared to cuttings without leaves. Ravindran & Mohankumar (1982, 1989) also reported that storage root yield was significantly higher in plants from vine cuttings with foliage than in plants from cuttings without foliage.

The three cutting lengths (20 cm, 25 cm and 30 cm) did not differ in total, marketable, medium, large, undersize and oversize storage root yield. The 30 cm cuttings resulted in higher yields of small storage roots than the 20 and 25 cm cuttings. There were no significant yield differences of small storage roots between the 20 and 25cm cuttings. Godfrey-Sam-Aggrey (1974) and Hall (1986) reported that 46 and 61 cm cuttings and cuttings of 40 to 45 cm, respectively produced significantly better yields than shorter cuttings. Other authors (Shanmugavelu *et al.*, 1972; Tanaka & Sekioka, 1976; Chen & Allison, 1982; Ravindran & Mohankumar, 1982; Sanchez *et al*., 1982; Bautista & Vega, 1991) reported that cuttings of 40 cm length produced better storage root yields than longer cuttings.

The cultivar x type of planting material interaction on total root yield is illustrated in Figure 6.7, showing differences in total root yield of cultivars when the cuttings were planted with and without leaves. Bareda cuttings with leaves resulted in a higher total root yield than the cuttings without leaves, while for Kudadie and Awasa-83 the presence or the absence of leaves on the cuttings has no effect on the total root yield.

The type of planting material x cutting length interaction on total storage root yield is illustrated in Figure 6.8. The 25 and 30 cm cutting with leaves produced a higher total root yield than the cuttings without leaves. In the case of 20 cm cutting the presence or the absence of leaves had no effect on the total root yield.

A significant higher order interaction was observed. The cutting length x type of planting material x orientation of cutting interaction on medium and large storage root yield was significant. The 30 cm cuttings without leaves planted horizontally was found to be the best combination for Bareda to produce the highest yield (103.3t ha $^{-1}$) of storage roots. For Awasa-83 the combination that produced the highest yield (63.8t ha $^{-1}$) of total storage roots was found to be 30 cm cuttings without leaves planted horizontally. In the case of Kudadie the highest yield (96.1t ha $^{-1}$) of storage roots was produced from the 20 cm cuttings, with leaves, planted horizontally (Appendix Table A6.6).

At both locations cultivar Kudadie produced the highest storage root yield and Awasa-83 the lowest. Kudadie produced 138.7t ha $^{-1}$ and Awasa-83 49.5t ha $^{-1}$ at Melkassa. At Awasa Kudadie produced 76.6t ha $^{-1}$ and Awasa-83 yielded 46.1t ha $^{-1}$. The total root yield of Kudadie ranged from 109 to 223t ha $^{-1}$ at Melkassa and 48.9 to 96t ha $^{-1}$ at Awasa (Appendix Table 6.4 and 6.6). The total storage root yield of Bareda ranged from 53 to 157.5t ha $^{-1}$ at Melkassa and 44.6 to 103.3t ha $^{-1}$ at Awasa (Appendix Table 6.4 and 6.6). The total root yield of Awasa-83 ranged from 29.6 to 67.4t ha $^{-1}$ at Melkassa and 35.5 to 63.8t ha $^{-1}$ at Awasa

(Appendix Table 6.4 and 6.6). Generally the average storage root yield of the three cultivars was higher at Melkassa than at Awasa.

At both locations cultivar Kudadie produced the highest storage root number and Awasa-83 the lowest. Kudadie produced 56 roots m $^{-2}$ and Awasa-83 produced 14.8 roots m $^{-2}$ at Melkassa (Table 6.2). At Awasa cultivar Kudadie produced 28 roots m $^{-2}$ and Awasa-83 yielded 18 roots m $^{-2}$ (Table 6.4). The total root number of Kudadie ranged from 25 to 85.6 roots m $^{-2}$ at Melkassa and 16.7 to 36 roots m $^{-2}$ at Awasa (Appendix Table 6.3 and 6.5). The total storage root number of Bareda ranged from 19.4 to 39.5 roots m $^{-2}$ at Melkassa and 12 to 33.7 roots m $^{-2}$ at Awasa (Appendix Table 6.3 and 6.5). The total root number of Awasa-83 ranged from 11.5 to 17.6 roots m $^{-2}$ at Melkassa and 14.6 to 26.1 roots m $^{-2}$ at Awasa (Appendix Table 6.3 and 6.5). Except for cultivar Awasa-83, the average storage root numbers of the cultivars were higher at Melkassa than at Awasa. The general trend of cultivars and cutting characteristics on total root yield and total root number are very similar for both locations.

At Melkassa the five months of growing season (April to August 2001) had more precipitation (648 mm) compared to the five months growing season (June to October 2001) of Awasa experiment, which received only (577 mm) Appendix Table A6.1. At Melkassa the crop had not experienced moisture stress since the rain was supplemented with the furrow irrigation.

The Melkassa experiment was planted (30 March 2001) two months earlier than the Awasa experiment, which was planted (31 May 2001) the maximum temperature at Melkassa during the first month of planting was 31^{o}C compared to the maximum temperature of 19.7 ^{o}C at Awasa.

Table 6.5 Effect of cultivar, position of planting, type of planting material and length of cuttings on storage root yields per hectare at Awasa

Treatment		**Storage root yield t/ha.**						
		Total	**Marketable**	**Small**	**Medium**	**large**	**Undersize**	**Oversize**
Cultivar	**Aw-83**	46.1	38.9	6.7	13.7	18.5	1.7	5.6
	Bareda	67.0	45.8	4.6	12.0	29.2	1.9	19.4
	Kudadie	76.6	60.8	7.6	16.7	36.5	3.4	12.7
	LSD_T	7.0	6.53	1.19	2.28	4.91	0.58	4.46
Planting position	**Vertical**	55.8	43.5	6.2	13.4	23.9	2.4	9.8
	Horizontal	70.8	53.4	6.4	14.8	32.1	2.2	15.2
	LSD_T	5.68	4.45	0.97	1.86	4.0	0.45	3.79
Terminal cutting	**Without leaves**	59.8	44.1	5.0	12.7	26.4	2.2	13.6
	With leaves	66.8	52.8	7.6	15.6	29.6	2.5	11.6
	LSD_T	5.68	4.45	0.94	1.86	4.00	0.47	3.7
Vine lengths	**20 cm**	62.9	46.4	5.9	13.3	27.2	2.3	14.3
	25 cm	64.6	49.2	5.5	13.5	30.1	2.1	13.4
	30 cm	62.3	49.8	7.5	15.5	26.8	2.6	9.8
	LSD_T	6.96	5.45	1.19	2.28	4.91	0.58	4.64
MEAN		63.3	48.5	6.3	14.1	28.0	2.3	12.5
CV%		27.2	27.8	46.6	39.9	43.3	61.4	91.5

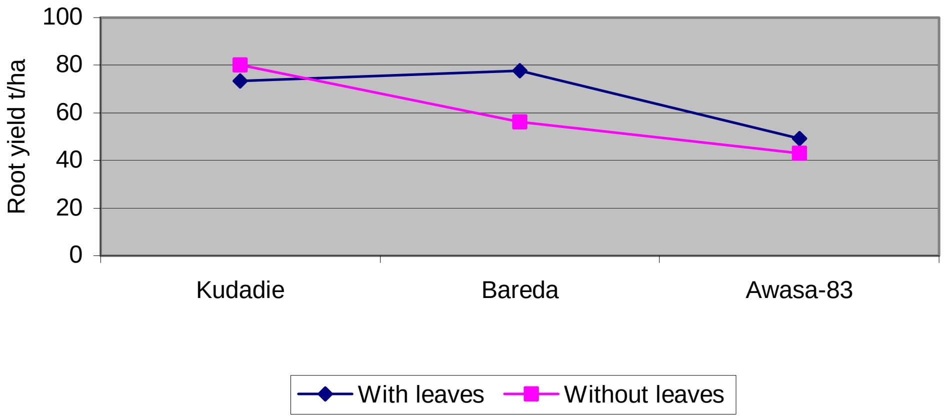

Figure 6.8 Interaction between cultivar and type of planting material on total root yield at Awasa

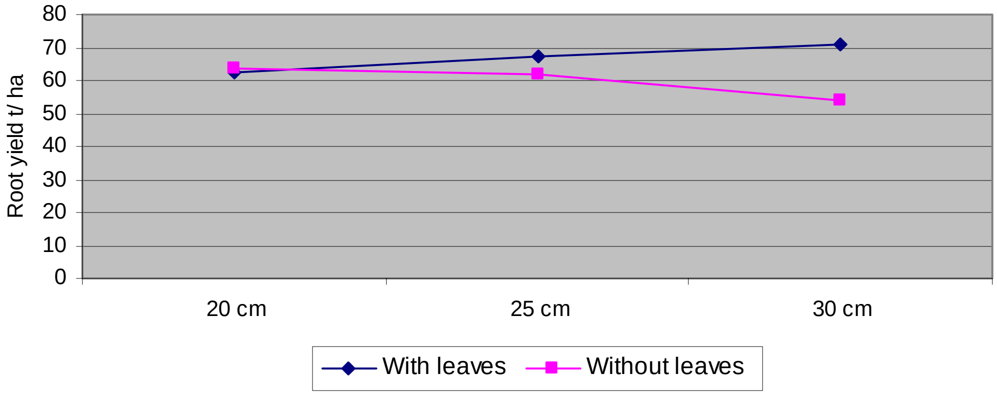

Figure 6.9 Interaction between type of planting material and cutting length on total root yield at Awasa

6.5 CONCLUSION

Although large differences occurred in yield between locations the cultivars and cutting treatments responded similarly at both locations, indicating the reliability of the results.

The cutting treatments did not have a major effect on storage root yield, whether the cuttings were 20, 25 or 30 cm long, planted with or without leaves. Root yields were increased when cuttings were oriented horizontally compared to the cuttings oriented vertically. From these trials and related literature it can be concluded that cutting characteristics *per se* have a relative small effect on storage root yield and farmers can follow local practices within these general guidelines.

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CHAPTER 7

PRODUCTION AND PARTITIONING OF DRY MATTER IN THREE SWEET POTATO CULTIVARS

7.1 ABSTRACT

Growth, dry mass production and partitioning pattern of local cultivars are not known. Changes in the dry mass of tubers, stems and leaves of three sweet potato cultivars (Awasa-83, Bareda and Falaha) were studied under field conditions in Ethiopia at Awasa and Melkassa. The objective was to quantify dry mass production and partitioning during different growth stages. The experimental design was a 3 x 8 factorial experiment in a randomized complete block, replicated three times.

The quantity and pattern of dry mass produced and partitioned differed among the three cultivars. Significant differences between cultivars and sequential harvesting dates were observed for roots, stems, leaves and total dry mass at Awasa and Melkassa. There were no significant interactions between cultivars and sequential harvesting dates except for root dry mass at Awasa. At Melkassa the cultivar Bareda produced the highest root dry mass, stem dry mass, leaf dry mass and total dry mass. Cultivars Awasa-83 and Falaha did not differ significantly in root, stem, leaf and total dry mass. Falaha was the most efficient in terms of dry mass partitioning to the storage roots (73% of the biomass), followed by Bareda (67%) and Awasa-83 (59%).

At Awasa significant differences were observed in the mean root dry mass production of the three cultivars. Bareda produced the highest root dry mass. Cultivar Awasa-83 produced

significantly higher stem, leaf and total dry mass than Bareda and Falaha. The highest stem dry mass, leaf dry mass and total dry mass was produced by Awasa-83. At Awasa, Bareda was the most efficient in terms of dry matter partitioning to the storage roots (60%), followed by Falaha (52%) and Awasa-83 (48%). The relatively poor growth and yield recorded at Awasa was mainly attributed to low rainfall during the growing season of 2001.

The total dry matter produced per sampling time and the dry matter partitioned to the roots, stems and leaves at different sampling times are presented. The variability among cultivars in dry matter partitioning suggests that the development of cultivars with higher dry matter partitioning to the storage roots is possible. The early maturing cultivar Falaha partitioned a larger portion of assimilates to the storage roots earlier in the growth period, when the intermediate and the late maturing cultivars still partitioned most of the dry matter to the leaves and the stems.

7.2 INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.) is an important food crop grown throughout the tropics. Low sugar types generally predominate. High starch content is a desired attribute of this staple food (Mok *et al.*, 1997). The succulent, starchy storage roots of sweet potato serve as a staple food, as animal feed (Ruyiz *et al.*, 1980; Lu *et al*., 1989; Posas, 1989; Woolfe, 1992), and to a limited extent as a raw material for industrial purposes such as a source of starch and for alcohol production (Winarno, 1982; Yen, 1982; Collins, 1984).

In the United States sweet potato is grown as a table vegetable (Bonte & Picha 2000). The North American market prefers the high sugar, orange-fleshed dessert type. Sweet potato has been

identified as a potentially important crop for Controlled Environmental Life Support Systems (CELSS) for manned space missions (Mason & Carden, 1982; Hill *et al*, 1984).
Staple sweet potato types typically have a white to cream flesh with a dry matter content ranging from 25% to 35%. The dry mass in sweet potato is directly correlated with starch content (Li & Liao, 1983). Dry matter content in excess of 35.0% is desired as a raw material in the starch processing industry (Mok *et al.*, 1997). However, as dry matter content increases, there is a corresponding decrease in acceptability as a table food (Lin *et al.*, 1995).

Dessert sweet potato types generally have cream to orange flesh and dry matter contents ranging from 18% to 26%, with starch contents ranging from about 13% to 22% (Picha, 1987). Cultivars showed quantitative differences in dry matter content based on harvest dates (Bonte & Picha, 2000). Little information is available on the dry matter partitioning between roots, leaves and stems, during growth and development. The crop growth period normally varies between 12 and 35 weeks (Chen & Xu, 1982; Hahn & Hozyo, 1984), but as long a duration as 25 to 50 weeks has been reported for some cultivars (Huett, 1976; Huett & O'Neill, 1976). However, most of the cultivars attain their maximum storage root yield within 12 to 22 weeks after planting (Steinbauer & Kushman, 1971; Huett, 1976; Gupta & Ray, 1979; Indira & Lakshmi, 1984; Nair & Nair, 1985; Nair *et al.*, 1986; Sen *et al.*, 1990). Storage roots contain 50% to 79% starch and 4% to 5% sugar on a dry mass basis (Liu *et al.*, 1985; Lila & Bala, 1987; Lila *et al.*, 1990; Goswami 1991; Li *et al.*, 1994) or 7 to 28% starch on a fresh weight basis (Huang, 1982; Indira & Lakshmi, 1984).

Leaf area index (LAI) is the ratio of the leaf area to land area and varies widely among sweet potato cultivars and at different growth periods, depending on the number of leaves retained and their size. Changes in the leaf area index during growth occur in three phases: it steadily increases from the second week after planting in the first phase, reaching a plateau between the 8th and 16th week after planting, and declines during the third phase due to leaf senescence. The maximum LAI during the second phase varied between 2 and 11 (Yu, 1981; Agata, 1982; Bourke, 1985; Mukhopadhyay *et al.*, 1992; Bhagsari & Ashley, 1990). LAI increases with increase in temperature (Agata, 1982; Mukhopadhyay *et al*., 1992), photoperiod (Mukhopadhyay *et al*., 1992), N application (Bourke, 1985), soil moisture (Enyi, 1977; Indira & Ramanujiam, 1985; Chowdhury & Ravi, 1990), and due to staking (Bhagsari, 1990). A higher rate of K fertilization had no effect on the LAI (Bourke, 1985).

Brown (1992) estimated that a LAI of 3 to 4 is required to intercept 95% of photosynthetic active radiation (PAR) in sweet potato. Most of the cultivars maintain LAI values of 3 to 4 between 8 and 16 weeks after planting. At this LAI the maximum weekly crop growth rate (CGR) varies between 106 and 133 g/m^{-2} (Enyi, 1977; Agata, 1982; Tiwari *et al*., 1985).

According to Bonte & Picha (2000) cultivars showed significant quantitative differences in dry matter content based on harvest dates. Total dry matter production and efficiency of dry matter allocation to storage roots determine the storage root yield. The increase in total dry mass as well as storage root dry mass follow a sigmoid pattern in sweet potato (Huett & O'Neill, 1976; Enyi, 1977; Bourke, 1985; Oswald *et al.*, 1994). A few reports indicate a linear increase in total dry mass (Li & Yen, 1988; Nair & Nair, 1995) and storage root dry mass (Nair & Nair, 1995). Based on dry matter partitioning, sweet potato generally exhibits three growth phases. In the initial phase, shoot growth dominates, with a large proportion of dry matter diverted to shoot growth. This is followed by a second phase of constant partitioning of dry matter between shoot and storage root growth. During the final phase, a major portion of dry matter is partitioned to the storage roots.

Availability of adequate soil moisture prolonged total dry matter production but reduced the proportion of dry matter allocated to storage roots (Enyi, 1977). An increase in N and K fertilizers considerably increased total dry mass and storage root dry mass (Bourke, 1985; Li & Yen, 1988). An increase in plant population decreased storage root dry matter and shoot dry matter per plant but significantly increased yield per hectare (Li & Yen, 1988).

Cultivars differ in total dry mass production. Sweet potato cultivars with a high total dry mass diverted more dry matter to storage roots compared to those with a lower total dry mass (Huett & O'Neill, 1976; Li & Yen, 1988). Enyi (1977) also reported that high yielding cultivars divert more dry matter to storage roots than low yielding ones.

No published information exists on the growth and development of sweet potato under field conditions in Ethiopia. The cultivars Awasa-83, Bareda and Falaha are nationally released cultivars. Dry matter production and partitioning of these and other released cultivars are not known. Therefore the main objectives of the field trials on the production and partitioning of dry matter were to characterize the growth and development of three cultivars at two experimental sites, Melkassa and Awasa by:

- determining the change in dry mass of the leaves, stems and storage roots during growth and development (partitioning of assimilates);
- comparing the efficiency of the dry matter partitioning to the storage roots of the three cultivars;

- characterizing the canopies in terms of the leaf area index and leaf area duration;
- attempting to explain differences in growth and yield by means of growth analysis, specifically of the crop growth rate, tuber growth rate and net assimilation rate; and
- determining the optimum time of harvesting for optimum dry matter content.

7.3 MATERIALS AND METHODS

The experiments reported in Chapter 7 were conducted on the same field and under the same climatic conditions as those in Chapter 6. The chemical and physical soil properties, weather data, and cultural practices are presented in Chapter 6.

Experimental design and treatments

At both Melkassa and Awasa, a 3 x 8 factorial experiment involving three cultivars (Awasa-83, Bareda and Falaha) and eight harvesting dates in a randomized complete block design with three replications was used. These cultivars are of different maturity groups. Falaha is an early maturing cream-fleshed cultivar, which requires 90 to 105 days to mature. Bareda is an intermediate maturing cream-fleshed cultivar, which requires 120 to 135 days. Awasa-83 is a late maturing white-fleshed cultivar, which requires more than 150 days.

The growth and development of different plant components were evaluated over eight harvest dates during tuber bulking. Sampling was started 45 days after planting and continued every two weeks until 150 days after planting. There were 72 plots, each plot consisting of five rows, 3 m long with 0.6 m between rows. Each row contained 10 plants, spaced 0.3 m apart. Two border rows were disregarded and the three central rows were used for the sequential harvesting every fortnight.

At both Awasa and Melkassa Agricultural Research Centres the recommended sweet potato cultural practices were followed. Land was plowed deeply, harrowed and disced. Ridges were made using a ridger-mounted tractor. Thirty to forty centimeters long vine cuttings were prepared from the terminal and the middle portions of the vine. They were planted on 31 March 2001 at Melkassa and 6 June 2001 at Awasa. At Awasa the field experiment was conducted under rain-fed conditions. At Melkassa the rain was supplemented by furrow irrigation. No fertilizer was applied. Weeds were effectively controlled manually. No pest or disease of any consequence occurred during the growing season.

Data recorded

Serial harvesting commenced 45 days after planting. Five representative plants of each cultivar were randomly sampled from each replication. Harvesting was done in the morning (8 to 10 am). Each plot was sampled only once. Sampling continued at two-week intervals. At the final harvest, 150 days after planting, all three cultivars were still growing actively. The final harvest was dictated by tuber quality. Plants were cut at the ground level, and separated into leaf blades and vines. Fresh weights were obtained immediately after cutting. The fibrous and tuberous roots were then harvested, cleaned and weighed. Sub samples of the fresh tubers and stems were dried in an air-forced oven at a temperature of 105 °C for 48 hours and the dry mass was determined. The dry mass of the stem includes the dry mass of both the vine and leaf petioles. The dry mass of the roots includes the dry mass of the fibrous, pencil, and tuberous roots. At every sampling at

Melkassa, leaf area was measured with a LI-3100 leaf area meter (LI-inc. Lincoln, Nebraska, USA) and the specific leaf area was determined. In order to minimize variations in leaf area measurements, the leaf area index was calculated from the dry mass of the leaves and the mean specific leaf area (52 g m^{-1}).

Statistical analysis

The experimental data were subjected to standard analyses of variance using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1989) to determine the effect of main effects and the interaction between them. Differences at $P \leq 0.05$ level were used as a test of significance and means were separated using Tukey's t-test. The trials at the two sites were analyzed separately (Appendix, Tables A7.3, A7.4, A7.5, A7.7, A7.8 and A7.9).

7.4 RESULTS AND DISCUSSION

Melkassa experiment

Root dry mass

The root dry mass of the three cultivars at Melkassa is presented in Figure 7.1 and in the Appendix Table A7.1. The short season cultivar, Falaha, formed storage roots 45 days after planting, while in the case of cultivars Awasa-83 and Bareda, the first signs of tuber formation were observed 60 days after planting (Appendix, Table A7.1). At 90 days all three cultivars showed similar tuber growth (43.9 to 64.6 g dry mass per plant). From 90 days after planting clear differences in bulking rate were observed.   Bareda had the highest tuber-bulking rate (13.3 g dry mass per plant per day), resulting in a final yield of 849.9 g at final harvest (150 days after planting). Falaha had an average bulking rate of 5.9 g per plant per day, resulting in a final yield of 418.9g. The long season cultivar, Awasa-83, had a bulking rate of 3.8g per plant per day, and a final root yield of 274.3g. All three cultivars were still growing actively 150 days after planting and considerable tuber bulking would have occurred if a longer growing period had been allowed. The late cultivar Awasa-83 may have been affected more than the other cultivars by terminating growth at 150 days.

Stem dry mass

The stem dry mass production of the three cultivars at Melkassa is presented in Figure 7.1. At 75 days after planting, all three cultivars showed similar stem growth (11.2 to 18.5 g dry mass per plant). From 75 days after planting clear differences in stem growth occurred. Bareda produced the highest stem dry mass of 276.5 g/plant at 150 days after planting, when it was still growing actively. Cultivars Awasa-83 and Falaha produced their highest stem dry mass of 225.4 and 110g/plant respectively at 135 days after planting, and declined thereafter. There was a significant difference in stem dry mass production of the three sweet potato cultivars during the different sampling dates at Melkassa (Appendix, Table A7.2). The observed pattern of stem growth does not reflect the accepted maturity groups. For both the early maturing Falaha and the late maturing Awasa-83 stem growth declined after 135 days, while the intermediate cultivar Bareda still exhibited active stem growth at 150 days after planting.

Leaf dry mass

The leaf dry mass production is presented in Figure 7.1. At 45 days after planting, all three cultivars showed similar leaf growth (7.8 to 11.7 g dry mass per plant) (Appendix, Table A7.3). From 75 days after planting, clear differences in leaf growth were observed. Bareda produced the highest leaf dry mass of 142.8 g/plant at 120 days after planting, but production declined thereafter. Cultivars Awasa-83 and Falaha produced the highest leaf dry mass of 166 and 90.6g/plant 135 days after planting and production for both of them declined thereafter.

Partitioning of dry matter to tubers

The partitioning of dry matter to the roots of the three cultivars is presented in Figure 7.2 and in the Appendix Table A7.4. There were differences between the cultivars in the portion of the dry matter partitioned to the roots. In the case of Falaha, a larger fraction of assimilates ranging from 29% to 73%, was diverted to the roots during the growing period. For cultivar Bareda the fraction of the dry matter allocated to the roots increased from 8 to 67% from 45 to 150 days after planting, while for cultivar Awasa-83 it increased from 4 to 53%. Although Bareda allocated less of the available assimilates to storage root growth than Falaha, a much higher final yield was produced by the cultivar Bareda. This finding differs from the results obtained by Huett & O'Neill (1976); Enyi (1977) and Li & Yen (1988), who reported that sweet potato cultivars with higher yields divert larger portions of assimilates to the storage roots.

Partitioning of dry matter to stems

The partitioning of dry matter to the stems is presented in Figure 7.2 and in the Appendix Table A7.4. The portion of the dry matter allocated to the stem during the sampling period varied among cultivars. The intermediate cultivar, Bareda, and the late maturing cultivar, Awasa-83, partitioned a larger fraction of assimilates to the stems earlier in the growth season. In the case of Bareda the stems constituted 38% of the dry mass at 45 days after planting. At 150 days after planting the stems still contained 22% of the dry mass. Cultivar Awasa-83 allotted 36% of the assimilates to stem growth at 45 days after planting. At 150 days after planting the stems still contained 29% of the dry mass. Falaha diverted the smallest proportion of assimilates to the stem growth (27% at 45 days and 15% at 150 days). A larger portion of the plant dry mass was partitioned to stems at an earlier stage of the cultivars growth. This finding is similar to the findings of Enyi (1977), who reported that shoot growth dominates during the first phase of sweet potato growth, with a large proportion of dry mass diverted to shoots.

Partitioning of dry matter to leaves

The partitioning of dry matter to the leaves of the three cultivars is presented in Figure 7.2 and in the Appendix Table A7.4. It is clear that Awasa-83 invested a larger portion of the available assimilates in leaf growth than the other two cultivars. In the case of Awasa-83 the leaves constituted 60% of the plant dry mass early in the growth season. At 150 days after planting the leaves still represented 18% of the dry mass. Falaha diverted the smallest fraction of assimilates to leaf growth (45% at 45 days and 12% at 150 days). Cultivar Bareda was intermediate in this regard with 54% of the assimilates partitioned to the leaves at 45 days. At 150 days after planting the leaves still constituted 11% of the dry mass. This study indicated that most assimilates were partitioned to the leaves at an earlier stage of growth, in agreement with the results of Enyi (1977).

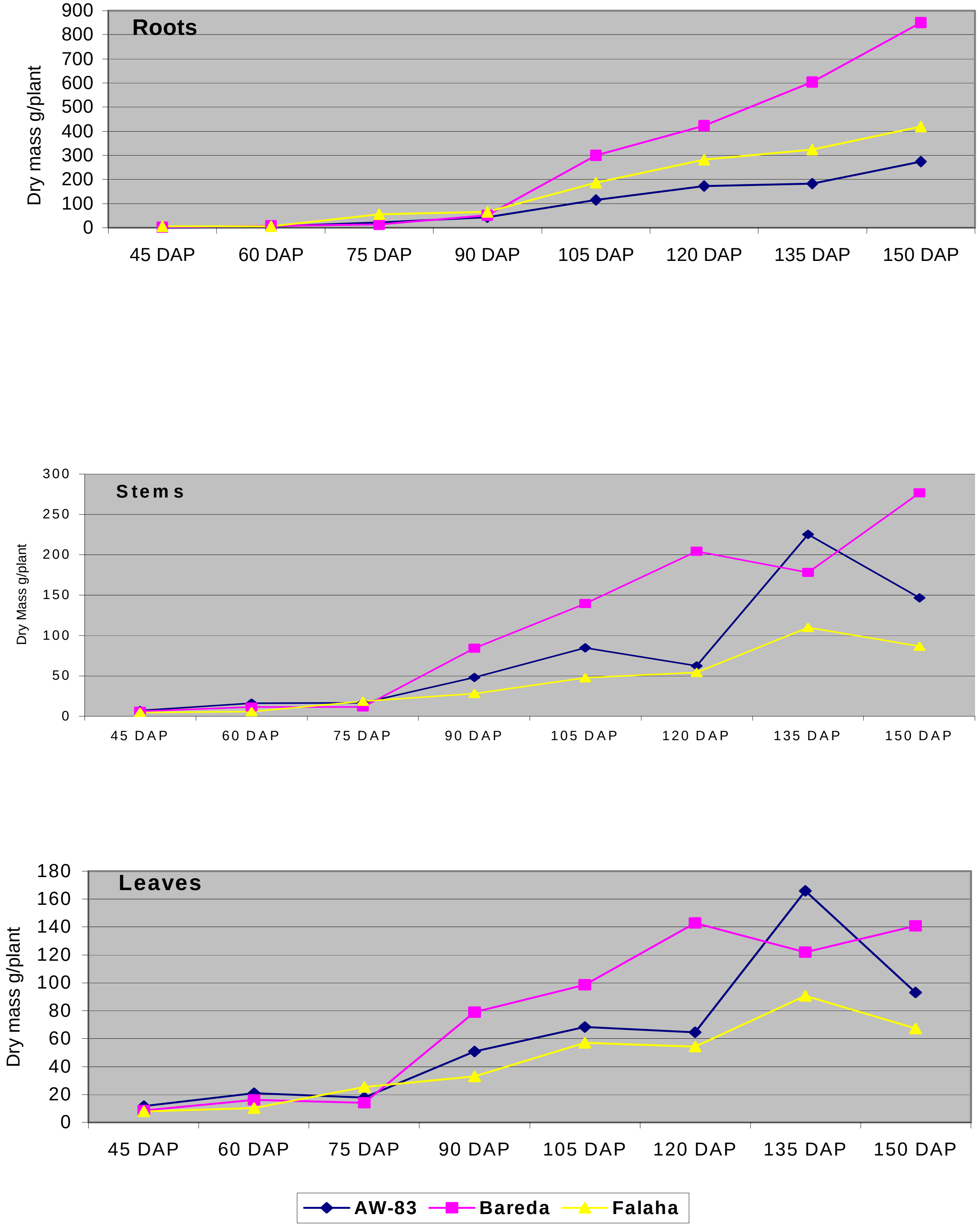

Figure 7.1 Dry mass of roots, stems and leaves of Awasa-83, Bareda and Falaha at different harvesting dates at Melkassa

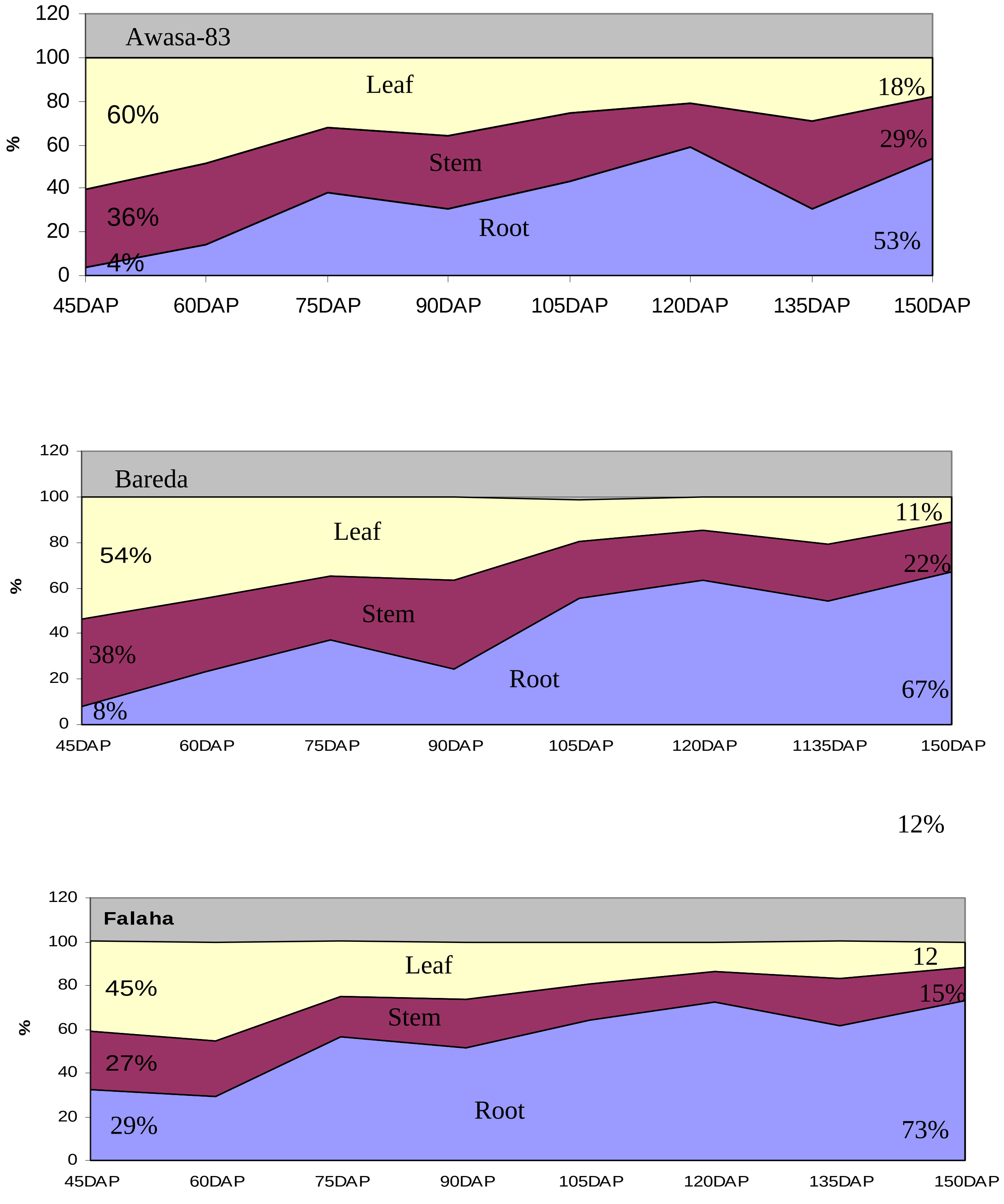

Figure 7.2 Percent dry matter partitioned to the roots, stems and leaves of the cultivars Awasa-83, Bareda and Falaha at Melkassa

Canopy development and growth rates at Melkassa

Data on the leaf area index (LAI), leaf area duration (LAD) and the net assimilation rate (NAR) are presented in Table 7.1 for the period 90 to 150 days after planting. The size (LAI), duration and efficiency (NAR) of the canopies during the period of tuber bulking should have a major influence on final yield.

The leaf area indices were relatively large, reflecting the lush canopy development at this site. Cultivar Bareda produced the largest canopy and Falaha the smallest. At the final harvest, 150 days after planting, the canopies were still active, with little or no sign of declining. The critical leaf area index (LAD_{95}) is defined as the canopy size which intercepts 95% of incoming radiation. Depending on the crop genotype, LAD_{95} values of 3 to 5 are typical for most cultivated crops. Forage crops, such as grasses, with erectophile leaf orientation may require a LAI of 8 to 10 under favorable conditions of maximum light interception (Gardner *et al*., 1994). Brown (1992) estimated that LAI of 3 to 4 is required to intercept 95% of photosyntheticaly active radiation (PAR) in sweet potato. During the tuber bulking periods Falaha and Awasa-83 produced canopies with LAI-values between 3 and 10, while Bareda had LAI-values of more than 10 for most of the tuber-bulking period. According to several authors, the LAI among sweet potato cultivars varied between 2 and 11 (Yu, 1981; Agata, 1982; Bourke, 1985; Indira & Ramanujam, 1985; Li & Kao, 1985; Tiwari *et al*., 1985; Mukhopadhyay *et al.*, 1992; Bhagsari & Ashley, 1990; Nair & Nair, 1995). Although no data to confirm the observation is available, it is suggested that all three cultivars exhibited excessive foliage development, and that cultural practices to limit foliage growth should be researched.

LAD expresses the magnitude and persistence of the leaf canopy. Leaf area duration was calculated from each sampling interval from 90 to 105 days after planting (LAD = average LAI X 15 days). The LAD during the tuber-bulking period was 751 days for Bareda with a final yield of 196t ha^{-1}. Awasa-83 produced a final yield of 56t ha^{-1} with a leaf area duration of 587 days, while with a leaf area duration of 402 days the final yield of Falaha was 95t ha^{-1}. Enyi (1977) reported that the leaf area duration of the seven cultivars he studied ranged from 240 to 616 days and there was no correlation with yield.

The NAR was calculated as the net gain of assimilates per unit leaf area per sampling cycle. Large variations in the NAR were recorded which probably reflects the inherent problem of representative sampling. However, with Bareda as the possible exception, the highest NAR values tended to occur during the 90 to 105 days interval. For the rest of the growing period, NAR showed a declining trend. The cultivar Bareda showed the highest net assimilation rate of 11.4 g m^{-2} day^{-1} between 90 and 105 days after planting, and the highest mean NAR of 7.6g m^{-2} day^{-1}. Cultivar Awasa-83 and Falaha showed mean NAR-values of 6.3 and 5.4g m^{-2} day^{-1} respectively. In this study, values of the mean NAR among cultivars varied from 37.8 to 53.2g m^{-2} week^{-1}, which is comparable to the highest value of the net assimilation rate 55 to 60g m^{-2} week^{-1} reported by Tsuno (1971).

The crop growth rate and tuber-bulking rate were estimated from the increase in dry mass per unit of land area at each consecutive sampling period (Table 7.1). Crop growth rates include top growth and tubers and varied between 1.7 and 21.7 g m^{-2} day^{-1}. The large variation should probably be attributed to variation in the samples. Bareda exhibited the highest rate of 21.7 g

m^{-2} day^{-1}, and the highest mean crop growth rate of 16.4 g m^{-2} day^{-1} (or 115 g m^{-2} $week^{-1}$) during the tuber-bulking phase. The comparable mean crop growth rates for the other two cultivars was 6.8 g m^{-2} day^{-1} for cultivar Awasa-83 and 6.3 g m^{-2} day^{-1} for Falaha. The mean crop growth rate of 120g m^{-2} $week^{-1}$ reported by Tsuno (1971) is comparable with the mean CGR of 115g m^{-2} $week^{-1}$ for Bareda. A mean crop growth rate of 20g m^{-2} day^{-1} (200kg ha^{-1} day^{-1}) is considered acceptable for most crops, particularly C_3 types. A mean crop growth rate of 30 g m^{-2} day^{-1} (300 kg ha^{-1} day^{-1} for grain) was recorded for C_4 types such as maize (Gardner *et al.*, 1994).

Tuber growth rate varied from less than one to more than 16 g m^{-2} $day^{-1,}$ which is equal to 112g m^{-2} $week^{-1}$). During the bulking period, Bareda had a mean tuber growth rate of 11g m^{-2} day^{-1} compared to rates of less than 5 g m^{-2} day^{-1} for the other two cultivars. Enyi (1977) reported that the tuber-bulking rate of seven sweet potato cultivars ranged from 50 to 131 g per plant $week^{-1}$ which is 22 to 57 g m^{-2} day^{-1}. The mean tuber bulking rate for the three cultivars examined in this study, ranged from 24 to 77 g m^{-2} day^{-1} is slightly higher than the results of Enyi, (1977) who recorded that a bulking rate of 22 to 57 g m^{-2} day^{-1} for seven cultivars. In terms of fresh mass, a rate of 11 g m^{-2} day^{-1} is equivalent to 3.2t tubers ha^{-1} $week^{-1}$. The large range of recorded tuber bulking rates clearly emphasizes the importance of maintaining agronomic inputs to optimize yield.

Table 7.1 Leaf area index, leaf area duration, net assimilation rate, and crop and tuber growth rate at Melkassa

Time	**LAI**			**Cumulative LAD days**			**NAR g m^{-2} d^{-1}**			**CGR g m^{-2} d^{-1}**			**TGR g m^{-2} d^{-1}**		
	Aw-8	**Bareda**	**Falaha**	**Aw-83**	**Bareda**	**Falaha**	**Aw-83**	**Bareda**	**Falaha**	**Aw-83**	**Bareda**	**Falaha**	**Aw-83**	**Bareda**	**Falaha**
90 DAP	5.5	8.3	3.3				5.8	7.8	2.8	5.8	11.7	1.7	1.5	2.5	0.6
105 DAP	7.2	10.5	6.1	95	141	71	6.4	11.4	10.1	8.3	21.7	11.1	4.7	16.5	8.2
120 DAP	6.6	15.4	5.5	104	194	87	2.4	4.3	6.7	2.8	12.2	6.6	3.9	8.2	6.3
135 DAP	17.6	12.6	9.9	182	210	116	4.2	6.6	5.0	13.6	15.2	8.9	0.7	12.0	2.8
150 DAP	9.9	14.8	7.2	206	206	128	1.9	7.8	2.4	3.4	21.1	3.2	6.0	16.4	6.3
Total	-	-	-	587	751	402									
Mean	-	-	-				6.3	7.6	5.4	6.8	16.4	6.3	3.4	11.1	4.8

Data not statistically analyzed

Awasa experiment

Root dry mass

The root dry mass production of the three cultivars was much lower at Awasa than at Melkassa, (Figure7.3 and Appendix, Table A7.5). All the cultivars exhibited storage root formation 75 days after planting. There were differences in root dry mass production of the three cultivars from 90 days after planting (Appendix, Table A7.5). Awasa-83 had the highest tuber-bulking rate (3.1g dry mass per plant day^{-1}), resulting in a final yield of 204 g at the final harvest (150 days after planting). Falaha had an average bulking rate of 1.9g per plant day^{-1}, resulting in a final yield of 147g and Bareda had a similar bulking rate during the mean bulking period from day 90 to day 150 and a final yield of 143.9g. All three cultivars were still growing actively 150 days after planting and considerable tuber bulking would have occurred if a longer growing period had been allowed. The late cultivar, Awasa-83, may have been affected more than the other cultivars by terminating growth at 150 days.

Stem dry mass

The stem dry mass production of the three cultivars at Awasa is presented in Figure 7.3 and in the Appendix Table A7.6. Cultivar Awasa-83 produced the highest stem dry mass of 157.3g/plant at 150 days after planting, while Falaha and Bareda produced approximately 50% lower stem dry masses. During the latter part of the growing season active vegetative growth still occurred in the case of cultivar Awasa-83, resulting in an increased stem mass, while stem mass of the other two cultivars tended to stabilise after day 105.

Leaf dry mass

The leaf dry mass production of the cultivars, Awasa-83, Bareda and Falaha, is presented in Figure 7.3 and in the Appendix Table A7.7. At 45 days after planting, clear differences in leaf growth were observed. Cultivar Awasa-83 produced the highest leaf dry mass of 68g/plant at 150 days after planting. Bareda and Falaha respectively produced 45g and 65g/plant at 105 days after planting and leaf production by both of them declined thereafter.

Partitioning of dry matter to tubers

Data on the partitioning of dry matter to roots of the three cultivars is presented in Figure 7.4 and in the Appendix Table A7.8. There were differences between cultivars in the proportion of dry matter partitioned to the roots. Bareda partitioned a larger fraction of assimilates, ranging from 9 to 60% to the roots during the growing period. For Falaha the dry matter portion allocated to root growth increased from 14 to 52% from 45 to 150 days after planting, while for cultivar Awasa-83 it increased from 22 to 48 %. Although cultivar Awasa-83 partitioned less of the available assimilates to storage root growth than Bareda and Falaha, it produced a much higher final yield than Bareda and Falaha. This finding differs from the results obtained by Huett & O’Neill (1976); Enyi (1977); Li & Yen (1988) who reported that sweet potato cultivars with higher yields divert larger portions of assimilates to the storage roots. It is an important observation which deserves further attention from agronomists and plant breeders.

Partitioning of dry matter to stems

The partitioning of dry matter to the stems of the three cultivars is presented in Figure 7.4 and in the Appendix Table A7.8. The stems of cultivar Awasa-83 constituted 38% of the dry mass at 45 days after planting. At 150 days after planting, the stems still contained 36% of the total dry mass. Cultivar Falaha allocated 37% of the assimilates to stem growth at 45 days after planting. At 150 days after planting, the stems still represented 28% of the dry mass. Bareda diverted less assimilates to the stem growth (32% at 45 days and 29% at 150 days). It is clear that larger portions of the plant dry mass were partitioned to the stems during earlier stages of growth. This finding is similar to the results obtained by Enyi (1977), who reported that shoot growth dominates during the first phase of sweet potato growth, with a large proportion of dry mass diverted to shoots.

Partitioning of dry matter to leaves

The partitioning of dry matter to the leaves of the three cultivars is presented in Figure 7.4 and in the Appendix Table A7. 8. The leaves of cultivar Bareda constituted 58% of the plant dry mass early in the growth season. At 150 days after planting, the leaves represent 11% of the dry mass. Falaha diverted 49% of the total dry mass to leaf growth early in the season. At 150 days after planting the leaves constituted 20% of the dry mass. Cultivar Awasa-83 invested the smallest fraction of assimilates in the leaf growth (40% at 45 days and 16% at 150 days). This study indicated that most assimilates were partitioned to the leaves at an earlier stage of growth. This finding is in agreement with the results obtained by Enyi (1977).

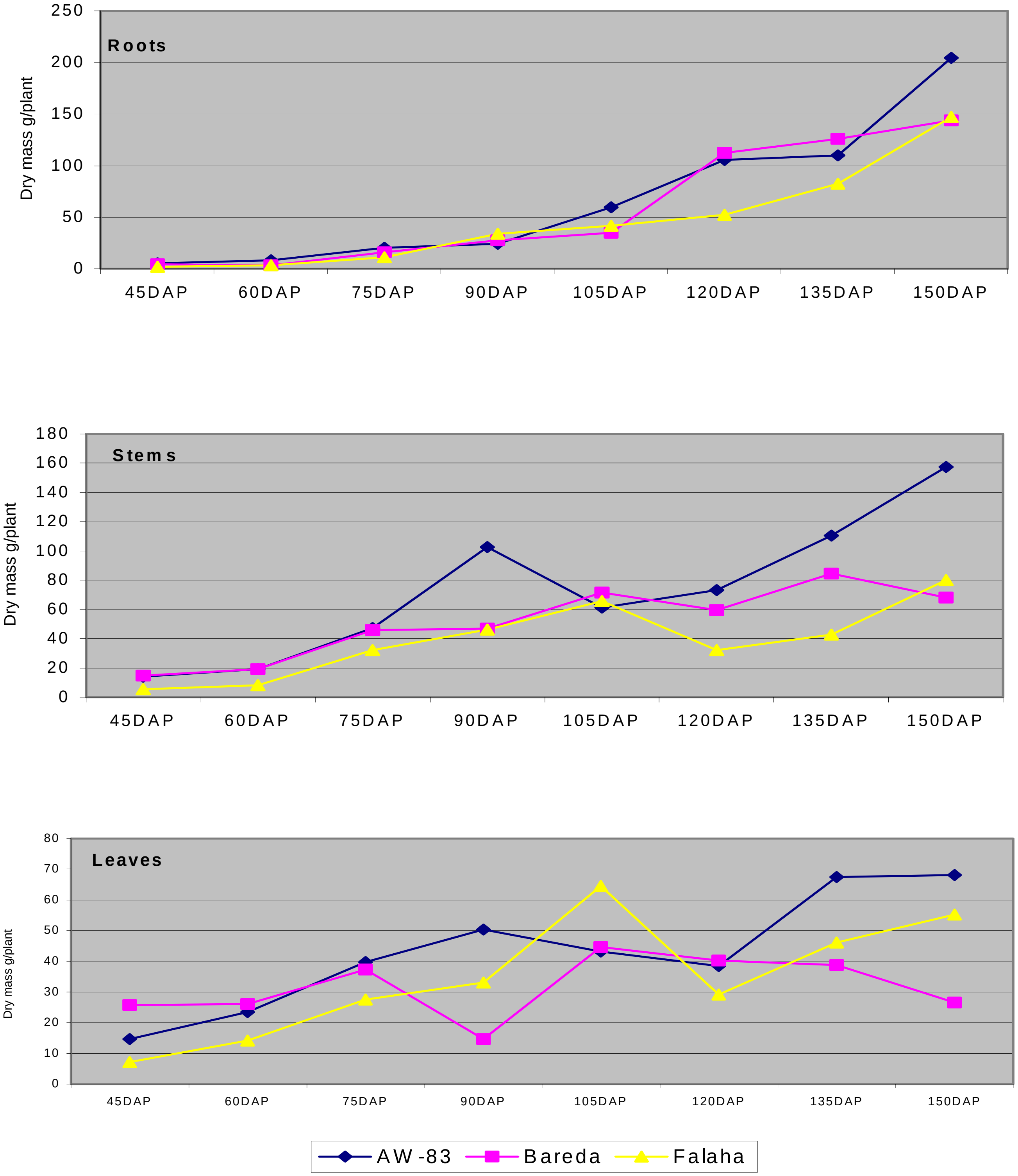

Figure 7.3 Dry mass of roots, stems and leaves of Awasa-83, Bareda and Falaha at different serial harvesting dates at Awasa

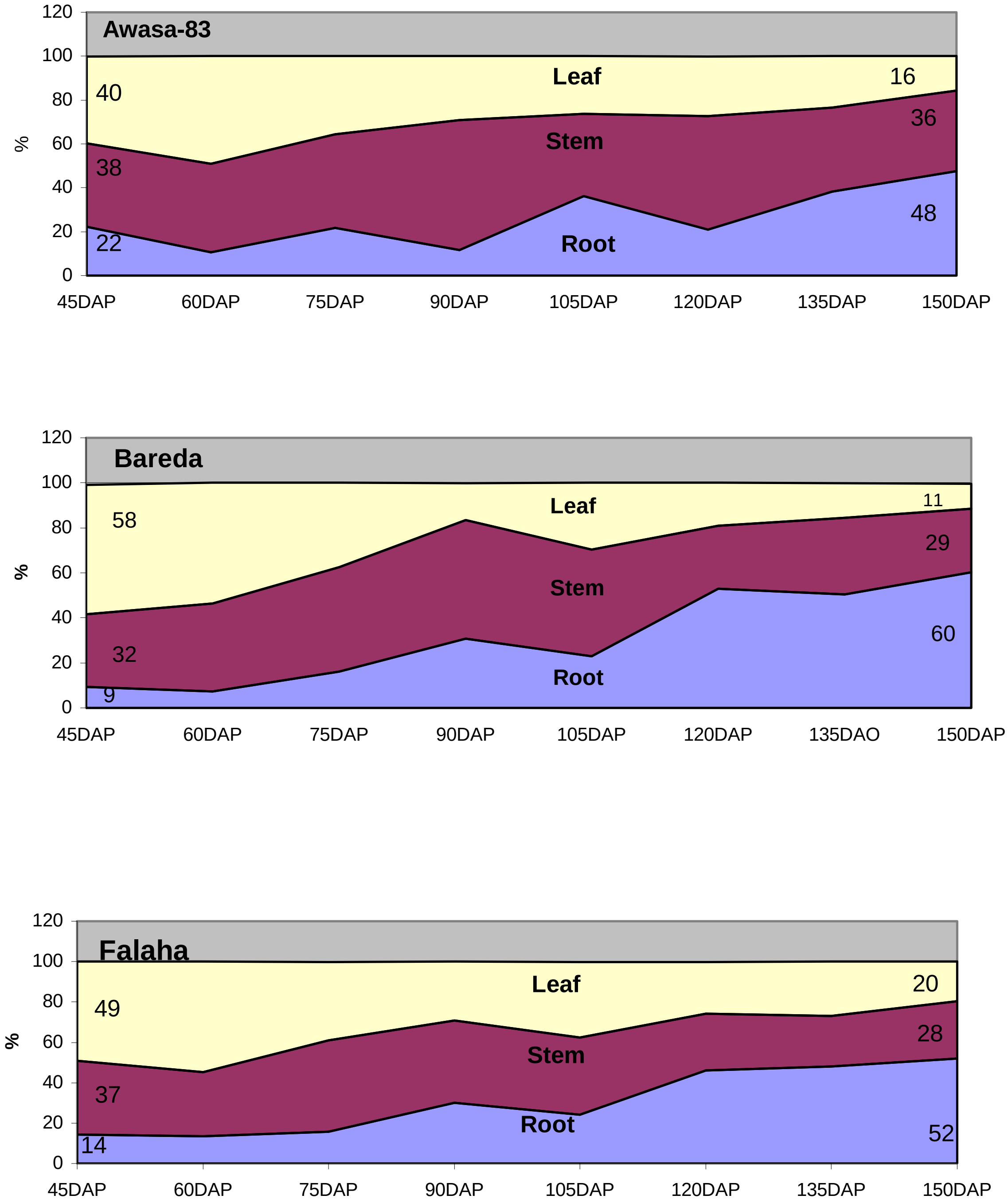

Figure 7.4 Percent dry matter partitioned to the roots, stems and leaves of the cultivars Awasa-83, Bareda and Falaha at Awasa

Canopy development and growth rates at Awasa

Although the leaf area indices obtained at Awasa for the three cultivars were higher than those reported by other authors, it was lower than at the Melkassa site. Data on the leaf area index (LAI), Leaf area duration (LAD) and the net assimilation rate (NAR) are presented in Table 7.2 for the period 90 to 150 days after planting. Bareda and Falaha maintained canopies with LAI values between 3 and 10 for most of the tuber-bulking period, while those of cultivar Awasa-83 ranged between 6 and 12. According to several authors LAI varied between 2 and 11 (Yu, 1981; Agata, 1982; Bourke, 1985; Indira & Ramanujam, 1985; Li & Kao, 1985; Tiwari *et al*., 1985; Mukhopadhyay *et al*., 1992; Bhagsari & Ashley, 1990; Nair & Nair, 1995).

The crop growth rates and tuber bulking rates were estimated from the increase in dry mass per unit of land area at each consecutive sampling period (Table 7.2). Crop growth rates include top growth and tubers and varied between 2.4 and 9.8g m^{-2} day^{-1}. The large variation and occasional negative values should be attributed to variation in the samples. Awasa-83 exhibited the highest rate of 9.8 g m^{-2} day^{-1}, and the highest mean crop growth rate of 4.3 g m^{-2} day^{-1} (or 30 g m^{-2} $week^{-1}$) during the tuber-bulking phase. The mean crop growth rate for Bareda and Falaha were 1.8 and 2.8 g m^{-2} day^{-1}, respectively. The mean crop growth rate of 120g m^{-2} $week^{-1}$ reported by Tsuno (1971) was much higher than the mean CGR of 30 g m^{-2} $week^{-1}$ for cultivar Awasa-83. A mean crop growth rate of 20 g m^{-2} day^{-1} (200kg ha^{-1} day^{-1}) is considered acceptable for most crops particularly C_3 types. A mean crop growth rate of 30 g m^{-2} day^{-1} (300 kg ha^{-1} day^{-1} for grain) was reported for C_4 types such as maize (Gardner *et al.*, 1994). Tuber growth rate varied from less than one to more than 6g m^{-2} day^{-1} (0.4t ha^{-1} $week^{-1}$). During the bulking period cultivar Awasa-83 had a mean tuber growth rate of 2.4 g m^{-2} day^{-1}.

Cultivar Bareda and Falaha had tuber growth rates of less than 2g m^{-2} day^{-1}. Enyi (1977) reported that the tuber bulking rates of seven sweet potato cultivars ranged from 50 to 131 g per plant $week^{-1}$ which is equivalent to 22 to 57 g m^{-2} day^{-1}. The mean tuber bulking rate for the three cultivars examined in this study ranged from 12 to 17 g m^{-2} day $^{-1}$ and is much lower compared to the tuber bulking rate values obtained by Enyi (1977). In terms of fresh mass a rate of 2.4 g m^{-2} day^{-1} is equivalent to 0.6t tubers ha^{-1} $week^{-1}$. This clearly emphasizes the importance of maintaining agronomic inputs to optimize yield.

Leaf area duration was calculated for each sampling interval from 90 to 105 days after planting (LAD = average LAI X 15 days). The LAD during the tuber bulking period was 553 days for Awasa-83 and the final yield was 41t ha^{-1} a LAD duration of 495 days for cultivar Falaha was associated with a final yield of 37t ha^{-1}, while for the leaf area duration of 399 days, the final yield of Bareda was 36t ha^{-1}. Enyi (1977) reported that the leaf area duration of seven cultivars he studied ranged from 240 to 616 days and were not correlation with yield.

The NAR was calculated as the net gain of assimilates per unit leaf area per sampling cycle. Large variations in the NAR were recorded which probably reflects the inherent problem of representative sampling. The highest NAR value for cultivar Awasa-83 was recorded during the 120 to 135 days interval. Cultivar Awasa-83 showed the highest net assimilation rate of 4.5 g m^{-2} day^{-1} between 120 and 135 days after planting and the highest mean NAR of 1.9 g m^{-2} day^{-1}. Cultivar Falaha and Bareda showed mean NAR of 1.4 and 1.1 g m^{-2} day^{-1} respectively. At this site values of the mean NAR among cultivars varied from 7.7 to 13.3 g m^{-2} $week^{-1}$, which is much lower than the high values of the NAR of 55 to 60 g m^{-2} $week^{-1}$ reported by Tsuno (1971) for sweet potato.

7.5 CONCLUSIONS

There were differences in dry mass production and partitioning of assimilates to different plant parts between cultivars and among sites. The relative poor growth and yield obtained at Awasa was mainly attributed to low rainfall during the growing season.

The size (LAI), duration (LAD) and efficiency (NAR) of the canopies during the tuber-bulking period play a major role in the final yield. The high yielding cultivars at both sites had larger canopy size (LAI), determining duration (LAD), net assimilation rate (NAR), crop growth rate (CGR) and tuber bulking rate (TBR) which influenced the final yield.

In the case of Falaha the highest fraction of assimilates ranging from 29 to 73 % was partitioned to the storage roots during the growing period. For cultivar Bareda the portion of the dry matter partitioned to the roots increased from 8 to 67 % from 45 to 150 days after planting, while for cultivar Awasa-83 it increased from 4 to 53 %. Although Bareda partitioned less of the available assimilates to storage root growth than Falaha a much higher final yield was produced by the cultivar Bareda at Melkassa.

The variability among cultivars in dry matter production and partitioning suggests that the development of cultivars with higher dry matter production and partitioning to the storage roots is possible. Selection of cultivars for high dry matter production and partitioning should continue, giving more emphasis to multi-locations evaluation to understand how cultivars react to divers agro-ecologies.

Table 7.2 Leaf area index, leaf area duration, net assimilation rate, crop (CGR) and tuber (TGR) growth rates at Awasa

Time	**LAI**			**Cumulative LAD days**			**NAR g m^{-2} d^{-1}**			**CGR g m^{-2} d^{-1}**			**TGR g m^{-2} d^{-1}**		
	Aw-8	**Bared**	**Falah**	**Aw-83**	**Bared**	**Falah**	**Aw-83**	**Bareda**	**Falah**	**Aw-83**	**Bareda**	**Falah**	**Aw-83**	**Bareda**	**Falaha**
90 DAP	8.8	2.8	6.1				2.6	-1.4	2.6	4.2	-0.7	2.8	-0.3	0.8	1.5
105 DAP	7.7	8.3	11.1	124	83	133	-0.5	2.8	1.9	-0.7	4.1	3.9	2.6	0.5	0.5
120 DAP	6.6	7.2	5.0	107	116	125	-1.3	3.2	-4.3	-1.5	4.1	-3.9	-2.0	5.2	0.7
135 DAP	12.1	7.2	8.3	140	108	100	4.5	1.9	2.6	9.8	2.4	3.8	5.3	0.9	2.0
150 DAP	12.1	5.0	9.9	182	92	137	4.3	-0.8	4.1	9.5	-0.7	7.4	6.3	1.2	4.3
Total	-	-	-	553	399	495									
Mean	-	-	-				1.9	1.1	1.4	4.3	1.8	2.8	2.4	1.7	1.8

Data not statistically analyzed

7.6 References

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CHAPTER 8

EFFECT OF PLANTING DENSITY AND CULTIVAR ON YIELD AND YIELD COMPONENTS OF SWEET POTATO IN ETHIOPIA

8.1 ABSTRACT

The effects of population density (50,000, 55,555, 75,000, and 100,000 cuttings per hectare) on the performance of three Ethiopian sweet potato cultivars were studied. The objectives were to determine the effect of plant population on yield and yield components and to investigate possible differences in the response among cultivars. Field studies were conducted during 2001 with the cultivars, Falaha (early maturing), Bareda (intermediate maturing) and Awasa-83 (late maturing). Total and marketable yields were found to be the highest at a population of 100,000 and the lowest at 50,000. The total fresh tuber yield increased from 50t ha $^{-1}$ at a population density of 50,000 to 82t ha $^{-1}$ at 100,000 plants ha $^{-1}$. Of the total yield 77% was marketable with approximately 35% large, 28% medium, and 14% small. Tuber size distribution was not affected by increasing planting density. The cultivars produced similar total and marketable storage root yields, but with a clear tendency towards more large storage roots in the case of Bareda, and more small storage roots in the case of Falaha.

The cultivar x planting density interaction was not significant, indicating that for all the parameters concerned the three cultivars reacted similarly on changes in plant population.

8.2 INTRODUCTION

Sweet potato has a long history as a lifesaver. Sweet potato kept millions from starvation in famine-plagued China in the early 1960s. In Uganda, when a virus ravaged cassava crops in the 1990s, rural communities depended on the sweet potato to keep hunger at bay. In the densely populated, semi-arid plains of eastern Africa, sweet potato is called cilera abana "protector of the children" http://www.cipotato.org/sweetpotato/sweetpotato.htm (2002). This alludes to the vital role it plays in thousands of villages where people depend on the crop to combat hunger. Sweet potato is high in carbohydrates and vitamin A and can produce more edible energy per hectare per day than wheat, rice, or cassava. It has an abundance of uses ranging from consumption of the roots or leaves to processing into animal feed, starch, flour, candy and alcohol.

It was first domesticated in Central America, but is now basically a crop of Asia, which accounts for about 93% of world production (FAO, 2000). Sweet potato is the sixth most important food crop in the world (FAO, 2000). It is also the third most important root crop in Africa (FAO, 2000). In Sub-Saharan Africa sweet potato is the third most important root crop after cassava (*Manihot esculenta*) and yam (Dioscorea spp.) (Ewell & Mutuura, 1994).

Although African farmers produce only about 9 million tons of sweet potato annually, most of the crop is cultivated for human consumption. African yields are quite low at 4 to 5t ha $^{-1}$ about a third of the Asian yields, indicating huge potential for future growth and improvement of the crop. In Africa the crop is grown on small scale, primarily to help ensure food security of the rural households (Ewell & Mutuura, 1994).

Ethiopia is one of the drought stricken countries of the world. Sweet potato is cultivated in Ethiopia mostly for storage roots for human consumption and the vegetative parts as animal feed. It ranks third after Enset (*Ensete ventricosum* Welw. Cheesman) and *Solanum* potato as the most important root crop produced in the country. Sweet potato is mainly grown by small scale, resource poor farmers. Although yields obtained are generally low, there is good potential for the crop since climatic and soil factors are largely favourable. The crop has relatively few pests and diseases, and pesticides are rarely used. Sweet potato can be grown in poor soils with little or no fertilizer.

Storage root yields vary widely between cultivars, location, and season (Austin & Aung, 1973; Wilson & Lowe, 1973). Fresh storage root yields of about 10 to 25t ha^{-1} in 16 to 20 weeks has been obtained in many countries (Bhagsari & Harmon, 1982; Li & Kao, 1985; Secreto & Villamayor Jr., 1985; Sen *et al*., 1988; Bhagsari, 1990; Rao & Sultana 1990). The world average storage root yield of sweet potato has been estimated to be 14.8t ha^{-1} (FAO, 2000). According to FAO the national average storage root yield of sweet potato is 8t ha^{-1} in Ethiopia. Experimental storage root yields ranging between 30 and 73t ha^{-1} have been reported by Hossain *et al*., (1987), Siddique *et al*., (1988), Hall & Harmon, (1989), Bhagsari & Asheley, (1990) and Varma *et al*., (1994). Under experimental conditions at Melkassa and Awasa Agricultural Research Centres, storage root yields ranging from 46 to 139t ha $^{-1}$ were obtained (Chapter 6).

Wide variability in storage root yield among sweet potato cultivars and individual plants of the same cultivar has been attributed to cultivar, propagation material, environment, and soil factors (Lowe & Wilson, 1975). In Ethiopia faulty land preparation, sub or supra-optimal plant population, improper method and depth of planting, lack of fertilization and carelessness during harvesting are some of the practices that may contribute to low and varying yields.

In high density plantings, interplant competition is greater and individual plant yields are lower and storage roots are smaller in size. Sweet potato is typically spaced 30 cm apart within the row and in rows approximately 90 cm apart (http://www.rec.udel.edu/class/kee/nov22.html). A 55,555 planting density is the recommended population for research purposes in Ethiopia, but local farmers consider this plant population sub optimum. To obtain 55,555 plants per hectare cuttings are spaced 30 cm apart within the row and in rows 60 cm apart. Fresh vine yield (above ground biomass) varies between 11 and 45.7t ha^{-1} (Singh & Mandal, 1976; Li & Kao, 1985; Sen *et al.*, 1990; Mukhopadhyay *et al.*, 1992). Yield per unit area is reportedly higher when cuttings are densely planted, however, production problems such as pests and diseases may be greater at high plant densities.

For successful sweet potato production in Ethiopia the optimum planting density have not yet been established and therefore, this experiment was designed with the following objectives:

- to determine the effect of planting density on yield and yield components; and
- to investigate differences in response to planting density among cultivars.

8.3 MATERIALS AND METHODS

A field experiment was conducted during 2001 at Awasa Research Centre in southern Ethiopia. The experiment reported in Chapter 8 was conducted on the same field and under the same climatic conditions as those reported in Chapters 6 and 7. The chemical and physical soil properties, weather data, and cultural practices are presented in Chapter 6.

A 3 x 4 factorial experiment in a randomized complete block design with four replications was planted. Treatments applied were three cultivars (Falaha, Bareda, and Awasa-83) and four planting densities (50,000, 55,555, 75,000, and 100,000 cuttings per hectare). The cultivars represent different maturity groups. Falaha is an early maturing cream-fleshed cultivar with a recommended growing period ranging from 90 to 105 days. Bareda is an intermediate maturing cream-fleshed cultivar with a recommended growing period ranging from 120 to 135 days, and Awasa-83 is a late maturing white-fleshed cultivar with a recommended growing period of more than 150 days. Awasa-83, Bareda, and Falaha are nationally released cultivars in Ethiopia.

The different planting densities were obtained by adapting the row and in row spacings. For the 50,000 cuttings per hectare a spacing of 0.5 m between rows and 0.4 m between cuttings (50 cm x 40 cm) was used. Each plot consisted of six rows of 3 m with 8 cuttings per row. The gross plot size of the 50,000 planting density was 8.4 m^2, and the net harvested area was 4 m^2. For the 55,555 cuttings per hectare treatment the rows were spaced 0.6 m apart and cuttings in the row were spaced 0.3 m (60 cm x 30 cm). Each plot consisted of 5 rows of 3 m and each row contained 10 cuttings. The gross plot size of the 55,555 planting density was 9 m^2 and the net harvested area was 4.32 m^2. For the 75,000 cuttings per hectare a between row spacing of 0.6 m and an in row spacing of 0.3 m (60 cm x 20 cm) was used. Each plot consisted of five rows of 3 m and each row contained 15 cuttings. The gross plot size for the 75,000 cuttings per hectare was 9 m^2 and the net harvested area was 4.68 m^2. For the 100,000 cuttings per hectare a spacing of 0.5 m between rows and 0.2 m between cuttings (50 cm x 20 cm) was used. Each plot consisted of six rows of 3 m and each row contained 15 cuttings. The gross plot size for the 100,000 planting density was 9 m^2 and the net harvested area was 5.2 m^2.

The land was deep plowed, harrowed and disced. Ridges were made using a tractor mounted ridger. Thirty centimeter long vine cuttings were prepared from the terminal and the middle portions of the vine. The experiment was planted on 2 June 2001, and was conducted under rain-fed conditions. The recommended sweet potato cultural practices were followed. The 30 cm cuttings of Awasa-83, Bareda and Falaha were planted vertically with two thirds (20 cm) of the lengths under the soil while the remaining one third (10 cm) was above the soil surface. No fertilizer was applied. Weeds were effectively controlled manually. No serious pest or disease problems occurred during the growing season. A one-time harvest was made on 5 November 2001. In each plot the two border rows as well as one plant at each end of the remaining three rows were discarded.

The experimental details regarding the grading of storage roots into small, medium, large, undersize, and oversize roots are presented in Chapter 7.

The experimental data were subjected to standard analyses of variance using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1989) to determine the effect of main factors and interaction between them. Differences at $P \leq 0.05$ level were used as a test of significance and means were separated using Tukey's t-test.

8.4 RESULTS AND DISCUSSION

Effect of plant population

The effect of plant population on storage root fresh mass per hectare is presented in Table 8.1. As the plant population increased form 50,000 to 100,000 plants ha $^{-1}$ the total fresh root yield increased by 63%, to 81.6t ha $^{-1}$. The marketable root yield increased by 72% to 65.6t ha $^{-1}$. The small storage root yield increased by 76% to 11.1t ha $^{-1}$, the medium storage root yield by 95% to 25.7t ha $^{-1}$ and the large root yield by 54% to 28.9t ha $^{-1}$ (Table 8.1). Li & Yen (1988) conducted an experiment using two cultivars (Tainung 62 and Tainung 63), two levels of irrigation (non-irrigated and irrigated), two types of NPK fertilizers (60:30:180, and 120:30:360), and three population densities (25,000, 33,333, and 50,000 cuttings ha $^{-1}$). Cuttings were planted with a spacing of 1.0 m between rows and 0.2, 0.3, and 0.4 m in the rows. They found that the highest density of 50,000 cuttings ha $^{-1}$ produced the highest root dry mass (10.3t ha $^{-1}$). This was followed in descending order by the 33,333 population yielding 9.3t ha $^{-1}$ and the 25,000 population producing 8.1t ha $^{-1}$, respectively. Bouwkamp & Scott (1980) conducted experiments using four cultivars (Redmar, Centennial, Nemagold, and MD 2262) and four planting densities (37,000, 28,000, 22,000, and 18,250 cuttings ha $^{-1}$). Cuttings were planted with a spacing of 0.9 m between rows and 0.3, 0.4, 0.5, and 0.6 m in the rows. Total yield and yield of roots measuring 5 to 9 cm diameter (no. 1 size) and 2.5 to 5 cm diameter (no. 2 size) were the highest for the highest planting density (37,000 cuttings ha^{-1}). The storage root yields reported in Table 8.1 are much higher than the yields obtained by Bouwkamp & Scott (1980) and Li & Yen (1988).

The effect of planting density on root dry mass is presented in Table 8.2. The root dry mass reflected the root fresh mass results. Total and marketable root dry mass increased as the plant population increased. The total root dry mass yield of 13.6t ha $^{-1}$ obtained from the 50,000 planting density (Table 8.2) was comparable to the 10.3t ha $^{-1}$ reported by Li & Yen (1988) for a plant population of 50,000. The 23.6t ha $^{-1}$ dry storage root yield obtained with the 100,000 population (Table 8.2) was twice as much as the maximum yield reported by Li & Yen (1988) for their highest population of 50, 000 cuttings per hectare.

The number and mass of storage roots per plant are presented in Tables 8.3 and 8.4, respectively. As the plant population increased from 50,000 to 100,000 plants ha $^{-1}$ the total storage root number per plant decreased from 5.1 to 3.8 (Table 8.3). Similar decreasing trends were observed for the marketable storage root number per plant. The total storage root mass per plant decreased from 1181g/plant to 812.3g/plant as the plant population increased from 55,555 to 100,000 plants ha $^{-1}$. Similar trends were observed for the marketable storage root mass per plant (Table 8.4).

An increase in plant population increased shoot fresh mass from 60.8 to 90t ha $^{-1}$ and the shoot dry mass from 8.2 to 12.9t ha $^{-1}$ (Table 8.1 & 8.2). The shoot dry mass of 9.9t ha $^{-1}$ obtained from the 50, 000 planting density (Table 8.2) was much higher than the 2.7t ha $^{-1}$ reported by Li & Yen (1988) for a population of 50,000. The 12.9t ha $^{-1}$ shoot dry mass obtained with a 100, 000 population (Table 8.2) was four times as much as the highest yield reported by Li & Yen (1988).

Table 8.1 Effect of cultivar and planting density on storage root yield and shoot fresh mass yield ha^{-1}

Treatment		Root yield t ha^{-1}					Shoot yield
		Total	Marketable	Small	Medium	Large	t ha^{-1}
Cultivar	**Falaha**	61.0	50.9	13.7	19.8	17.4	44.5
	Bareda	70.3	47.5	5.2	16.2	26.2	79.5
	Awasa-83	61.3	50.2	8.7	19.1	22.6	92.6
	LSD$_T$	12.4	7.8	2.3	2.2	6.8	23.1
Planting density	**50,000**	50.0	38.2	6.3	13.2	18.7	66.7
	55,555	61.6	42.7	8.4	14.3	20.6	60.8
	75,000	63.5	51.6	11.0	20.4	20.3	70.9
	100,000	81.6	65.6	11.1	25.7	28.9	90.4
	LSD$_T$	19.0	8.9	2.7	2.5	7.8	26.7
Mean		64.2	49.5	9.2	18.4	22.1	72.2
CV%		26.9	21.9	35.5	16.6	42.8	44.6

Table 8.2 Effect of cultivar and planting density on root and shoot dry mass yield in t ha^{-1}

Treatment		Root dry mass t ha^{-1}		Shoot Dry mass
		Total	Marketable	t ha^{-1}
Cultivar	**Falaha**	15.6	13.0	6.4
	Bareda	19.1	13.0	11.7
	Awasa-83	19.4	15.9	12.5
	LSD$_T$	3.5	2.5	2.9
Planting density	**50,000**	13.6	10.4	9.9
	55,555	16.8	11.8	8.2
	75,000	18.1	14.8	9.8
	100,000	23.6	18.9	12.9
	LSD$_T$	4.1	2.9	3.4
Mean		18.0	14.0	10.2
CV%		27.4	25.1	40.2

Table 8.3 Effect of cultivar and planting density on fresh storage root number on a per plant basis

Treatment		Number of storage roots per plant				
		Total	**Marketable**	**Small**	**Medium**	**Large**
Cultivar	**Falaha**	7.07	3.47	1.84	1.11	0.52
	Bareda	3.12	2.05	0.56	0.72	0.78
	Awasa-83	3.71	2.54	0.92	0.94	0.72
	LSD_T	0.97	0.46	0.33	0.15	0.19
Planting density	**50,000**	5.10	2.80	1.08	0.91	0.77
	55,555	5.09	2.81	1.20	0.86	0.77
	75,000	4.53	2.73	1.23	1.01	0.56
	100,000	3.82	2.42	0.91	0.91	0.60
	LSD_T	1.13	0.44	0.32	0.18	0.22
Mean		4.6	2.7	1.1	0.9	0.7
CV%		29.3	19.9	35.0	23.2	39.3

Table 8.4 Effect of cultivar and planting density on fresh storage root mass on a per plant basis

Treatment		Storage root mass g/per plant				
		Total	**Marketable**	**Small**	**Medium**	**Large**
Cultivar	**Falaha**	889.9	743.7	203.4	286.1	254.1
	Bareda	1092.5	672.9	73.4	223.9	378.9
	Awasa-83	898.1	745.8	124.2	276.9	344.7
	LSD_T	190.9	104.89	31.7	33.3	92.3
Planting density	**50,000**	1000.1	764.4	126.2	263.4	374.7
	55,555	1181.0	774.4	150.7	257.7	370.4
	75,000	847.5	688.2	146.9	271.5	269.8
	100,000	812.3	656.2	110.8	256.6	288.7
	LSD_T	220.4	121.1	36.59	38.51	106.63
Mean		960.2	720.8	133.70	262.32	325.9
CV%		27.7	20.3	33.0	17.7	39.5

Cultivars

The three cultivars (Falaha, Bareda, and Awasa-83) produced similar total and marketable yields of fresh storage roots, but differed in small, medium, and large storage root yields per hectare (Table 8.1). Falaha produced higher yields of small and medium storage roots than Bareda. Bareda produced a higher yield of large storage roots than Falaha. Cultivars differed in total and marketable root dry mass. Cultivar Awasa-83 produced the highest (19.4t ha $^{-1}$) total root dry mass, and Falaha the lowest 15.6t ha $^{-1}$. Awasa-83 also produced a higher marketable root dry mass than Falaha and Bareda (Table 8.2).

The cultivars produced similar marketable yields of fresh storage roots, but differed in total, small, medium, and large storage root yields per plant (Table 8.4). Bareda produced higher total and large storage root yields than Falaha. Falaha produced higher yields of small and medium roots per plant than Bareda.

The three cultivars differed in total, marketable, small, medium and large storage root numbers per plant (Table 8.3). Falaha produced more total, marketable, small and medium storage roots per plant. Bareda and Awasa-83 produced more large storage roots per plant than Falaha.

The cultivars differed in shoot fresh mass (Table 8.1) and shoot dry mass (Table 8.2). Cultivar Awasa-83 produced the highest shoot fresh and dry mass per hectare.

Cultivar x density interaction

None of the cultivar x planting density interactions were statistically significant indicating that for all the parameters evaluated the three cultivars reacted similarly and consistently to changes in plant population (data presented in appendix A8.5).

8.5 CONCLUSIONS

Although some differences occurred in yield and yield components between cultivars a similar and consistent increase in total storage root yield was observed as the plant population increased from 50,000 to 100,000 cuttings per hectare. This consistent increase in storage root yield with increasing plant population up to 100,000 cuttings per hectare clearly indicates the potential to increase storage root yield by increasing the plant population. This diverges from the lower plant populations (40,000 to 50,000 cuttings per hectare) often recommended for sweet potato production. With higher planting densities farmers will need to ensure that appropriate cultural practices are applied to reduce increased plant to plant competition. Cooperative on farm trials in Ethiopia to calibrate plant population recommendations are envisaged.

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CHAPTER 9

GENERAL DISCUSSION

Sweet potato is one of the most productive food crops per unit area and per unit time, and relatively free from serious pests and diseases. Despite its potential importance it is a crop of which the agricultural potential remains surprisingly unexploited, given the growing population and the pressure on natural resources. Compared to many other crops, sweet potato receives little research attention and many aspects of its growth, development and yield reactions are still poorly understood. While reviewing the literature it was clear that despite a number of field trials of mainly local relevance, there is a lack of research designed to improve production. The general approach of this study was to focus on some of the scientific principles that may affect agronomic practices in order to increase sweet potato production, especially in Ethiopia.

Morphological and anatomical studies (Chapter 3) demonstrated the root formation characteristics, and the presence and importance of the preformed root primordia are probably recorded for the first time. The prominent preformed root primordia in sets of four to ten on the stems adjacent to the leaf bases explains the remarkable capacity of sweet potato cuttings to initiate roots within hours after planting. Preformed root primordia produce adventitious roots with pentarch, hexarch or septarch steles. Storage roots are adventitious roots that will normally originate from undamaged preformed root primordia on the nodes of cuttings or newly formed vines. Under specific circumstances adventitious wound roots originating from the cut ends of stem or leaf cuttings can also develop into storage roots (Spence & Humphries, 1971; Hartman *et al*., 2002). Lateral roots originate from damaged root primordia and from adventitious roots exhibit tetrarch steles and form the fibrous root system. Although the root anatomy of sweet potato has been documented by various authors, especially Wilson & Lowe (1973) and Du Plooy (1989), little or no attention was previously given to the origin of the identified root types. It is suggested that with this understanding of root origin and root anatomy much of the existing unspecific and confusing terminology, for instance the identification of "thick" and "thin" roots (Lowe & Wilson, 1974; Du Plooy, 1992) can be eliminated. A better understanding of root development may initiate new research to optimise the rooting of cuttings as well as to manipulate potential storage root numbers.

While the morphological and anatomical observations emphasized the potential of sweet potato cuttings to quickly activate root formation, the literature revealed a remarkable lack of information on the rooting of cuttings, and factors affecting it. This initiated the trials presented in Chapter 4. When cuttings were planted in growth chambers with different temperatures, temperature ranging from 24 to 28 ^{o}C was found to be the most suitable for early root and shoot growth. When cuttings were planted in soil with different water contents, 80% of field water capacity was found to be optimal for root and shoot development. More interesting was the remarkable root development that occurred at 40% of field capacity. This may be an indication that soil water content is not critical during the establishment of cuttings. This topic deserves further research attention. The use of large soil volumes to allow a more gradual depletion of water to confirm the initial observations is required. Comparing root development of sweet potato under conditions of water stress to that of other crops should be interesting. Another aspect of root development on which little is known is how the early or late thickening of adventitious roots into pencil roots or storage roots, and the fraction of adventitious roots exhibiting secondary thickening, affect normal root functions like uptake of water and nutrients.

Morphologically the number of preformed root primordia, and thus the potential to produce storage roots, is similar for all nodes of a cutting. This was to a certain extent reflected in the pot experiment results reported in Chapter 5, where on average 3.7 storage roots were produced on cuttings with three nodes below the soil surface, with 33% on node one, 30% on node two and 37% on node three. In terms of fresh mass of storage roots, node one contributed 45%, node two 27% and node three 27%. This distribution pattern may reflect the relative proximity of the nodes to the source of assimilates from the leaves. In most situations there will be many more potential storage roots (i.e. adventitious roots) than required for a good yield, and physiological and environmental factors will determine the fraction of adventitious roots developing into storage roots. In this regard the research of Choudhury *et al*. (1986) and Du Plooy (1992) did, however, indicate that more storage roots will develop with an increase in the number of subterranean nodes. Site-specific cultivar x genotype interactions probably dictate the number and size of storage roots per cutting and per individual node, and thus indirectly the required number of subterranean nodes per cutting. Data for sweet potato seems to be scarce compared to potato (*Solanum tuberosum*) where Struik *et al.* (1990) and others have published a large amount of information on factors determining tuber number and tuber size distribution.

The effect of cutting characteristics on yield and yield components was investigated in field experiments at two sites in Ethiopia, and reported in Chapter 6. Higher yields were obtained from terminal and middle cuttings than from basal cuttings. This may at least be partly due to the preformed root primordia on younger cuttings having been less exposed to adverse conditions than those on basal cuttings. Whether the growth vigour of the older primordia on basal cuttings is similar to that of younger primordia on terminal cuttings, has not yet been demonstrated. The same arguments probably apply to the stem buds. The observation of

Eronico (1981) that the yield of middle and basal cuttings was 60% less than that from terminal cuttings, may well be explained on the same basis. The horizontal planting method resulted in higher yields than vertical planting, in accordance with the results of Chen & Allison (1982). However, this is not a consistent trend, as can be seen from the results in Chapter 6. Based on field observations it is postulated that horizontal planting will be advantageous in the case of shallow soils with growth limitations in the subsoil, but as far as can be ascertained this has not yet been demonstrated in trials. Generally good yields were obtained from most of the cutting characteristic treatments applied in the Ethiopian field trials. It was clear that within reasonable limits cutting characteristics *per se* had a relative small effect on yield. The implications being that farmers need not be too concerned about this, as even short basal cuttings can produce acceptable results, should better planting material not be available.

Especially for a crop like sweet potato, where carbohydrate is stored in storage roots, it can be hypothesized that yield will be a direct function of canopy productivity. To investigate this, standard growth analyses to quantify size, duration and efficiency of the canopy were conducted with three genotypes at two locations in Ethiopia (Chapter 7). The size of the leaf canopies was probably supra - optimal (LAI 5 to 10) during storage root development of all three cultivars. This may partly explain the absence of clear relationships between canopy characteristics and yield. Similarly there were no clear differences in the length of the growing periods of the early medium and late cultivars, with all the canopies still actively growing after 150 days. Due to differences in canopy size the leaf area duration (LAD) during the bulking phase was 751 days for Bareda, 587 days for Awasa-83 and 402 days for Falaha, associated with root yields of 196t ha $^{-1}$, 56t ha $^{-1}$ and 95t ha $^{-1}$ respectively. The calculated crop growth rates (CGR), storage root growth rates and net assimilation rates (NAR) were too variable to be conclusive. Whether the large variation was due to sample size and sample variation (especially for a highly variable crop like sweet potato) or not, it must be concluded that the results did not justify the effort, and the suitability of these growth analyses to explain yield differences can be questioned. The cultivar Falaha partitioned a larger fraction of the assimilates to storage roots (73% after 150 days) than Bareda (67%) and Awasa-83 (53%). Yet Bareda produced a much higher root yield than the other two cultivars. It is clear that yet unidentified genotype x environment interactions determined root yield to a greater extent than did canopy productivity.

Sweet potato generally tends to produce vigorous vegetative growth which is often not reflected in storage root yield. Plant population directly affects the potential number of storage roots, and increasing plant population may thus increase yield. Many smallholder farmers in Ethiopia maintain that higher plant populations result in better yields. Chapter 8 reports on a trial where three cultivars were planted at densities ranging from 50,000 to 100,000 cuttings per hectare. Surprisingly storage root size distribution was not affected by plant population, although Bareda tended to produce larger storage roots, while Falaha tended to produce smaller storage roots. Increasing planting density from 50,000 to 100,000 cuttings per hectare increased the storage root fresh mass by 60% from 50t ha $^{-1}$ at 50,000 planting density to 82t ha $^{-1}$ at 100,000 cuttings ha $^{-1}$. The increase in plant population also increased the storage root number per meter square by 50% from 25.5 at 50,000 cuttings to 38.2 at 100,000 cuttings per hectare. This may imply that the increase in sites for storage root formation (number of preformed root primordia) was responsible for the increase in yield.
Logically a lower plant population will be optimal under conditions favoring formation of a large number of storage roots per cutting, and *vice versa*. Thus the genotype x environment interaction in storage root set will determine the ideal plant population for a specific situation.

This may partly explain why plant populations of less than 50,000 cuttings per hectare are often recommended (Bouwkamp & Scott, 1980; Li & Yen, 1988). In Ethiopia on-farm plant population trials will be necessary before final recommendations can be made.

This investigation touched on some important factors affecting sweet potato production, with the emphasis on understanding principles which may influence production practices. In many instances more questions were raised than were answered. This was partly due to the high degree of variation in growth and yields, an aspects acknowledged by many authors (i.e. Lowe & Wilson, 1975). However, definite contributions were made. Some of the confusing concepts regarding the root system were clarified. The capacity for root formation even in relatively dry soil was demonstrated, and the contribution of individual subterranean nodes to storage root yield tentatively quantified. The field experiments in Ethiopia demonstrated the high yield potential of the crop. The cutting characteristics experiment revealed that most of the treatments applied to different maturity groups of sweet potato cultivars gave good yields. The growth analysis experiment contributed to a better understanding of the pattern of dry matter accumulation and partitioning to different plant parts at different stages of crop growth, and the planting density experiment indicated the possible advantages of higher plant populations.

This investigation should be followed up with basic studies on root development and rooting capacity; on the contribution of individual subterranean nodes to yield, and on source-sink relationships during bulking of the storage root. Field trials, preferably on-farm trials in Ethiopia, are essential in order to translate the results into farming practices.

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SUMMARY

In Ethiopia sweet potato (*Ipomoea batatas* (L.) Lam.) is grown mainly in the densely populated southern part and in the eastern part of the country where the crop is considered as an insurance crop. This crop has recently attracted interest as a potential cash crop and producers are faced with production problems. The aim of this study was to better understand factors affecting production and productivity. This was achieved through the following:

1. Investigation of the origin and structure of adventitious roots
2. Effect of temperature and soil moisture content on establishment of cuttings
3. Influence of cutting characteristics on storage root formation at individual nodes
4. Effect of cutting characteristics on yield and yield components
5. Growth analyses studies and
6. Study the effect of plant population.

The experiment on origin and structure of adventitious roots in sweet potato provided a good opportunity for better understanding of the origin of the preformed root primordia on sweet potato vine cuttings. The main objectives of this study were to investigate the origin of adventitious roots and provide additional information on the structure of sweet potato roots and find possible relationships between origin, structure and function of the roots.

The conclusions from this study can be summarized as follows:

1. Most adventitious roots in sweet potato are derived from preformed root primordia, situated at both sides of the node at the leaf base and ranging from four to ten in number.
2. Wound roots develop from cut ends of stems, leaf petioles, and other wounds on stem in response to the wounding effect in preparing the cuttings.

3. Both nodal and wound adventitious roots have the potential to develop into storage or pencil roots.
4. Lateral roots from adventitious roots and from damaged preformed root primordia are normally non-pigmented, tetrarch or infrequently pentarch, with no potential to develop into storage roots.

The experiment on the effect of temperature and soil moisture content on establishment of sweet potato cuttings provided information on early root development. The main objective was to determine the effect of temperature and soil moisture content on root and shoot growth during establishment of cuttings. The conclusions from this study can be summarized as follows:

1. Temperatures ranging from 24 to 28 °C were found to be the most suitable for early root and shoot growth.
2. Better root growth was achieved at 80% of field capacity. Lower or higher moisture regimes resulted in less root growth, but even at an initial moisture content of 40% of field capacity, substantial root development occurred.

The experiment on influence of cutting characteristics on storage root formation at individual nodes of cuttings quantified the contribution of individual subterranean nodes to total storage root number and mass. The main objectives of this study were to determine the contribution made by individual subterranean nodes of terminal, middle and basal cuttings to storage root formation, and to determine the influence of cutting orientation and presence or absence of leaves on cuttings, on storage root formation on individual nodes. The results can be summarized as follows:

1. Similar numbers of storage roots were formed at each of the subterranean nodes.
2. Almost half of the storage root fresh mass accumulated at node 1. This distribution pattern may reflect the relative proximity of the node to the source of the assimilates from the leaves.
3. Considering the result of this experiment there may be little benefit in planting more than three nodes below the soil surface.

The field experiments were conducted in Ethiopia at Awasa and Melkassa Research Centers. The cutting characteristics experiment evaluated three Ethiopian sweet potato genotypes for their ability to produce storage root yield, using two positions of planting (horizontal and vertical), two types of planting material (terminal vine cuttings with and without leaves) and three cutting length (20, 25 and 30 cm). Conclusions from this study can be summarized as follows:

1. The cutting treatments did not have a major effect on storage root yield, whether cuttings were 20, 25 and 30 cm long planted with or without leaves.
2. Large differences occurred in yield between locations, the cultivars responded similarly to the treatments at both locations.

Regarding the dry matter production and partitioning I evaluated three Ethiopian sweet potato cultivars for their ability to produce and partition assimilates to different plant parts. The highest yielding cultivar at both locations had a larger canopy size (LAI) and duration (LAD), crop growth rate (CGR) and tuber-bulking rate (TBR). The variability among cultivars in dry mass production and partitioning suggested that the development of cultivars of high dry matter production and partitioning to the storage root is possible in the future.

The effect of planting density on the performance of three Ethiopian sweet potato genotypes was studied. Similar and consistent increases in total storage root yield of all three cultivars were observed as the plant population increased from 50,000 to 100, 000 cuttings. This consistent increase in yield with increasing planting density up to 100, 000 cuttings per hectare clearly indicates the potential to increase storage root yield. However, this recommendation diverge from the lower plant populations often recommended for sweet potato production in other countries and should be substantiated in on-farm trials.

APPENDIX

Appendix Table A6.1 Summary of weather data at Melkassa.

	Rainfall	Air temperature (^oC)		Evapo-ration	Relative H	Sunshine
2001	**mm**	**Min**	**Max**	**mm**	**%**	**Hrs/day**
March	96.7	15.5	28.9	210.2	58	6.8
April	27.0	14.9	31.2	247.8	44	9.8
May	137.6	16.7	30.5	192.2	54	9.0
June	103.0	16.4	28.5	165.5	53	8.2
July	221.4	16.2	26.4	152.4	64	7.8
August	159.4	15.8	25.8	131.3	71	6.8
Sept	50.8	13.5	28.2	229.4	59	8.9
October	1.4	12.3	30.1	227.2	46	8.6
1977-2001						
March	43.8	15.6	30.2	8.8	58	8.8
April	47.3	15.2	29.8	8.2	62	8.2
May	52.2	15.4	30.9	8.5	59	8.2
June	72.1	16.2	30.0	7.1	69	8.7
July	188.9	15.4	26.6	5.8	80	8.3
August	176.9	15.2	26.2	5.4	83	6.9
Sept	83.7	14.2	27.4	5.2	75	7.2
October	47.6	11.8	28.0	7.0	63	7.4
Total	811					
Mean		13.8	28.6			

Appendix Table A6.2 Summary of weather data at Awasa.

2001	Rainfall mm	Mean daily temperature (^oC)		Evapo-ration mm	Relative H %
May	225.9	20.8		66.6	70
June	151.7	19.7		75.6	72
July	115.0	16.8		80.7	71
August	126.2	19.8		68.5	73
Sept	112.9	19.9		105.2	75
October	71.2	20.4		121.3	69
1972-2001		Min	Max		
May	178.1	18.2	26.5	8.5	59
June	97.4	18.3	21.4	7.1	69
July	110.2	16.8	20.0	5.8	80
August	149.3	18.2	20.4	5.4	83
Sept	129.9	18.2	20.2	5.2	75
October	89.8	18.3	20.0	7.0	63
Total	1055				
Mean		12.5	26.6		

Appendix Table A6.3 Total storage root number of the three sweet potato cultivars in all possible combinations of the 36 treatments at Melkassa Significant at the $P \leq 0.05$ level

Cultivar	Cutting length (cm)	Type of planting material cutting	Orientation of cutting	Total number of roots /m^2
Awasa-83	20	Without leaves	Vertical	11.5
	20	Without leaves	Horizontal	17.3
	20	With leaves	Vertical	13.3
	20	With leaves	Horizontal	17.6
	25	Without leaves	Vertical	12.9
	25	Without leaves	Horizontal	15.0
	25	With leaves	Vertical	11.5
	25	With leaves	Horizontal	17.6
	30	Without leaves	Vertical	16.4
	30	Without leaves	Horizontal	15.0
	30	With leaves	Vertical	16.3
	30	With leaves	Horizontal	12.9
Mean				14.8c
Bareda	20	Without leaves	Vertical	19.4
	20	Without leaves	Horizontal	34.7
	20	With leaves	Vertical	22.2
	20	With leaves	Horizontal	21.8
	25	Without leaves	Vertical	18.5
	25	Without leaves	Horizontal	19.8
	25	With leaves	Vertical	26.9
	25	With leaves	Horizontal	29.5
	30	Without leaves	Vertical	19.5
	30	Without leaves	Horizontal	39.5
	30	With leaves	Vertical	20.6
	30	With leaves	Horizontal	18.6
Mean				24.3b
Kudadie	20	Without leaves	Vertical	58.5
	20	Without leaves	Horizontal	25.1
	20	With leaves	Vertical	57.4
	20	With leaves	Horizontal	58.1
	25	Without leaves	Vertical	52.7
	25	Without leaves	Horizontal	51.2
	25	With leaves	Vertical	46.8
	25	With leaves	Horizontal	85.6
	30	Without leaves	Vertical	62.2
	30	Without leaves	Horizontal	41.9
	30	With leaves	Vertical	50.7
	30	With leaves	Horizontal	82.0
Mean				56.0a
C.V%				35.4

Appendix Table A6.4 Total storage root yield of the three sweet potato cultivars in all possible combinations of the 36 treatments at Melkassa (Significant at the P≤0.05 level)

Cultivar	Cutting length (cm)	Type of planting material Cutting	Orientation of cutting	Total yield t ha $^{-1}$
Awasa-83	20	Without leaves	Vertical	29.6
	20	Without leaves	Horizontal	57.9
	20	With leaves	Vertical	47.7
	20	With leaves	Horizontal	59.5
	25	Without leaves	Vertical	38.0
	25	Without leaves	Horizontal	67.4
	25	With leaves	Vertical	38.6
	25	With leaves	Horizontal	61.2
	30	Without leaves	Vertical	42.2
	30	Without leaves	Horizontal	55.3
	30	With leaves	Vertical	50.7
	30	With leaves	Horizontal	45.5
Mean				49.5c
Bareda	20	Without leaves	Vertical	82.8
	20	Without leaves	Horizontal	189.0
	20	With leaves	Vertical	68.2
	20	With leaves	Horizontal	93.6
	25	Without leaves	Vertical	71.5
	25	Without leaves	Horizontal	90.9
	25	With leaves	Vertical	53.0
	25	With leaves	Horizontal	103.6
	30	Without leaves	Vertical	86.3
	30	Without leaves	Horizontal	157.5
	30	With leaves	Vertical	63.0
	30	With leaves	Horizontal	79.3
Mean				94.9b
Kudadie	20	Without leaves	Vertical	119.6
	20	Without leaves	Horizontal	109.0
	20	With leaves	Vertical	130.7
	20	With leaves	Horizontal	185.8
	25	Without leaves	Vertical	112.7
	25	Without leaves	Horizontal	142.9
	25	With leaves	Vertical	122.7
	25	With leaves	Horizontal	131.6
	30	Without leaves	Vertical	113.9
	30	Without leaves	Horizontal	149.7
	30	With leaves	Vertical	122.4
	30	With leaves	Horizontal	223.4
Mean				138.7a
C.V%				48.5

Appendix Table A6.5 Total storage root number of the three sweet potato cultivars in all possible combinations of the 36 treatments at Awasa (significant at the P≤0.05 level)

Cultivar	Cutting length (cm)	Type of planting material cutting	Orientation of cutting	Total number of roots /m^2

Awasa-83	20	Without leaves	Vertical	16.8
	20	Without leaves	Horizontal	20.8
	20	With leaves	Vertical	14.6
	20	With leaves	Horizontal	15.9
	25	Without leaves	Vertical	18.3
	25	Without leaves	Horizontal	22.1
	25	With leaves	Vertical	16.6
	25	With leaves	Horizontal	16.4
	30	Without leaves	Vertical	19.6
	30	Without leaves	Horizontal	26.1
	30	With leaves	Vertical	15.3
	30	With leaves	Horizontal	16.2
Mean				18.2b
Bareda	20	Without leaves	Vertical	22.2
	20	Without leaves	Horizontal	20.7
	20	With leaves	Vertical	17.6
	20	With leaves	Horizontal	15.5
	25	Without leaves	Vertical	22.4
	25	Without leaves	Horizontal	19.2
	25	With leaves	Vertical	12.0
	25	With leaves	Horizontal	17.6
	30	Without leaves	Vertical	21.8
	30	Without leaves	Horizontal	30.7
	30	With leaves	Vertical	18.3
	30	With leaves	Horizontal	17.3
Mean				19.6b
Kudadie	20	Without leaves	Vertical	16.7
	20	Without leaves	Horizontal	29.7
	20	With leaves	Vertical	36.0
	20	With leaves	Horizontal	28.5
	25	Without leaves	Vertical	27.0
	25	Without leaves	Horizontal	28.0
	25	With leaves	Vertical	31.2
	25	With leaves	Horizontal	24.6
	30	Without leaves	Vertical	30.3
	30	Without leaves	Horizontal	32.6
	30	With leaves	Vertical	29.1
	30	With leaves	Horizontal	23.2
Mean				28.1a
C.V%				24.3

Appendix Table A6.6 Total storage root yield of the three sweet potato cultivars in all possible combinations of the 36 treatments at Awasa (Significant at the $P \leq 0.05$ level)

Cultivar	Cutting length (cm)	Type of planting material cutting	Orientation of cutting	Total number of roots /m^2
Awasa-83	20	Without leaves	Vertical	35.6
	20	Without leaves	Horizontal	56.4
	20	With leaves	Vertical	37.5
	20	With leaves	Horizontal	46.5
	25	Without leaves	Vertical	41.3

	25	Without leaves	Horizontal	54.2
	25	With leaves	Vertical	42.9
	25	With leaves	Horizontal	45.0
	30	Without leaves	Vertical	43.6
	30	Without leaves	Horizontal	63.8
	30	With leaves	Vertical	42.8
	30	With leaves	Horizontal	43.6
Mean				46.1c
Bareda	20	Without leaves	Vertical	61.9
	20	Without leaves	Horizontal	89.4
	20	With leaves	Vertical	49.2
	20	With leaves	Horizontal	69.5
	25	Without leaves	Vertical	75.9
	25	Without leaves	Horizontal	79.7
	25	With leaves	Vertical	50.3
	25	With leaves	Horizontal	60.5
	30	Without leaves	Vertical	56.7
	30	Without leaves	Horizontal	103.3
	30	With leaves	Vertical	44.6
	30	With leaves	Horizontal	63.8
Mean				67.0b
Kudadie	20	Without leaves	Vertical	48.9
	20	Without leaves	Horizontal	81.4
	20	With leaves	Vertical	82.8
	20	With leaves	Horizontal	96.1
	25	Without leaves	Vertical	70.9
	25	Without leaves	Horizontal	82.0
	25	With leaves	Vertical	79.3
	25	With leaves	Horizontal	93.5
	30	Without leaves	Vertical	77.3
	30	Without leaves	Horizontal	80.1
	30	With leaves	Vertical	62.6
	30	With leaves	Horizontal	65.5
Mean				76.7a
C.V%				27.2

Appendix Table A7.1 Root dry mass (g/plant) at Melkassa

Treatment	AW-83	Bareda	Falaha
45 DAP	0.7c	1.3c	6.1d
60 DAP	6.0c	8.3c	6.7d
75 DAP	21.0c	14.8c	56.2cd
90 DAP	43.9.0 bc	51.9c	64.6cd
105 DAP	114.9bc	300.1bc	187.6bc
120 DAP	173.2ab	423.4abc	282.6ab
135 DAP	183.6ab	603.8ab	324.5ab
150 DAP	274.3a	849.8a	418.9a
LSD_T	152.66	152.66	152.66
MEAN	102.2	281.7	168.4
CV %	87.5	90.1	61.8

Appendix Table A7.2 Stem dry mass (g/plant) at Melkassa

Treatment	AW-83	Bareda	Falaha
45 DAP	7.0c	6.0c	5.0d
60 DAP	16.2c	11.6c	5.9d
75 DAP	16.8c	11.2c	18.5cd
90 DAP	48.2bc	84.2bc	27.9cd
105 DAP	84.9bc	139.3bc	47.5bcd
120 DAP	62.4bc	204.2ab	54.1bc
135 DAP	225.4a	178.0ab	110.0a
150 DAP	146.6ab	276.5a	86.6ab
LSD_T	59.96	59.96	59.96
MEAN	75.9	113.9	43.2
CV %	81.4	68.2	56.8

Appendix Table A7.3 Leaf dry mass (g/plant) at Melkassa

Treatment	**AW-83**	**Bareda**	**Falaha**
45 DAP	11.7b	8.5b	7.8d
60 DAP	20.8b	16.1b	10.4d
75 DAP	17.7b	14.0b	25.4cd
90 DAP	50.9ab	78.9ab	33.1bcd
105 DAP	68.4ab	98.5a	57.1abc
120 DAP	64.7ab	142.8a	54.2abc
135 DAP	166.0a	121.8a	90.6a
150 DAP	93.1ab	141.0a	67.2ab
LSD$_T$	38.3	38.3	38.3
MEAN	61.7	77.7	43.2
CV %	66.5	66.5	66.5

Appendix Table A7.4 Mean percent dry matter partitioned to different organs for the three cultivars at different stage of growth at Melkassa.

Treat	**Roots**			**Stems**			**Leaves**		
DAP	**Aw-83**	**Bareda**	**Falaha**	**Aw-83**	**Bareda**	**Falaha**	**Aw-83**	**Bareda**	**Falaha**
45 DAP	3.6	8.2	32.2	36.1	38.0	26.5	60.3	53.8	41.3
60 DAP	13.9	23.1	29.1	37.6	32.2	25.7	48.3	44.7	45.2
75 DAP	37.8	37.0	56.2	30.3	28.0	18.5	31.9	35.0	25.4
90 DAP	30.8	24.2	51.4	33.7	39.2	22.2	35.6	36.7	26.4
105 DAP	42.9	55.5	64.2	31.7	25.8	16.3	25.5	18.2	19.5
120 DAP	59.1	63.5	72.3	20.1	21.5	13.8	20.8	15.0	13.9
135 DAP	30.7	58.5	61.8	39.9	24.6	21.4	29.4	20.9	17.3
150 DAP	53.3	67.1	73.1	28.5	21.8	15.1	18.1	11.1	11.7
Mean	34.0	42.1	55.0	32.2	28.9	19.9	33.7	29.4	25.1

Data not statistically analyzed

Appendix Table A7.5 Root dry mass (g/ plant) at Awasa

Treatment	AW-83	Bareda	Falaha
45 DAP	8.2c	4.2b	2.1c
60 DAP	5.1c	3.5b	3.6c
75 DAP	24.2c	16.0b	11.2bc
90 DAP	20.2c	27.4b	34.1bc
105 DAP	59.4bc	34.7b	41.6bc
120 DAP	29.5c	112.4a	52.3bc
135 DAP	109.8b	125.8a	82.3ab
150 DAP	204.4a	143.9a	147.3a
LSD_T	35.5	35.5	35.5
Mean	57.6	58.5	46.8
CV %	68.9	68.9	68.9

Appendix Table A7.6 Stem dry mass (g/ plant) at Awasa

Treatment	AW-83	Bareda	Falaha
45 DAP	14.1c	14.8b	5.4b
60 DAP	19.2c	19.0b	8.2b
75 DAP	47.3bc	45.9ab	32.0ab
90 DAP	103.0ab	47.0ab	46.3ab
105 DAP	61.1bc	71.5a	65.8a
120 DAP	73.2bc	59.7ab	32.1ab
135 DAP	110.5ab	84.5a	42.9ab
150 DAP	157.3a	68.1a	80.1a
LSD_T	33.8	33.8	33.8
Mean	73.1	51.3	39.1
CV %	65.3	65.3	65.3

Appendix Table A7.7 Leaf dry mass (g/ plant) at Awasa

Treatment	**AW-83**	**Bareda**	**Falaha**
45 DAP	14.6c	25.7a	7.2c
60 DAP	23.4c	26.1a	14.1bc
75 DAP	39.7abc	37.3a	27.6abc
90 DAP	50.4ab	14.6a	33.1abc
105 DAP	43.2abc	44.7a	64.6a
120 DAP	38.4abc	40.3a	29.1abc
135 DAP	67.5a	38.7a	46.1ab
150 DAP	68.1a	26.6a	55.3a
LSD$_T$	18.4	18.4	18.4
Mean	43.2	31.7	34.6
CV %	53.1	53.1	53.1

Appendix Table A7.8 Mean percent dry matter partitioned to different organs for the three cultivars at different stage of growth at Awasa

Treat	**Roots**			**Stems**			**Leaves**		
DAP	**Aw-83**	**Bared**	**Falaha**	**Aw-83**	**Bared**	**Falaha**	**Aw-83**	**Bared**	**Falaha**
45 DAP	22.2	9.4	14.3	38.1	32.2	36.7	39.5	57.6	49.0
60 DAP	10.7	7.2	14.0	40.3	39.1	31.8	49.2	53.7	54.7
75 DAP	21.8	16.1	15.8	42.5	46.3	45.1	35.7	37.6	38.9
90 DAP	11.6	30.8	30.0	59.3	52.7	40.8	29.1	16.4	29.2
105 DAP	36.3	23.0	24.2	37.3	47.4	38.2	26.4	29.6	37.5
120 DAP	20.9	52.9	46.0	51.8	28.1	28.3	27.2	19.0	25.6
135 DAP	38.2	50.5	48.1	38.4	33.9	25.1	23.5	15.5	26.9
150 DAP	47.6	60.3	52.1	36.6	28.5	28.3	15.8	11.1	19.6
Mean	26.2	31.3	30.6	43.0	38.5	34.3	30.8	30.1	35.2

Data not statistically analyzed

Appendix Table A7.9 Mean dry mass production of roots, stems and leaves of the three cultivars (g/plant) at different stage of growth at both sites

	Roots		Stems		Leaves		Total	
DAP	**Melk**	**Awasa**	**Melk**	**Awasa**	**Melk**	**Awasa**	**Melk**	**Awasa**
45	2.71e	4.04e	6.00c	11.43d	9.34e	15.83c	18.10d	32.11d
60	6.98e	4.86e	11.25c	15.48d	15.78e	21.15bc	34.00d	40.68d
75	30.63e	17.17de	15.47bc	41.71cd	19.04de	34.87ab	65.10d	93.75cd
90	53.44de	27.22de	54.40bc	65.33bc	54.30cd	32.68abc	161.10cd	127.23c
105	200.85cd	45.25cd	90.55b	66.14bc	74.67abc	50.87a	388.60bc	162.26c
120	356.64b	64.74c	106.92b	55.02bc	87.24bc	35.92ab	550.80b	155.70c
135	307.03cd	105.87b	167.81a	79.31ab	126.14a	50.76a	601.00ab	235.94b
150	514.33a	165.21a	169.90a	101.84a	100.46ab	49.98a	784.70a	317.03a
Mean	184.08	54.30	77.66	54.53	60.87	36.51	322.94	145.59
LSD_T	152.7	35.5	59.9	33.8	38.4	18.4	230.1	73.3
C.V %	87.5	68	81.45	65.33	66.48	53.16	75.17	53.11

Appendix Table A7.10 Percent dry matter partitioned to different parts of sweet potato crop during different growth stages.

	Roots		Stems		Leaves	
DAP	**Awasa**	**Melkassa**	**Awasa**	**Melkassa**	**Awasa**	**Melkassa**
45	12.58	14.97	35.60	33.15	49.30	51.60
60	11.95	20.52	38.05	33.09	52.00	46.41
75	18.31	47.05	44.49	23.75	37.19	29.25
90	21.39	33.17	51.35	33.77	25.69	33.71
105	27.89	51.69	40.76	23.30	31.35	19.22
120	41.58	64.75	35.34	19.41	23.07	15.84
135	44.87	51.09	33.61	27.92	21.51	21.00
150	52.11	65.55	32.12	21.65	15.77	12.80
Mean	28.81	43.60	38.9	27.0	32.0	28.7

Not statistically analyzed

Appendix Table A8. 1 Effect of planting density on total storage root yield of three sweet potato cultivars in Ethiopia

	Density (plants ha $^{-1}$)				
	50,000	**55,555**	**75,000**	**100.000**	
Cultivar	Total storage root yield (t ha $^{-1}$)				**Mean**
Falaha	45.1	57.9	64.1	76.7	61.0
Bareda	52.1	74.5	64.9	89.7	70.3
Awasa-83	52.7	52.4	61.6	78.3	61.3
Density means	50.0	61.6	63.5	81.6	
Overall mean					64.2

LSD cultivar = 12.4
LSD density = 14.3
LSD C x D = NS
CV = 27%

Appendix Table A8. 2 Effect of planting density on marketable storage root yield per hectare of three sweet potato cultivars in Ethiopia

	Density (plants ha $^{-1}$)				
	50,000	**55,555**	**75,000**	**100.000**	
Cultivar	Marketable storage root yield t ha $^{-1}$				**Mean**
Falaha	36.9	48.4	54.7	63.7	50.9
Bareda	33.0	38.3	46.5	72.2	47.5
Awasa-83	44.8	41.3	53.6	61.0	50.2
Density means	38.2	42.6	51.6	65.6	
Overall mean					49.5

LSD cultivar = 7.8
LSD density = 9.0
LSD C x D = NS
CV = 21.9%

Appendix Table A8. 3 Effect of planting density on total root dry mass yield t ha $^{-1}$ of three sweet potato cultivars in Ethiopia

	Density (plants ha $^{-1}$)				
	50,000	55,555	75,000	100.000	
Cultivar	Total root dry mass yield (t ha $^{-1}$)				**Means**
Falaha	12.1	14.7	15.9	19.8	15.6
Bareda	12.9	20.4	17.6	25.4	19.1
Awasa-83	15.6	15.4	20.9	25.7	19.4
Density means	13.6	16.8	18.1	23.6	
Overall mean					18.0

LSD cultivar = 3.6
LSD density = 4.0
LSD C x D = NS
CV = 27.5%

Appendix Table A8. 4 Effect of planting density on marketable root dry mass yield per hectare of the three sweet potato cultivars in Ethiopia

	Density (plants ha $^{-1}$)				
	50,000	55,555	75,000	100.000	
Cultivar	Marketable root dry mass yield t ha $^{-1}$				**Means**
Falaha	9.9	12.3	13.6	16.4	13.0
Bareda	8.2	10.8	12.6	20.5	13.0
Awasa-83	13.3	12.4	18.1	19.8	15.9
Density means	10.4	11.8	14.8	18.9	
Overall mean					14.0

LSD cultivar = 2.5
LSD density = 2.9
LSD C x D = NS
CV = 25.1%

Appendix Table A8.5 Effect of planting density on total and marketable storage root numbers plant $^{-1}$ and ha $^{-1}$ of three sweet potato cultivars in Ethiopia

		Root number plant $^{-1}$	
Planting density	**Cultivar**	**Total**	**Marketable**
50.000	**Falaha**	7.6	3.5
50.000	**Bareda**	3.1	2.0
50.000	**Awasa-83**	4.6	3.0
55,555	**Falaha**	8.4	3.9
55,555	**Bareda**	3.1	2.0
55,555	**Awasa-83**	3.8	2.6
75,000	**Falaha**	6.8	3.6
75,000	**Bareda**	3.4	2.1
75,000	**Awasa-83**	3.4	2.5
100,000	**Falaha**	5.6	2.9
100,000	**Bareda**	2.9	2.2
100,000	**Awasa-83**	3.1	2.2
LSD_T population		1.1	0.4
LSD_T cultivar		1.0	0.4
Mean		4.7	2.7
C.V%		29.3	19.9