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^{o}C than at 15/13^{o}C (day/night), and higher at a soil temperature of 30^{o}C than 15^{o}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^{o}C than at 29/20^{o}C. Seasonal plantings in northwestern Argentina suggest that flower and seed production are best with daily maximum temperatures between 23 to 24^{o}C and minimum temperatures between 13 to 19^{o}C (Folquer, 1974). In Puerto Rico flowering in a greenhouse did not occur above 27^{o}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^{o}C for three days before bedding (Su *et al*., 1965). Prior exposure of tubers to 43^{o}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^{o}C. At temperatures above 32^{o}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^{o}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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