IMPORTANCE AND SUSTAINABILITY OF ROOT CROPS-BASED SYSTEMS IN SUB-SAHARAN AFRICA

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–I *must* have an Abstract for Pam to include in the Annual Report–

MAJOR ROOT CROPS IN TROPICAL AFRICA

Cassava (*Manihot esculenta* Crantz), yams (*Dioscorea* spp.), cocoyam (*Xanthosoma sagitifolium* Schott and *Colocasia esculenta* (Schott) Crantz) are the major root crops grown in tropical sub-Saharan Africa. They provide the bulk of the carbohydrate and are in this respect supplemented by cereals such as rice (*Oryza sativa*) and maize (*Zea mays*). Root crops are, therefore, plants cultivated for their carbohydrate – rich swollen underground storage organs consisting anatomically of roots (cassava), stems (yams) and modified stems (rhizomes) of cocoyams. The root crops of importance grown in tropical Africa are presented in Table 1. Temperate and subtropical root crops such as garden beets (*Beta vulgaris*), carrots (*Daucus carota*), Irish potato (*Solanum tuberosum*), and sweet potato (*Ipomoea batata* (L) Lam) are also grown as minor crops.

Within the *Manihot* genus, only one edible species, *Manihot esculenta*, is known to be cultivated. This is contrary to the genus *Dioscorea* in which, in addition to *Dioscorea rotundata*, *caynensis* and *alata*, there are many other species also grown for food. These, together with their geographical distribution, are given in Tables 2a and 2b. These crops and others grown in the tropical region were traditionally established in systems which permitted rapid regrowth of forests and therefore ensured closed forest regrowth after cropping. This shifting and/or rotational bush fallow system of cropping

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was severely criticized in the past as being wasteful and inefficient but now receives praise for conservation of resources (Podoch and Vayda, 1983; Nye and Greenland, 1961). With about 0.2 million square kilometers out of about 16 million square kilometers of potential tropical forest land being cleared annually (Myers, 1979), it is evident that careful management of these lands is essential to ensure land-resource conservation. Tropical experience and practical evidence show that as human population increases, more and more land is cleared, period of fallow is shortened, and land resource is irreversibly destroyed by erosion. A clear look at the traditional systems as practiced in tropical mixed root crop systems may explain further their benefits in ecosystem preservation as a basis for developing future research strategies for cropping systems.

IMPORTANCE OF ROOT CROPS IN AFRICA

The importance of root crops in Africa transcends their use as starchy foods. Some, such as yams, are of such importance that Coursey (1982) described them as "part of our cultural heritage". The cycle of life of yam cultivators in the "Yam Zone" revolves around processes in the life cycle of the yam: clearing of the land, cultivation and mounding, weeding, harvesting and storage. Social status of a man is very much related to the size of his yam barn. While the area under yam remained static in some countries, in Cameroon, for example, it increasing during the past decade, while that of cassava has generally increased rapidly during the same period (Coursey, 1982; IITA, 1986). Not only is cassava an acceptable substitute for yams but its labor and soil fertility requirements are much less. Therefore with increasing population and subsequent land area constraints, cassava cultivation is favored over yam. The two crops are focused on in this review.

TRADITIONAL, TRANSITIONAL AND PERMANENT ROOT CROPS SYSTEMS

The yam has, since its domestication in Africa, traditionally been cultivated first under shifting cultivation and later in sequences of intercropped mixtures (Coursey, 1967). Cassava, which was introduced into Africa in the 16th century by the Portuguese was also grown under similar systems and has spread so wide that Africa now accounts for 40% of the world's production (FAO, 1984). The spread of cassava, often at the expense of yams, is related to its adaptation to marginal soils (some too poor to support other crops), its resistance to drought, the easy and inexpensive stem propagation methods [compared to yams which require tubers (also used as food)]. Cassava also has the advantage of relatively low cost of production as it requires less weedings than yam and also has the ability to store tubers (roots) in the soil for extended periods, coupled with its relative flexibility in planting and weeding times. Its potential yield may reach 75 tons/ha or 250,000 calories/ha/day (De Vries *et al.*, 1967).

Cassava and yams (and the other minor roots and tubers such as cocoyams) are, in Africa, produced mainly by small-scale farmers with limited resources on fragmented farm sizes, 70% of which rarely exceed two hectare (Okigbo and Greenland, 1976; Nweke *et al.*, 1988). Their system of cropping, which illustrates man's struggle with his environment, and from which he obtains sustenance, evolved from shifting cultivation to different stages of more intensive multiple cropping systems (Figure 1).

SHIFTING CULTIVATION AND BUSH FALLOW SYSTEM

This food production system in which a short (1-2 years of crop) is followed by a long (6 or more years) of fallow is extensively practiced in the root and tuber crop producing zones of Africa (Nye and Greenland, 1960; Okigbo and Greenland, 1976). Simple tools, usually machetes and axes, are used to clear forests and/or grassland vegetation, allowed to dry and set on fire. Seedbed preparation methods vary with vegetation (primary or secondary vegetation), land types, crops to be grown and tradition. First crops after forest vegetation may be grown under a no-till system, in which case slits are made with machetes or hoes and seeds or cuttings introduced into the soil. If yam is planted under a no-till system, soil from holes are mixed with fresh organic matters and returned to the holes prior to the sowing of the seed yams. The yam seedbed at sites likely to be inundated may be on mounds differing in size, depending on the likely level of inundation anticipated (Figure 2, Plates 1 to 4). Yam, cassava, cocoyam, maize, rice, leafy vegetables (e.g., African spinach, cocorus) and fruit (e.g., okra, melon), and grain legumes are usually intercropped in complex mixtures. Usually there are one or two crops of major importance to the farmer: the base crops. The other crops may be included for emergency incomes (vegetables), hungry season crop (green maize-on-the-cob), or to supplement family diets (vegetables, grain legumes). The number of crops in the mixture may vary from 5 to as many as 50 (Okigbo, 1971). Degree of complexity varies from highly complex in compound farms to a simple mixture of a few crops, as locations of farms are farther away from the homestead (Nwosu, 1973; see Plate 5).

A loose distinction between shifting cultivation and bush fallow systems lies in intensity of cropping. Shifting cultivation relies entirely on natural fallow for soil nutrient regeneration; it is ecologically stable at low populations because enough spare land is available to permit extended fallow periods. At high population pressures, cultivation period is lengthened while fallow period is correspondingly reduced. Consequently, the system breaks down due to loss of soil fertility and increased erosion hazards. As sedentary agriculture developed, permanent homesteads were constructed and man lay ownership to land around his homestead.

THE PLACE OF ROOT CROPS IN TRADITIONAL SYSTEMS

Cassava is grown mainly for human consumption in Africa with 20°N and 20°S latitudes under a wide range of environments and cropping systems, ranging from shifting cultivation to bush fallow systems of various durations (Figures 1a, 1b and 1c; Okigbo and Greenland, 1976; Doku, 1967; Ezumah and Okigbo, 1980). It is usually the last crop in a rotational system often harvested from fields that have been under fallow – unweeded before it reverts to the alternating fallow phase. It is invariably grown in mixture with other crops which include yams, maize, cocoyams, sugarcane, plantain, beans, cowpeas (*Phaseolus vulgaris*), Egusi (*Vignia unguiculata*), melons, and assorted vegetables.

Yams are grown as the first crop after a fallow period, again in mixtures. Thus in the traditional setting of Africa, cassava, yams and cocoyam production systems are similar because they are part of the subsistence operations whose scale of production is limited by the drudgery of manual labor, lack of modern inputs, diseases and pests, obstacles in wide adoption of improved technologies attributed to the mixed cropping system, and limitation of knowledge of client farmers. The commonly observed crop combinations are yam + maize + cassava; cocoyam + plantain + maize + cassava; yam + cassava + pigeon pea; cassava + maize; cassava + peanut. There is also the poorly developed monoculture based on (a) yam or (b) cassava. The monocultural systems contributed very little in total production of these crops in Africa (Okigbo, 1978; Nwosu, 1973; Ezumah and Okigbo, 1980).

The traditional African farmer seems to know the limits of the productivity of his land. Shifting cultivation as practiced in Africa was an advanced soil conservation and management system which was popular at the time, blending with the social structures of the people. Viewing and Wims (1973) discussed an attempt in which efforts were made to eliminate the usual fallow period of 10-20 years in the Kilombero Valley of Southeastern Tanzania. Permanent agriculture was imposed by substituting fallow with heavy N, P, K, line and cattle-dung fertilization. Common crops grown are cassava, maize, rice and soybeans. Crops used in the experiment were rice, maize and soybeans. Yields were almost reduced to zero after six years in the NPK-treated plots, but liming and cattle dung in addition to NPK improved yield. Availability of cattle dung at 30 t/ha was the limiting factor, leading the authors to conclude that shifting cultivation in the way it is "··· practiced by the farmer today is still the best cropping system on the groundwater laterite of Southern Tanzania". This discouraging result seems to echo the observations of Nye and Greenland (1960) as cited by Roch (1973), in which they emphasize that "··· after a quarter of a century of experiment in the African tropics we have failed to introduce to the forest regions any method of stable food production superior to the system of natural fallowing used in shifting cultivation".

CASSAVA AND YAM IN TRADITIONAL MIXED CROP SYSTEMS

Plants as food have been sought by man, first in the wild from where he gathered them, later under his protection in the wild, and finally as cultivated crops. The food acquisition habit is closely related to the peoples' eating habits (Rindos, 1984). Yams, specifically *Dioscorea rotundata*, *D. caynensis* and *D. dumetrum*, which are indigenous to West Africa, were probably domesticated 3,000 to 2,000 B.C. (Coursey, 1976). A consumption pattern must have been acquired by chance. Human beings might not have found *raw* yams palatable but for the fact that yam grubbed up by the elephant, wild pigs or other forest animals (tamed by man about 58,000 B.C.) got roasted in the bush fire. In that form, yam became so tasty that man protected the plant, first in the wild, then as replacement planting in the forest (Rindos, 1984), later in rubbish dumps near settlements (Shaw, 1972), and finally under cultivation to ensure reliable, table food supplies. Other crops, both introduced and indigenous, which permitted or enhanced the swallowing habit for starchy staples common in West African food, may have been domesticated with yam. Many of these crops are used as additives, compliments or replacements in preparing yam dishes, e.g., fluted pumpkins (*Telfaria occidentalis*), okra (*Abelmoschus esculentus* (L) Moench) and Elephant Grass (*Pennisetum purpureum*); or as replacements or complements, e.g., cassava from Brazil, sweet potato, cocoyams and introduced yams from China (*D. esculenta*).

Both cassava and yam have very high production potentials when unhindered by agroecological conditions or by technical environment of growth. Thus cassava cultivars well adapted to acid or nonfertile soils are available to subsistence farmers (Edwards and Kang, 1979). These cassava cultivars are much more valuable now that land is increasingly becoming scarce, the available arable land being degraded under sedentary and continuous cropping. In this regard, mixed cropping with cassava and other long duration crops such as yams are generally preferred by the farmer in the tropical environment because:

(a) Intercropping has the yield advantage over monocropping because the total productivity of two or more crops grown together is usually higher than that from single cropping of each of the components (Willey, 1980; Trenbeth, 1976).

(b) The growth environment of crops is improved; thus soil temperature, moisture level and pest situation may be more favorable for crop growth (IITA, 1976; Lectine, 1978).

(c) Rapid and extended vegetative cover by the combined crop association results in better soil erosion control (Aina *et al.*, 1979); more efficient nutrient utilization in the soil profile may be achieved (IITA, 1985).

(d) For subsistence farmers who depend upon their physical labor for crop production, cultural practices which enable a distribution of labor requirements over time may gain wide acceptance. This is so for the cash-starved cassava and yam system where labor alone takes up to 60-70% of the paid production input (Nweke *et al.*, 1967).

To be advantageous, a specific intercropping system should be such that competition between the crop association is reduced to a minimum. Reduction in such plant interaction may be achievable by the following means:

(i) Ensuring complementarity by growing crop varieties in association which make demands on growth resources at differing times while retaining the diversity of crops required by farmers: varietal complementarity (Willey, 1979).

(ii) Growing component crops whose adaptation to growth resource demands is physiologically different: physiological complementarity.

(iii) Using spatial arrangements, populations and planting patterns which minimize competition and ensure optimum yield: temporal complementarity (Willey, 1979).

Each of these three aspects of complementarity is briefly reviewed.

Varietal Complementarity

Cassava, like yam, is slow growing at initial stages (during the first six weeks), as illustrated by the development of a leafy canopy of cassava (Figure 3).

Ground coverage by leaves is not achieved at these early stages, during which weeds are serious problems (Moody and Ezumah, 1975; Akobundu, 1980). By intercropping with fast-growing annuals, better ground coverage is achieved and the weed problem is reduced (Ikeorgu, 1983; Leihner, 1980; Ikeorgu *et al.*, 1989). Under such an intercropping system the yield of the major crop, cassava, may not be adversely affected by the subsidiary crops and the total output of the system may be higher (Tables 3 and 4). As illustrated in Figure 3, with the leaf area development of component crops in the cassava intercrop system, which also parallels the biomass production, cassava growth is very slow during the first three months. These were the months of rapid growth and development of melon (*Colycinthis* spp.) and maize (*Zea mays*), while okra (*Abelmoschus esculentus* (L) Moench) was less rapid. Further varietal complementarity between long duration crops such as cassava and short season annuals is shown by a complex mixture of cassava with maize, okra and cowpea (Table 5). The residual correlation matrix shows very low, nonsignificant negative or positive correlations between these crops and cassava, indicating that any adverse competitive interaction with cassava was not reflected in its root yield. The data suggest that cassava eventually recovered from such competitive effects during the long growing season following the removal of the annual crops from the intercrop environment.

Certain plant types, e.g., upright leafed maize (Kawosoke), transmit more light through their canopies than the more leafy, late maturing maize such as TZPB. This fact is illustrated by the difference in light transmitted to associated cassava through the maize varieties at two populations (30,000 and 60,000), which was higher through Kawosoke than through TZPB (Figure 4; IITA, 1984).

Similarly, sparse-canopy, early-maturing Pool 16 maize intercropped with cassava facilitated higher intercrop maize population than the spreading, late-maturing TZSRW (Figure 5). Etiolation of cassava stems, which eventually causes stem lodging and reduction in root yield (Figure 6; IITA, 1984), is directly related to maize architecture and population (Tables 6 and 7). These morphological effects of intercropping on component crop species in the systems need to be borne in mind when selecting crops for intercropping systems. Though the cassava in mixed systems may have enough time to recover completely from the effects of competition at early stages by the intercrop components, irreversible effects such as lodging of etiolated cassava may be induced at high populations of subsidiary crops, e.g., maize in the mixture, resulting in reduced yield (Figure 6) and failure of cassava to recover from intercrop competition effects (Table 7) even when post-maize growth periods of cassava (245 days) are much longer than the cassava + maize association period (120 days).

Temporal Complementarity

Temporal complementarity to reduce plant interaction in intercrop situations implies manipulation of planting patterns, spatial arrangements of plants and component populations in a given system in order to minimize interactions and achieve better overall production. With respect to a cassava- and yam-based system in humid Africa, rotations based on patterns in which high nutrient-demanding crops such as maize and yams are followed by less nutrient-demanding crops such as cassava are common. Often, a crop which has a high nutrient requirement is followed by crops which have a low nutrient requirement, e.g., sorghum or guinea corn followed by nutrient-building crops such as food legumes, e.g., pigeon pea (*Cajanus cajan*). The nutrient-building crops are again followed by high nutrient-demanding crops such as yam and maize before reverting to less nutrient-demanding crops as cassava and finally to fallow. It is pertinent to note that mixtures of crops rather than monocroppings are rotated (Okigbo, 1980; Ezumah and Okigbo, 1980).

Crop mixtures may be rotated in relays, for example, maize or sorghum in which cowpeas are usually relayed in the subhumid tropics (Barker, 1979; Muleba and Ezumah, 1985). Rotation may involve all crops established simultaneously, e.g., cassava + pigeon pea. The complexity of crops established and relay or rotation pattern depend very much on the prevailing rainfall. As rainfall decreases to less than 500 mm per year, relay cropping becomes more important since the total rainfall and its duration is too short to permit two long-duration crops with a high demand for moisture to be grown (Kassam, 1981; Muleba and Brockman, 1985).

Temporal and varietal complementarity of crops in mixture may be achieved by establishing not only crops of contrasting but compatible growth habits, but also by manipulating their populations to levels that ensure optimum yields of the major crops. Figure 7 shows that yield of maize intercropped with cassava is significantly reduced by increasing the populations of associated okra and cowpea. Not only is maize yield reduced by high subsidiary crop populations but its reduction is greater in the absence of fertilizer.

As the spatial arrangements of intercropped cassava and maize approaches a square pattern, their yield increases over a rectangular pattern (Table 8). Not only does light intercepted through the maize to the cassava canopy increase (Figure 8a), but also a linear relationship was established between light intercepted (%) and cassava root yield (Figure 9; IITA, 1981). By using cassava with strap leaf more light can be transmitted to early-maturing crops, making it possible for these crops to be grown successively through cassava (Lawson, 1988).

Physiological Complementarity

A common occurrence in compound farm situations is a multi-story plant system in which protected trees interact with other crops in prevailing food systems (Plate 5). In Plate 5 a structural tree, the Iroko (up to 30 m tall), grows in the same farm as other protected useful trees (e.g., oil bean *Pentacleuthra macrophyllum*, etc.), and at lower strata are plantains, coconuts and *Raphia* spp; at a still lower layer one finds staked yams, cassava and maize, and at the lowest level are cocoyams and leafy vegetables. A lesser number of tree plants and lesser complexity in crop association are observed as one moves to farms farther away from homesteads (Plate 6; Nwosu, 1973). This temporal arrangement in space also involves physiological complementarity because crops known to be tolerant to shade, such as the cocoyams (*Colocasia esculenta* and *Zanthosoma sagittifolium*) and the leafy vegetables such as African spinach (*Cochorus olitorus*), are usually grown under shades (Plate 7). Tallest staking materials, sometimes up to 10-15 m, may be used to support yams under such situations. Without staking, yam yield in such multistory associations is usually so low that it is not a practice advocated by farmers.

PESTS AND DISEASES IN ROOT CROP MIXED SYSTEMS

Since the rainfall pattern usually permits growing of long duration crops such as cassava and yam in sequences or in association with short duration crops such as maize, cowpeas, and vegetables, the interrupted availability of crop hosts during the whole year influences the level of inoculum. The warm to humid cycles of weather favor some diseases, e.g., cassava bacterial blight (*Xanthomonas compestris* pv *manihotis*) and fungi (Lawson and Terry, 1984; Persley, 1978). The bacterial blight of cassava manifests itself with angular leaf spot phase which is observed soon after the first rains. It develops and causes wilting and tip dieback of cassava as the rainy season progresses. Persley (1978) observed a reoccurrence of the angular leaf spots from cassava cuttings left on the field for the five months of dry weather soon after the first rains in the following wet season, an indication that the casual organisms survived the long dry season.

Seasonal variation of the pest situation is illustrated by the mealybug incidence of cassava, whose abundance is high during the dry season. Re-emergence of the mealybug during the succeeding dry season is shown by their almost immediate reappearance on stunted leaf buds, indicating survival through the wet season (IITA, 1984; Nwanze *et al.*, 1978). Nyiira (1977) reported fluctuations in the green spider mite (*Monenychellus tanajoa* Bonder) with changes in temperature and rainfall. The environmental factors may reduce the host population and correspondingly reduce predator survival. Effect of rainfall may be (a) direct physical destruction of pests (mites) and (b) by depriving food to predators, causing their migration. Survival of predators throughout the season in alternate hosts has been suggested by Nyiira (1977). The hosts observed were *Euphorbia prunifolia*, a hedge plant in Uganda, and *Manihot glasiovii.*

An effect on host survival, notable under an intercropping situation, which is not widely documented for plant communities in the tropics, is the relationship between multiplicity of plants in complex crop mixtures and protected trees in multistory association, with their associated disease-pest complex. Although IITA (1978) reported lower incidence of maize borer under intercropping with cassava than sole, and Arene's (1976) report on reduced bacterial blight of cassava by intercropping, the picture remains complex and uncertain, probably because the factors which influence both disease and host under intercropping systems are numerous.

WEED AND EROSION CONTROL

One area in which the results are certain is weed control. Intercropping with the low growing spreading crops such as melon (*Citrullus lunatus*) and sweet potato could replace two-three weedings in yam + maize or cassava + yam systems (Akobundu, 1987b). Legumes used as live mulches gave excellent weed control; however, their utility in root crop systems needs to be studied further, in view of the need to disturb soils in order to retrieve the subterranean tubers. Only one weeding is required in complex mixtures of cassava + cowpea + maize with or without okra, provided the plant establishment was adequate (IITA, 1984).

Farmers in Africa recognized the potential of live mulch and are indeed practicing its use by selectively weeding their fields according to their classification of weeds. Thus Pierson (1973) reported weed classification as follows:

(a) those harmful to the standing crop,

(b) those indifferent to the present crop but helpful to the next,

(c) those which grow late and which are slow and helpful to all crops.

Weeds in the first category are usually identified and removed while the others may be left. In addition to having an intercrop fallow, a farmer thus has to leave in place "live" mulch which reduces labor required to weed his field in addition to checking erosion. Clean weeding is therefore not advantageous in that it exposes the soil to erosion hazards. The African farmer knows this.

Some of the legume crops suitable as cover crops and essentially for weed control include *Calapogonium mucumoides*, *Centrosema pubescens*, *Dolichos hosei*, *Glycine javanica*, *Indigofera specata*, *Pueraria phaseoloides*, *Stylosanthes gracilia*, etc. (Okigbo and Lal, 1977). Cover crops may be managed in different ways. They may be turned under and used as green manure in conventional tillage systems or killed with contact herbicides, such as paraquat, and used as sod in no-tillage or strip tillage systems. Lal *et al.* (1979) reported significant improvement in physical and chemical characteristics of the soil attributed to legumes and grass cover in an alfisol in Nigeria. Both organic matter and nutrient levels were higher under sod, a result of erosion control. Cassava root yields, when some of these cover crops were used as sod-mulch in a zero tillage system, were superior to control (Lal *et al.*, 1977; Table 9). Two grasses (*Brachiara* and *Melinis*) and two legumes (*Pueraria* and *Stylosanthes*) as cover crops gave excellent soil protection and cassava root yields.

YAMS IN MODIFIED ENVIRONMENTS

Yams and cassava are normally adapted to similar environments, with yams being more suitable in the savannah (subhumid) ecologies. Of the two major yam species grown in Africa, *D. caynensis* and *D. rotundata*, the former demands richer soil and is more adapted to humid environments, while the latter thrives better in the drier subhumid environment (Onwueme, 1978). Both are, however, grown in both humid and subhumid environments. As soil nutrient status declines with increasing human population and cropping intensity, *D. rotundata* may gain ground in the humid environments.

Yam growers in Africa generally prefer large tubers which require large sets as planting materials, large mounds, staking and careful harvesting by digging with hand tools – since bruising results in loss of the yam by rotting in storage. Staking is achieved by individual single poles, by poles arranged in a pyramid, with a trellis, and on living trees. Trees, preferably legume hedges, can be manipulated in an alley cropping system so that yam vines may twine on them (Figure 10; Plate 8).

The direct effect of staking are better leaf display, increase in leaf area and leaf area duration, and subsequently higher tuber yields (Lyonga, 1982; Enyi, 1973). Positive correlation was observed between leaf number, leaf area and tuber yield at 25 weeks. Better response to N and K, the most important nutrients, not only for cassava but also for most tropical root crops (Miege and Lyonga, 1982; Tomo *et al.*, 1980; Onwueme, 1978) is attained. From Table 10b it can be seen that staking significantly increased yam tuber yield, especially if K and N are added. Enyi (1973) reported a coefficient of determination of 94% between leaf area duration of yam and tuber yield. Increasing height of staking has also been shown to result in higher tuber yield (Table 10b), evidently reflecting the effect of better leaf display.

Most farmers in West Africa grow yams on mounds. Size of mount is related to drainage and different crops in complex mixtures with yams are positioned on mounds according to their microenvironmental requirements. Thus, as illustrated in Figure 11, yams, maize and cassava which do not tolerate flooding are placed high on the mound while rice and cocoyams are at the base of the mounds. Short season crops which may be harvested prior to any flooding incidence, such as vegetables, are placed between the yams and the rice (Okigbo and Greenland, 1976).

Mounding or heaping of soil in various sizes in which the yam sets are planted is an integral part of a modification of the environment for yam growth. Ferguson and Gumbs (1982) showed that soil compaction to bulk density of 1.2 g/cm^3 and 1.6 g/cm^3 from 1.1 g/cm^3 significantly reduced tuber yield of *Dioscorea alata*. Provided the soil is loosened, ridging (or mounding) appear to have no effect on yam tuber yield. Lyonga (1982), working with *D. rotundata* in the Cameroons, found no effect of ridging on tubers except a slightly higher number of damaged tubers from that planting (Table 12). Loosening the soil is thus an integral part of yam cultural practices.

Kang and Wilson (1981) showed that mounding resulted in significant tuber yield increases and that soil type in the three-soil series in Southwestern Nigeria had little effect on yam tuber yield (Table 22). The soils' gravel content ranged from nil to 45% at the 15-30 cm depth. Addition of fertilizer gave the highest tuber yield increase of only 6%, while mounding resulted in about 25% root yield increase.

STABILIZING FACTORS IN ROOT CROP-BASED CROP MIXTURES

Continuous Crop Cover: Erosion hazard attributed to the torrential rainfall in tropical Africa accounts for rapid loss of top soil, higher rate of leaching, loss of soil fertility, and subsequently reduce productivity of the land (Franzen *et al.*, 1983; Juo *et al.*, 1979; Lal, 1976). The long duration root crops, especially cassava, provide sustained crop cover which minimizes the period of direct impact of rain on soil and thus reduces erosion (Garrou, 1969; Aina *et al.*, 1978). Favorable microenvironmental benefits attributed to a mixed crops system include cooler soil temperature, higher water retention attributed to the "mulching effect" of vegetative cover, and a more favorable temperature for microorganic development. In intercrops with legumes, for example, the lower temperature favors activity of nitrogen-fixing rhizobia (Whitney *et al.*, 1985). A direct favorable microorganic effect is that of mycorrhiza of cassava, which is more active at low P levels and cool temperatures. Unavailable P in soil is released by mycorrhiza (Howler, 1980; Kang *et al.*, 1982), a situation which favors component or following crops in intercropping systems with cassava.

Cassava + maize has been continuously intercropped in an alfisol in Southern Nigeria for six years without significant reduction in cassava or maize yield. This again is attributed to (a) continuous vegetative cover provided by the intercrop system, (b) high organic matter and residue generated by the continued crop species estimated at seven tons dry weight per hectare, and (c) activity of microorganisms (Ikeorgu, 1983; IITA, 1981).

Yam + maize + vegetables in compound refuse followed by cocoyam + maize + vegetables (plus refuse) rotation is the most common continuous cropping sequence in Southeastern Nigeria (Okigbo, 1978). This system has persisted year after year, sometimes for more than 40 years. No inorganic fertilizer has been used but there have been "bad" years followed by "good" years – events attributed more to unfavorable rainfall, the unusual spread of diseases, or pests such as cutworms.

The observations on compound mixed root crop systems lends hope to the more recently developed "Alley Cropping System" in which crops or mixtures of crops are grown between alley hedges (Plate 8). With the hedges as sources of organic matter and nutrients, mixtures of crops can be continuously grown between the alleys (Figure 1; Kang *et al.*, 1985).

The concept of agrosilviculture is increasingly popular and offers great hope for continuous land use. Onwubuya (1987) reported that the fresh fruit yield of the oil palm (*Eleas guinensis*) was unaffected by the relatively shorter (less tall) food crop intercrops, e.g., cassava, maize and pineapple, compared with the tall crop species such as plantain, when these were established as intercrops with the oil palm (Table 13). The total revenue from the entire system increased by including food crops, especially cassava and cocoyam. This system is viable only during the early phases of the oil palm growth, prior to complete canopy coverage. Spatial arrangements of the oil palm which permit longer indefinite intercrop and/or management systems are desirable.

A more favorable environment for yam and cassava growth and development has been reported under plastic mulching at IITA (1976). Plastic mulching not only completely replaces staking but extends the leaf area duration by preventing direct contact between the yam foliage and the soil, which is the main source of diseases attacking yam leaves (Plate 9). Higher moisture retention and lower soil temperature have been reported under the mulching (Lal, 1977) and higher insolation through reflected light on the plastic mulch to yam leaf surface is presumed (IITA, 1986).

SUMMARY

Yam and cassava are very important root crops grown in Africa south of the Sahara. Yam, which is limited to the yam zone of Western Africa, contributed in culture and development as well as the food habits of Western Africans. Cassava, introduced into Africa in the 16th century, readily fitted in the prevailing production systems, a factor attributable to its wide ecological adaptation, inexpensive production methods and the fact that it is a ready substitute to yam and other already existing starchy pastes in Africa. The starchy staples (including cassava) are by far the dominant sources of food energy in Western and Central Africa.

The production systems of the root crops ranged from the now-outmoded shifting cultivation to various transitional multiple cropping systems. Intercropping is dominant. Instead of the classical sole crop rotation system operating in Europe, mixtures of crops are usually rotated. Development of continuous cropping systems, as classically known in temperate climates, derives impetus from the success of compound farm systems which rely heavily upon household refuse. Therefore organic matter, together with any inorganic nutrient infusion into the system, is a prerequisite to resilience of root crop-based mixed crop systems. This is why the alley cropping system depends upon generation, success of hedgerow, and sustenance of organic matter biomass for soil enrichment by the hedgerow.

REFERENCES

Table 1a. Root crops grown in tropical sub-Sahara West Africa.

Major plant group		Common wave	Botanical name	Place of origin
Monocotyledone	*Dioscoreacea*	White guinea yam White yam	*Dioscorea rotundata* Pior	West Africa
		Yellow guinea yam Yellow yam, Attoto yam	*Dioscorea caynensis* Lam	West Africa
		Water yam, Winged yam	*Dioscorea alata*	S.E. Asia
	Araceae	Old Cocoyam, Taro Eddoes, Dasheen	*Colocasia esculenta* (L) Schott	S.E. Asia (Polynesia?)
		New cocoyam, Tania	*Xanthosome sagittifolium* Schott	Central and South America
Dicotyledonae	*Euphorbiaceae*	Cassava, Manioc Yuka, Mandioca, Tepioca	*Manihot esculenta* Grantz	Brazil
	Convoluvlaceae	Sweet potato Batata	*Ipomoea batatas* (L) Pior	Central and North America
	Solanceceae	Irish potato German potato	*Solanum tuberosum* L.	Andean South America

Table 1b. Major food yam species (from Coursey, 1978, p. 191).

	Africa	Asia	America
Major economic spp.	*D. rotundata* Poir[ab] *D. caynensis* Lam.[b]	*D. alata* L.[a] *D. esculenta* (Lour.)	 *D. trifida* L.
Secondary spp.	*D. bulbifera L.*[c]	*D. bulbifera* L.[c]	*D. convolvulacea* Cham. et. Schlecht
	D. preussii Pax. *D. praehensilis* *D. sansibarensis* Pax. *D. dumetorum* (Knuth) Pax.	*D. hispida* Dennst. *D. pentaphylla* (L) Benth. *D. nummularia* Lam. *D. opposita* Thunb.[d] *D. japonica* Thunb.[d]	*Rajania cordata* L.

[a] These species are true cultigens, unknown in the wild.

[b] Some authors regard *D. rotundata* as only a subspecies of *D. caynensis.*

[c] *D. buloifera* is the only species common to both Africa and Asia. The African form is, however, quite distinct and is sometimes regarded as a separate species, *D. latifolia* Benth.

[d] These are both often known as *D. batatas* Decne and are temperature species native to China and Japan.

Table 1c. Major root crops in sub-Saharan Africa.

Region	Country	Cassava	Yam	Cocoyam	Sweet potato
West Africa	Benin	600	680	12	34
	Cameroon	625	400	812	130
	Ghana	1,823	715	670	–
	Guinea	628	78	34	78
	Guinea Bissau				
	Ivory Coast	804	2,256	306	30
	Liberia	307	16	17	9
	Nigeria	11,090	17,625	1,842	254
	Sierra Leone	99	–	1,842	254
	Togo	385	472	21	7
Total West Africa		16,362	22,242	3,733	555
Central Africa	CAR	904	194	534	–
	Congo	626	13	22	13
	Eq. Guinea	53			34
	Gabon	253	51	54	1
	Zaire	14,029	168	27	311
	Burundi	430	6	100	480
	Rwanda	573	5	31	987
Total Central Africa		16,868	443	287	1,826
Total sub-Saharan Africa		33,230	22,685	4,020	2,381
AFRICA		49,116	22,731	4,026	5,056
Sub-Saharan as % AFRICA		67.7	99.9	99.9	47.1

Table 2a. Indigenous root and tuber crops of Africa.

Scientific name	Common name	Distribution and status
Amorphophallus spp.	Elephant yam	Humid and subhumid tropical Africa – wild
Anchomanes difformis	–	Tropical Africa – wild
Cyrtosperma senegalense	–	Tropical Africa – wild
Dioscorea bulbifera	Earial yam	Tropical Africa – cultivated and wild*
Dioscorea dumetorum	Three-leaved yam	Tropical Africa – cultivated in Eastern Nigeria
Dioscorea rotundata	White guinea yam	Humid and subhumid areas of West Africa – cultivated***
Icacina senegalensis	False yam	West and Central Africa – wild
Plectranthus esculentus	Risga	Tropical Africa – cultivated*
Solenostemum rotundifolius	Hause potato	Tropical Africa – cultivated*
Sphenostylis stenocarpa	African yambean	West and Central Africa – cultivated
Stylochiton warneckei	–	Tropical Africa – wild

* Of minor local importance in parts of West Africa.

** Of limited local importance in West Africa.

*** Of major regional or local importance in West Africa.

Table 2b. Root crops production in tropical sub-Saharan Africa.

Crop	Region	Production (tons)	Africa (Total)	Africa (%)	African Sub-Saharan (%)
Cassava	West	16,362	49,116	33.3	
	Central	16,868	49,116	34.3	
	–	–	–	–	67.6
Yams	West	22,249	22,731	97.9	
	Central	489	22,731	2.1	
	–	–	–	–	95.6
Sweet potato	West	555.2	5,056.3	11.0	
	Central	1,826.2	5,056.3	11.0	
	–	–	–	–	47.1

Table 3. Average yields (tons/ha) of cassava/maize/okra/melon (2-yr. mean).

Crop mixture	Cassava	Maize	Okra	Melon
1. Sole cassava (Ca)	25.3	–	–	–
2. Cassava + okra (OK)	23.1	–	0.4	–
3. Cassava + melon (Me)	22.2	–	–	0.32
4. Cassava + okra + melon	19.2	–	0.63	0.21
5. Cassava + maize (Ma) + melon	18.2	2.63	–	0.71
6. Cassava + maize + okra	18.0	2.7	0.15	–
7. Cassava + maize	17.9	3.1	–	–
8. Cassava + maize + melon + okra	17.3	2.6	0.20	0.17

Table 4. Naira returns from cassava/maize/okra/melon intercrop.

Crop mixture	Cassava	Maize	Okra	Melon	Total	Net
1. Cassava/maize	2,685	1,550	–	–	4,235	3,150
2. Cassava/maize/okra	2,730	1,315	238	–	4,283	3,127
3. Cassava/maize/okra	2,595	1,300	180	238	4,313	3,020
4. Cassava/maize/okra	2,700	1,350	135	–	4,185	2,782
5. Cassava	3,795	–	–	–	3,795	2,710
6. Cassava/melon	3,330	–	–	448	3,778	2,663
7. Cassava/okra/melon	2,880	–	567	294	3,741	2,626
8. Cassava/okra	3,465	–	360	–	378	2,710

1 $US = $\pm$8.5 Naira.

Table 5. Residual correlation matrix of four crop complex mixtures (from variance–covariance matrix).

Cowpea	–	1.00			
Maize	–	0.06^{ns}	1.00		
Okra	–	0.32^{ns}	0.01^{ns}	1.00	
Cassava	–	0.33^{ns}	0.19^{ns}	0.13^{ns}	1.01
		Cowpea	Maize	Okra	Cassava

Table 6. Effect of maize variety on agronomic characteristics of cassava TMS 30572 at maize harvest.

Maize variety	Plant height (cm)	Stem girth (cm)	Internode length	Branches /plant	Leaves /plant
IK84A–2135	98.7	1.5	16.6	3.1	48.6
IB84A–203	108.3	1.6	17.7	3.7	53.7
TZSR–Y–1	98.8	1.5	18.1	2.3	43.6
1368 × 5012	110.4	1.6	18.3	3.4	52.1
9450 × 4001	103.4	1.5	18.8	2.5	45.1
MEANS	103.9	1.5	17.9	3.0	48.6
LSD (5%)	15.3	ns	1.3	ns	ns
C.V. %	7.8	4.0	4.0	4.0	1.9

Table 7. Effect of maize population on plant characteristics of cassava at maize harvest.

Maize population plant/ha	Plant height (cm)	Internode length	Stem diameter (cm)	Branches /plant	Leaves /plant
10,000	92.7	13.7	1.57	3.8	57.4
20,000	98.5	15.5	1.56	3.2	50.4
40,000	104.0	16.9	1.56	3.2	51.7
80,000	111.6	20.3	1.55	2.6	45.4
160,000	112.8	23.2	1.48	2.3	38.4
MEAN	103.9	17.9	1.54	3.0	48.7
LSD (5%)	7.08	1.1	0.07	0.70	5.6

Table 8. Effect of planting geometry and relative plant population on cassava yields in maize/cassava crop mixtures (1980-1981).

Treatment	Plant density (maize/cassava)	Plant/placement (maize/cassava)	Yield* (t/ha)
1	25/12.5	80 × 50/80 cm	
2	25/12.5	160 × 25/50 × 100 cm (double rows)	23.96de
3	25/12.5	25 − 75 80/80 × 100	19.25bc
4	40/10	50 × 40 (double rows)/125 × 80	12.44a
6	0/12.5	− /80 × 100 cm	25.31d

* Values with a common letter are not significantly different at 0.05 according to Duncan's test.

Table 9. Cassava yield (t/ha) as affected by cover crops (after Lal, Wilson and Okigbo, 1977).

	Cassava root yield
Cover crops	
Panicum maximum	3.50
Setaria sphacelata	7.90
Brachiaria ruziziensis	17.39
Melinis minutiflora	18.85
Legumes	
Centrosema pubescens	15.01
Pueraria phaseoloides	19.49
Glycine weightii	14.12
Stylosanthes guyanensis	19.83
Control	8.05
LSD (0.05)	2.53

Table 10a. Effects of N, K and stating on bulking rate of yam tubers (kg/ha/week).

	Unstaked	Staked
K_0	10,554	2,222
K_1	1,280	2,459
N_0	1,141	2,184
N_1	1,193	2,497
	SE	± 98

Table 10b. Effect of height of stakes on yam yield (Lyonga, 1982).

Height of stake "m"	Yield ton/ha	% No stake
3.0	20.3	133
1.5	17.4	114
No stake	15.3	100

Table 11. Effect of land preparation methods on yam yield.

Observation	Flat beds	Ridges
Total tuber t/ha	17.02	15.70
Wt. damaged tuber t/ha	1.09	0.03
Wt. usable tuber t/ha	15.93	15.67

Table 12. Effects of mound size and fertilizer on average tuber yield (tons/ha) in three locations[†].

Mound size	Dimensions (cm) Height	Diameter	No Fertilizer	+	Fertilizer		
Flat	0	1500	7.83 (69)		7.43	(66)	(67.5)
Small mound	13	50	8.50 (75)		9.13	(81)	(78.0)
Medium mound	24	100	9.40 (83)		10.00	(69)	(86.0)
Large mound	30	150	9.46 (84)		11.30	(100)	(92.0)
		× (77.8%)			(84)		

† Figures in brackets are % yields expressed against yield observed with large heaps and fertilizer. (Source: Kang and Wilson)

Table 13. Production cost, total revenue and oil palm fresh fruit bunch yield per hectare from oil palm-food crop system (Onwubuya and Eneh, 1987)

Treatment	Food crop revenue 1978-1980		Mean ffb yield 1983-1985 kg/ha
	Net revenue N	Net revenue– cost of establishing oil palm	
Oil palm			8,044
Oil palm + maize + pineapple	4,212	3,256	9,092
Oil palm + cassava	5,294	4,338	5,538
Oil palm + yam	1,011	55	7,987
Oil palm + cocoyam	3,084	2,128	8,517
Oil palm + plantain	2,253	1,297	5,040
Oil palm + yam + cassava	986	30	7,461
		LSD, $P < 0.50$	2,514