Tropical Root Crops
Their Improvement and Utilization

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About IITA ....

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IITA seeks to develop alternatives to shifting cultivation that will maintain the productivity of the land under continuous cultivation in the humid and subhumid tropics; to develop higher yielding pest and disease resistant varieties of cowpeas, yams and sweet potatoes worldwide, and of maize, rice, cassava and soybeans in Africa, and to strengthen national agricultural research systems by a comprehensive training program and collaborative research.

IITA was established in 1967 by the Ford and Rockefeller Foundations, which provided the initial capital for buildings and development, and the Federal Military Government of Nigeria, who allotted 1,000 hectares of land for a headquarters site seven kilometers north of Ibadan.

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Abstract
In Africa, cassava, yams, sweet potato and cocoyams are widely grown by subsistence farmers and are important staples. They are the major source of energy for well over 200 million people in the continent. The leaves of these crops, except those of yams, are used as vegetables.
These root and tuber crops are well adapted to diverse soil and environmental conditions as well as farming systems. Cassava and sweet potato, particularly the former, are tolerant to drought.
The major biological constraints to increased and stable production of root and tuber crops in Africa are diseases, insect pests, nematodes and weeds. Other limiting factors include traditional agronomic practices which have not benefitted from research as well as the unavailability of appropriate storage and processing technologies.
This booklet outlines the general approaches to overcoming the production constraints for each crop and reviews the progress already made.

Introduction
Importance of tropical root crops
The major tropical root crops — cassava, yams, sweet potato and cocoyams — are widely grown and mostly used as subsistence staples in many parts of the tropics and subtropics in Africa (Table 1). They are the major source of energy for well over 200 million people in the continent (Table 2) and they account for 31 percent of the major staples produced in sub-Saharan Africa (Paulino and Yeung, 1981). The trend of production shows a steady increase of 2.7 percent per annum (FAO, 1982).

Advantages of root crops
In Africa, cassava grows from sea level to 1,800 m and from the sub-Sahel semiarid region to 25° south. Sweet potato grows from sea level to 2,300 m and between 30°N and 30°S while yams are found from sea level to 800 m and between 25°N and 15°S. Cocoyams, on the other hand, grow mostly in the lowland humid tropics (Figures 1 and 2). Root crops, except yams, grow on a wide range of soils and they can give satisfactory yields even on poor acid soils. Cassava and sweet potato grow from high rainfall areas to semi-arid regions because they tolerate drought and a wide range of soils. They also play a vital role in alleviating famine by providing sustained food supplies when other crops fail. Cocoyams, however, are best adapted to wet and inundated areas. They are also very tolerant to shade in the forest. Root crops are, in general, well adapted to diverse traditional farming systems under the different environmental conditions in Africa. These crops are highly efficient producers of

Table 1: Root crop production statistics in Africa and in the world

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area ('000 ha)</th>
<th>Yield (t/ha)</th>
<th>Production ('000 t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Africa</td>
<td>World</td>
<td>Africa</td>
</tr>
<tr>
<td></td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>7433</td>
<td>14054</td>
<td>53</td>
</tr>
<tr>
<td>Yams</td>
<td>2364</td>
<td>2476</td>
<td>95</td>
</tr>
<tr>
<td>S/potato</td>
<td>794</td>
<td>11771</td>
<td>7</td>
</tr>
<tr>
<td>Cocoyams</td>
<td>1046</td>
<td>1266</td>
<td>83</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11637</td>
<td>29567</td>
<td>39</td>
</tr>
</tbody>
</table>

%: Data for Africa are percentage of world data for respective crops.
calories compared to other food crops, particularly in the tropics. Their high efficiency as food producers arises partly from their plant architecture since strength in other parts of the plant is not needed to support bulky and heavy roots and tubers. Increase in size of the edible part need not, therefore, be associated with increased production of nonedible tissue.

Not only are root crops capable of relatively high efficiency in production of edible carbohydrate, but their efficiency for protein production is also higher than commonly realized (Table 3) (Coursey and Booth, 1977).

For example, on a dry weight basis, cassava leaf, depending on variety, contains 26 to 41 percent crude protein with a mean of 32 percent (IITA, 1974) while sweet potato leaf has 13 to 28 percent with a mean of 19 percent (IITA, 1980). On a fresh weight basis, the percentage of protein in roots and tubers appears low, but when related to dry matter content, as any nutritional calculation should be, the protein content of certain root crops such as yams and sweet

Table 2: Per caput daily caloric supply in country groups of Africa by commodity group as percent of total.

<table>
<thead>
<tr>
<th>Commodity Group</th>
<th>Equatorial Africa</th>
<th>Humid West Africa</th>
<th>East Africa</th>
<th>Semi-arid West Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root crops</td>
<td>41.4</td>
<td>29.6</td>
<td>18.6</td>
<td>19.1</td>
</tr>
<tr>
<td>Cereals</td>
<td>26.7</td>
<td>38.9</td>
<td>48.5</td>
<td>49.0</td>
</tr>
<tr>
<td>Pulses</td>
<td>4.9</td>
<td>1.5</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Fruits &amp; vegetables</td>
<td>6.2</td>
<td>7.7</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Oil crops</td>
<td>10.4</td>
<td>12.7</td>
<td>9.1</td>
<td>13.3</td>
</tr>
<tr>
<td>Livestock products</td>
<td>3.2</td>
<td>3.7</td>
<td>6.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Other products</td>
<td>7.2</td>
<td>5.9</td>
<td>9.6</td>
<td>7.7</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

Sources: FAO, ICS data files and TAC review of priorities for international support to agricultural research, Rome 1979.
potato seems to be similar to some of the grains (Coursey and Haynes, 1970). For instance, several water yam varieties contain protein up to 12 percent. White yam varieties contain 5 percent (Table 4) with fairly good amino acid composition (Table 5) although sulphur-containing amino acids seem to be rather limiting (Harvey, 1981). Despite this nutritional value, root crops are often said to be the cause of malnutrition in high consumption areas.

Table 3: Calorie and protein productivity of various food crops in West Africa (after Coursey and Booth, 1977).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Calorific production (million cal/ha)</th>
<th>Protein production (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>8.2</td>
<td>37</td>
</tr>
<tr>
<td>Yams</td>
<td>5.7</td>
<td>107</td>
</tr>
<tr>
<td>S/potato</td>
<td>7.4</td>
<td>96</td>
</tr>
<tr>
<td>Cocoyams</td>
<td>4.5</td>
<td>80</td>
</tr>
<tr>
<td>Irish potato</td>
<td>4.7</td>
<td>128</td>
</tr>
<tr>
<td>Maize</td>
<td>3.2</td>
<td>82</td>
</tr>
<tr>
<td>Rice</td>
<td>3.2</td>
<td>72</td>
</tr>
<tr>
<td>Sorghum</td>
<td>2.4</td>
<td>70</td>
</tr>
<tr>
<td>Soybean</td>
<td>0.8</td>
<td>78</td>
</tr>
</tbody>
</table>

Regardless of their obvious advantage as important staple root crops in the tropics, there has been an apparent neglect in research and development activities even when they are increasingly becoming important as industrial crops and animal feed (Okigbo, 1980). This is partly because root crops are usually considered inferior since they are cheaper than cereals and are believed to be very low in protein content. Also, people often believe in an inverse relationship between root crop consumption and standard of living. Another and more important reason is that large quantities of grains have been imported from outside the continent discouraging farmers from producing more of the locally adapted root crops. However, in recent years, there has been increasing political and scientific awareness in many countries of Africa of the importance of improving production. The great potential for root crops in contributing to food and agriculture in the
continent will be realized once people start using modern production and utilization technology. This potential has not been tapped and it is particularly relevant in view of diminishing resources, increasing population, and the ecological conditions that make root crops a logical source of carbohydrate (Haynes, 1974). For these reasons, production and utilization techniques should be developed and evaluated, and made available to farmers.

Table 4: Crude protein content (% N (d.w. x 6.25) in populations of white yam (Dioscorea rotundata) (after Harvey, 1981).

<table>
<thead>
<tr>
<th>Population</th>
<th>No. of clones</th>
<th>Mean value ± standard deviation (No. of samples)</th>
<th>Minimum value</th>
<th>Maximum value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>4.26 ± 0.54 (103)</td>
<td>3.25</td>
<td>6.31</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4.96 ± 0.73 (16)</td>
<td>3.81</td>
<td>6.25</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>5.74 ± 1.27 (9)</td>
<td>3.94</td>
<td>8.28</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>5.18 ± 0.76 (17)</td>
<td>3.94</td>
<td>7.06</td>
</tr>
<tr>
<td>4</td>
<td>81</td>
<td>4.83 ± 0.88 (81)</td>
<td>3.03</td>
<td>6.56</td>
</tr>
<tr>
<td>5</td>
<td>194</td>
<td>5.98 ± 1.00 (194)</td>
<td>3.36</td>
<td>9.01</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>6.06 ± 1.21 (29)</td>
<td>4.33</td>
<td>9.43</td>
</tr>
</tbody>
</table>

Table 5: Comparison of the amino acid composition of yams (g/16gN) (after Harvey, 1981)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>aspartic acid</td>
<td>10.5</td>
<td>11.1</td>
<td>12.7</td>
<td>9.6</td>
<td>10.8</td>
</tr>
<tr>
<td>threonine</td>
<td>3.7</td>
<td>2.9</td>
<td>3.0</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>serine</td>
<td>5.1</td>
<td>4.1</td>
<td>5.9</td>
<td>4.2</td>
<td>4.0</td>
</tr>
<tr>
<td>glutamic acid</td>
<td>12.7</td>
<td>14.1</td>
<td>13.0</td>
<td>16.0</td>
<td>14.8</td>
</tr>
<tr>
<td>proline</td>
<td>4.0</td>
<td>3.7</td>
<td>3.0</td>
<td>2.6</td>
<td>3.1</td>
</tr>
<tr>
<td>glycine</td>
<td>3.9</td>
<td>3.0</td>
<td>2.9</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>alanine</td>
<td>4.2</td>
<td>3.7</td>
<td>4.4</td>
<td>3.4</td>
<td>3.5</td>
</tr>
<tr>
<td>valine</td>
<td>4.7</td>
<td>3.8</td>
<td>4.4</td>
<td>3.6</td>
<td>3.9</td>
</tr>
<tr>
<td>methionine</td>
<td>1.7</td>
<td>1.3</td>
<td>1.1</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>isoleucine</td>
<td>3.8</td>
<td>3.2</td>
<td>3.0</td>
<td>3.0</td>
<td>3.3</td>
</tr>
<tr>
<td>leucine</td>
<td>6.7</td>
<td>5.7</td>
<td>5.4</td>
<td>5.4</td>
<td>5.6</td>
</tr>
<tr>
<td>tyrosine</td>
<td>3.2</td>
<td>2.2</td>
<td>1.7</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>phenylalanine</td>
<td>4.8</td>
<td>4.5</td>
<td>3.9</td>
<td>4.1</td>
<td>4.7</td>
</tr>
<tr>
<td>histidine</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
<td>1.6</td>
</tr>
<tr>
<td>lysine</td>
<td>4.2</td>
<td>4.6</td>
<td>4.6</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td>arginine</td>
<td>7.7</td>
<td>7.4</td>
<td>6.9</td>
<td>8.9</td>
<td>6.3</td>
</tr>
<tr>
<td>cystine</td>
<td>1.2</td>
<td>0.8</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>tryptophan</td>
<td>0.9</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>
CASSAVA

Constraints to production
In Africa, the major biological constraints to stable cassava production are diseases such as cassava mosaic (CMD) and bacterial blight (CBB). More recently, pests such as the cassava mealybug (CM) and the green spider mite (CGM), which were accidentally introduced from Latin America, are causing severe damage (Hahn, et al., 1979). In addition, traditional, unimproved agronomic practices and processing methods have seriously limited production on the continent.

Approaches to overcoming the constraints
The experience of the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria is reviewed here since 1967 when the Institute was established.

Varietal improvement
Cassava breeding with particular emphasis on CMD resistance was initiated in Tanzania by Storey in 1937 (Nichols, 1947). Storey made an interspecific cross between cultivated cassava (Manihot esculenta) and a related species (M. glaziovii) and obtained 20 F1 plants at Amani, Tanzania. The F1 plants were further backcrossed three times onto cultivated cassava. Some progenies of the backcrosses showed good promise for CMD resistance. Later, in 1956, Beck (1980) introduced into Nigeria from Tanzania the seeds resulting from Storey's interspecific crosses, raised seedlings and selected a clone, 58308, that still remains resistant to CMD (Hahn, 1980). Hahn (1980) extensively used this clone as a source for resistance both to CMD and CBB, and as a source of low cyanide in his early breeding stages between 1971 and 1973. Using the clone as a parent, he produced improved cassava breeding populations (Figure 3) from which many good selections were made under local conditions in many countries in Africa.

This rapid progress in cassava breeding at IITA is from IITA being located at an ideal site for screening breeding material efficiently for resistance to the major diseases and pests. Also, IITA's environmental conditions represent the major cassava growing areas in tropical
Africa. As a result, many improved disease resistant and high yielding varieties were released in Gabon, Liberia, Nigeria, Seychelles, Sierra Leone, and Tanzania (Zanzibar). In Nigeria, it was estimated that by 1983 the disease resistant, high yielding cassava varieties were grown on over 200,000 ha. and are highly popular among cassava farmers. By 1984, varieties were being sent out to 31 countries in Africa in tissue culture form after going through proper quarantine procedures.

From the preliminary yield trials each clone was tested for dry matter content and consumer acceptance assessed at an advanced breeding stage. A large number of genotypes were screened for low cyanide content using the picrate leaf test method. The selections were again found to have low leaf and root cyanide content using Cooke's enzymatic assay method (Cooke, 1978). Through continuous selection and recombination of the low cyanide genotypes, an improved low cyanide population (Figure 4) with high yield potential and disease resistance was developed from which many improved low cyanide clones were selected. An automated enzymatic assay method was developed to test for cyanide levels more rapidly and accurately (Rao and Hahn, 1983) using Cooke's manual method (Cooke, 1978). With this method, about 300 samples could be analysed per day under highly controlled conditions.

Sources of resistance to CM and CGM.

Figure 3. Mean yield and disease resistance scores of improved varieties since the beginning of IITA's cassava improvement program.

Interspecific crosses with cassava
were identified and incorporated into susceptible, but high yielding and disease resistant clones. Results obtained by 1984 indicated that pubescence on young apical leaves is an important factor responsible for resistance to both insect and mite pests. In addition, Singh and Hennessey (IITA, 1981) reported an antibiosis form of resistance to CM. All performance tests were carried out without fertilizers at several locations with a wide range of environmental conditions including high rainfall, sandy soil and dry savanna.

**Biological control**

Biological control trials on CM and CGM were carried out using natural enemies introduced from Latin America — the continent of origin. Promising results were obtained for CM in Nigeria with *Apoanagrus lopezi* (IITA, 1982). Natural enemies of CM were released in Zaire and Guinea Bissau. All trials were carried out in cooperation with the national governments.

**Agronomic practices**

Cassava, unlike other root crops such as yams and cocoyams, is a long duration crop (10 to 24 months) a characteristic which is sometimes advantageous and sometimes disadvantageous for agronomic purposes. This is because cassava does not allow for rapid tur-
nover in a rotation. Therefore, land cannot be released for short duration crops (2-4 months) such as maize, melon, cowpea, soybean or vegetables in a sole cropping system. However, cassava is traditionally grown in a mixture of many short duration crops. This way the farmer derives maximum return per unit of land and time using minimum inputs to get maximum food production security. Cassava is ideal for intercropping with short duration crops which reach maturity when cassava is attaining maximum leaf area and the tubers are beginning to develop (Okigbo, 1977).

**Land preparation**

With well drained, good soils cassava is normally grown on flat land. However, when soils have poor drainage as well as poor physical and chemical properties, cassava is grown on mounds or on ridges. For example, when preparing land in Zaire, heaps of dry grass and broad leaves are partially buried with the soil and set on fire (Ezumah, 1980). Mounds are then constructed by earthing up the soil. Their size varies from 75 cm diameter x 1.5 m high to 4 m x 1.5 m depending on soil conditions and water table (Figure 5). On a large mound, in Abakaliki, Nigeria, as many as 12 crop species may be grown (Okigbo, 1980).

**Shade**

In the high rainfall forest regions, cassava is often grown under shade of economic trees such as oil palm, coconut or cocoa. However, shade reduces growth. Compared to unshaded cassava, 40 percent shade reduces growth by 9

<table>
<thead>
<tr>
<th>Water Table</th>
<th>Hard</th>
<th>Loose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fertile</td>
<td>Poor</td>
</tr>
<tr>
<td>High</td>
<td>![Diagram of high water table conditions]</td>
<td>![Diagram of high water table conditions]</td>
</tr>
<tr>
<td>Medium</td>
<td>![Diagram of medium water table conditions]</td>
<td>![Diagram of medium water table conditions]</td>
</tr>
<tr>
<td>Low</td>
<td>![Diagram of low water table conditions]</td>
<td>![Diagram of low water table conditions]</td>
</tr>
</tbody>
</table>

*Figure 5. Mound or ridge site in relation to water table and soil type.*
percent while 60 percent shade reduces it by 32 percent (Table 6). Furthermore, under oil palms in Nigeria, cassava yield was reduced 74 percent and there was not even much yield increase with fertilizers (IITA, 1974).

Table 6: Effect of shade on fresh tuber weight and number of tubers of cassava (IITA, 1981).

<table>
<thead>
<tr>
<th>Shade</th>
<th>Tuber weight (kg/pl.)</th>
<th>No. tubers</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAP</td>
<td>17</td>
<td>17 25</td>
</tr>
<tr>
<td>no shade</td>
<td>1.44</td>
<td>11 12</td>
</tr>
<tr>
<td>20% shade</td>
<td>1.26 2.2</td>
<td>11 12</td>
</tr>
<tr>
<td>40% shade</td>
<td>0.91 2.15</td>
<td>11 9</td>
</tr>
<tr>
<td>60% shade</td>
<td>0.82 1.62</td>
<td>10 10</td>
</tr>
<tr>
<td>LSD .05</td>
<td>0.33 0.66</td>
<td>3 3</td>
</tr>
</tbody>
</table>

Soils
As human population increases people tend to grow more cassava because it is a highly efficient carbohydrate producer and performs relatively well on poor soils. However, this poses agronomic problems. As population increases, land is more frequently or continuously used. As a result, soils become poorer and productivity decreases (Table 7).

To compensate for the low yields, farmers plant more per unit area of land so that productivity decreases further due to more diseases, pests, nematodes and soil degradation.

Regarding fertilizers, no positive yield response were observed either to N or K applications on newly cleared land. Instead, tuber yields were depressed with increasing rates of N particularly without K (Kang, Juo and Heys, 1981). However, on poor soils, there seemed to be some response to N. The yield tended to increase with liming (lime rate to 4 t/ha) (IITA, 1979) and with K for certain varieties (IITA, 1982).

Although cassava is very tolerant to drought, the longer the moisture cycle in proportion to the growing season from planting to harvest, the higher the yield (IITA, 1982). Cassava yield was increased by 86 percent when black plastic mulch was used (IITA, 1976). This

Yield of up to 50 t/ha in one and half years is possible from IITA's improved cassava line, TMS 4 (2) 1425, at IITA, Ibadan, Nigeria. This line is resistant to both cassava mealybug (CM) and cassava green spider mite (CGM).
yield increase might be primarily due to better soil moisture preservation. Tuber density, measured by length and dry weight, was not significantly affected by the soil bulk density (1.4 to 1.8). This indicates that cassava can withstand soil compaction more than grain crops such as maize, cowpea or soybean (IITA, 1980).

**Planting material**

The quality of planting material affects stand, vigor, tuber formation and final yield. Stem cuttings taken from basal portions and having a length of 20 cm or 30 cm and a diameter of 2 cm to 3 cm had a higher sprouting rate, more stems per plant, more and larger tubers as well as heavier roots (IITA, 1982). Highest sprouting, between 84 and 92 percent, was obtained 26 to 27 days after planting showing that plant establishment and canopy development are very slow. For this reason, there is very high soil loss in cassava due to run off and erosion (IITA, 1979). Tuber formation began 40 days after planting in basal cuttings 20 cm to 30 cm long and from intermediate cuttings 30 cm long. However, in upper cuttings 10 to 20 cm long tubers started forming 70 days after planting (IITA, 1982).

**Intercropping**

Cassava, like yams and cocoyams, is generally grown in a mixture with many other crops (Table 8). Crop combinations may include maize, sugarcane, beans, groundnuts, melon, banana and assorted vegetables (Okigbo, 1977).

**Table 8: Area ('000 ha) under sole and mixed root crops in Nigeria (1970/71) and Malawi (1968/69).**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Sole</th>
<th>Mixed</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nigeria*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>307.2</td>
<td>112.6</td>
<td>26.8</td>
</tr>
<tr>
<td>Yams</td>
<td>503.7</td>
<td>733.2</td>
<td>59.2</td>
</tr>
<tr>
<td>Cocoyams</td>
<td>27.4</td>
<td>173.9</td>
<td>86.4</td>
</tr>
<tr>
<td>Malawi**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>65.0</td>
<td>532.4</td>
<td>89.1</td>
</tr>
</tbody>
</table>


**Table 7: Soil fertility and cassava yield in relation to human population density in Eastern Nigeria (after Lagemann, 1977).**

<table>
<thead>
<tr>
<th>Population density</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Org. C. (%)</td>
<td>2.35 ± 0.07</td>
<td>2.30 ± 0.17</td>
<td>1.20 ± 0.07</td>
</tr>
<tr>
<td>pH</td>
<td>4.59 ± 0.06</td>
<td>4.71 ± 0.06</td>
<td>4.45 ± 0.04</td>
</tr>
<tr>
<td>Ca + Mg me/100g</td>
<td>1.64 ± 0.34</td>
<td>1.90 ± 0.25</td>
<td>1.28 ± 0.14</td>
</tr>
<tr>
<td>N me/100g</td>
<td>0.18 ± 0.01</td>
<td>0.17 ± 0.01</td>
<td>0.09 ± 0.005</td>
</tr>
<tr>
<td>P me/100g</td>
<td>25.01 ± 4.18</td>
<td>10.58 ± 2.30</td>
<td>9.77 ± 0.51</td>
</tr>
<tr>
<td>K me/100g</td>
<td>0.09 ± 0.01</td>
<td>0.06 ± 0.005</td>
<td>0.11 ± 0.01</td>
</tr>
<tr>
<td>Cassava</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield (t/ha)</td>
<td>10.8</td>
<td>3.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Density (plants/ha)</td>
<td>12,848</td>
<td>20,069</td>
<td>38,442</td>
</tr>
</tbody>
</table>

Farmers interplant crops to derive maximum returns in terms of space, time and labor. The cropping sequence and choice of crops must, therefore, minimize plant and labor competition at critical growth periods.

The most important advantages of intercropping are (Okigbo, 1977):

- better protection against soil erosion
- insurance against crop failure.
- more efficient use of labor
- more or less continuous crop harvesting providing varied food stuffs and minimizing storage requirements.

Some disadvantages of intercropping are (Okigbo, 1977):

- difficulty of mechanical harvesting
- difficulty of applying improved inputs such as fertilizers and herbicides
- difficulty of large scale production.

Cassava-maize intercropping

Cassava is most commonly intercropped with maize throughout tropical Africa. To assess this, cassava was intercropped with maize and/or melon. Results showed that cassava yield was affected a little (Table 9) whereas total calorie production from intercropping was much higher than what would have been obtained if the crops were not in a mixture.

The decline in cassava yield when intercropped with maize is closely related (r = 0.90) to drop in light intensity from about 75 to 60 percent (IITA 1980; 1981). On the other hand, it was found that a 5 to 10 percent increase in light reaching cassava interplanted with maize resulted in a cassava yield increase of 32 percent (IITA, 1982). It also appears that early maturity and lower maize leaf density are advantageous in cassava-maize intercropping.

However, intercropping cassava with maize had no effect on maize grain yield regardless of cassava plant architecture (IITA, 1980; IITA, 1982) and regardless of N rates or maize plant population (Table 10) (IITA, 1980). The best yields and the best returns per hectare were obtained when cassava and maize were planted at the same time or with.

Table 9: Yield (t/ha) of cassava grown in association with other crops (after IITA, 1975; IITA 1981).

<table>
<thead>
<tr>
<th></th>
<th>Sole cassava</th>
<th>Cassava with maize</th>
<th>Cassava with maize and melon</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1975</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting time</td>
<td>12.1</td>
<td>10.0</td>
<td>12.0</td>
</tr>
<tr>
<td>1</td>
<td>15.0</td>
<td>10.6</td>
<td>11.7</td>
</tr>
<tr>
<td>2</td>
<td>15.8</td>
<td>10.8</td>
<td>11.7</td>
</tr>
<tr>
<td>3</td>
<td>11.8</td>
<td>11.9</td>
<td>19.1</td>
</tr>
<tr>
<td>4</td>
<td>10.5</td>
<td>9.6</td>
<td>7.9</td>
</tr>
<tr>
<td>5</td>
<td>7.5</td>
<td>7.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>100</td>
<td>83</td>
<td>93</td>
</tr>
<tr>
<td><strong>1980</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.9</td>
<td>11.5</td>
<td>11.9</td>
</tr>
<tr>
<td><strong>1981</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (%)</td>
<td>19.2</td>
<td>15.4</td>
<td>13.4</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>Overall mean</td>
<td>15.7</td>
<td>12.7</td>
<td>12.4</td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>81</td>
<td>79</td>
</tr>
</tbody>
</table>

Plant population/ha - cassava: 10,000 plants
- maize: 10,000 plants in 1975; 40,000 in 1980;
20,000 in 1981.
Cassava was planted not more than two months after planting maize (Okigbo, 1977). In addition, since a high maize population significantly affects cassava yield, the maize population should not exceed 30,000 plants/ha if good cassava yields are to be expected (IITA, 1980).

No pronounced differences in soil moisture were observed when two different maize varieties with differing plant architecture (erect vs. spreading type) were interplanted with cassava (IITA, 1981; IITA, 1982).

Cassava-groundnut intercropping
Another important intercropping system is that of cassava and groundnuts which is widely used, particularly in central Africa. This combination is good for soil and human nutrition as well as nematode control. The groundnuts cover the soil quickly reducing erosion and keeping temperatures low at the same time fixing nitrogen. It also provides sulphur-containing amino acids which reduce cyanide problems. This system also reduces most root-knot nematode populations (personal communication with F.E. Caveness, 1984).

Cassava-cowpea intercropping
The cassava—cowpea combination seems to be an efficient land user. Overall results suggest that both crops should be planted at the same time for best performance (Table 11).

On the other hand, it was found that cowpea interplanted with narrow leaf cassava yielded up to 92 percent of sole cowpea yield whereas with normal leaf cassava, cowpea yielded only 40 percent of sole cowpea because less light reached the cowpea (IITA, 1982). However, this combination may result in problems for cassava if used continuously for long periods without proper rotation because cowpea will build up root-knot nematode population (personal communication with F.E. Caveness, 1984).

Table 10: Effect of intercropping cassava on maize yield (t/ha) at different N rates and maize populations (IITA, 1980).

<table>
<thead>
<tr>
<th>Associated crop</th>
<th>Sole maize</th>
<th>Maize with cassava</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0 kg N/ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize pop. 1*</td>
<td>1.80</td>
<td>1.93</td>
</tr>
<tr>
<td>Maize pop. 2</td>
<td>1.70</td>
<td>1.87</td>
</tr>
<tr>
<td>Mean</td>
<td>1.75</td>
<td>1.90</td>
</tr>
<tr>
<td><strong>60 kg N/ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize pop. 1</td>
<td>2.30</td>
<td>2.45</td>
</tr>
<tr>
<td>Maize pop. 2</td>
<td>2.40</td>
<td>2.39</td>
</tr>
<tr>
<td>Mean</td>
<td>2.35</td>
<td>2.42</td>
</tr>
<tr>
<td><strong>120 kg N/ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize pop. 1</td>
<td>2.28</td>
<td>2.52</td>
</tr>
<tr>
<td>Maize pop. 2</td>
<td>2.12</td>
<td>2.10</td>
</tr>
<tr>
<td>Mean</td>
<td>2.20</td>
<td>2.31</td>
</tr>
<tr>
<td>Overall mean</td>
<td>2.10</td>
<td>2.21</td>
</tr>
</tbody>
</table>

*Maize plant population 1 = 1 x 0.33 m, 1 plant/hill; maize plant population 2 = 1 x 1 m, 3 plants/hill.
Cassava populations: 1 x 1 m, 10,000 plants/ha.

Table 11: Effect of intercropping with cassava and planting time sequence on cowpea yield (kg/ha) (after IITA, 1979).

<table>
<thead>
<tr>
<th>Combination</th>
<th>Relay time in days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Cassava / 1 row cowpea</td>
<td>653</td>
</tr>
<tr>
<td>Cassava / 2 rows cowpea</td>
<td>552</td>
</tr>
<tr>
<td>Cowpea / 1 row (sole)</td>
<td>676</td>
</tr>
<tr>
<td>Cowpea / 2 rows (sole)</td>
<td>701</td>
</tr>
</tbody>
</table>
Leaf harvest

Cassava leaves are often a favorite vegetable in many parts of Africa particularly in Central Africa. There is also a potential to use cassava leaves as an animal feed. When cassava leaves are harvested at intervals of one, two and three months, tuber yields are reduced by 62, 52 and 25 percent, respectively (Table 12).

Weed control

On average, weeds reduce cassava yield by 59 percent (Table 13). Complete yield losses have been reported particularly those caused by speargrass (*Imperata cylindrica*). The runners of this grass can pierce the tubers causing them to rot. Weeding requires about 30 percent of total labor inputs.

Disease and insect resistant varieties have less of a weed problem because their canopies fully cover the ground. However, weeding two or three times is required before cassava fully develops its canopy. When available and economic, herbicides can be used to control weeds in cassava fields (Table 14) (IITA, 1983). Surface mulching with various types of crop residues or with grass can have a significant effect on weed control and yield. Plastic mulch controlled weeds completely and gave yields almost two-fold (IITA, 1976).

Continuous cassava production on the same field

When root crops are grown continuously on the same field, there is normally reduction in yield. To test the possibility of growing root crops continuously on the same field by adding organic matter, trials were conducted with cassava, yam and maize at Umudike, Nigeria, between 1940 and 1960 (Figure 6). Results show

---

**Table 12: Effect of leaf harvest on fresh tuber yield and leaf yield of cassava (after Dahniya et al., 1981).**

<table>
<thead>
<tr>
<th>Part</th>
<th>Variety</th>
<th>None</th>
<th>3 months</th>
<th>2 months</th>
<th>Monthly</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuber yield (t/ha)</td>
<td>Isunikaniyan</td>
<td>11.2bc</td>
<td>8.4bc</td>
<td>3.2c</td>
<td>1.4c</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>TMS 30211</td>
<td>30.9a</td>
<td>17.8b</td>
<td>18.5b</td>
<td>9.0bc</td>
<td>19.1</td>
</tr>
<tr>
<td>Mean</td>
<td>21.1</td>
<td>13.1</td>
<td>10.9</td>
<td>5.2</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>100</td>
<td>62</td>
<td>52</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf yield (t/ha)</td>
<td>Isunikaniyan</td>
<td>4.5bc</td>
<td>4.1b</td>
<td>7.7b</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TMS 30211</td>
<td>7.6b</td>
<td>11.9a</td>
<td>13.6a</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6.1</td>
<td>8.0</td>
<td>10.7</td>
<td>8.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 13: Effect of weeds on cassava yield (after IITA, 1974-79).**

<table>
<thead>
<tr>
<th>Cassava yield (t/ha)</th>
<th>Weed free</th>
<th>Weedy</th>
<th>Yield reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>26.4</td>
<td>10.6</td>
<td>58</td>
</tr>
<tr>
<td>1978</td>
<td>23.4</td>
<td>13.9</td>
<td>41</td>
</tr>
<tr>
<td>1979 (1)</td>
<td>22.2</td>
<td>7.5</td>
<td>66</td>
</tr>
<tr>
<td>1979 (2)</td>
<td>16.5</td>
<td>4.0</td>
<td>76</td>
</tr>
<tr>
<td>1979 (3)</td>
<td>21.1</td>
<td>8.9</td>
<td>58</td>
</tr>
<tr>
<td>Mean</td>
<td>21.9</td>
<td>9.0</td>
<td>59</td>
</tr>
</tbody>
</table>
that it is possible to grow cassava, yam and maize continuously on the same field when organic matter is added.

**Processing and hydrogen cyanide (HCN)**

Cassava contains hydrogen cyanide in tubers and leaves in the form of cyanogenic glucosides which release HCN on hydrolysis when tissues are destroyed. No acyanogenic cassava variety has been reported, but the level of the HCN varies with variety. The low cyanide varieties — below 10 mg/100g of fresh wt. — are generally low yielding compared to the high cyanide varieties — above 20 mg/100g fresh wt. It is necessary to eliminate this cyanide to improve palatability through processing that requires one or a combination of peeling, grating, fermenting, dehydrating, sun drying, frying or boiling (Table 15). Fermentation before processing into products such as *chikwangue*, *fufu* (Zaire) and *ntuka* eliminates almost all total and free HCN while total HCN is reduced 83 to 96 percent in such products as *gari*, *atteke* and *oyoko* which are peeled and grated before processing.

On the other hand, total HCN in *gari* is reduced 83 to 98 percent when stored for four months under ambient conditions and in *eba*, a cooked form of *gari*, total HCN is reduced almost 100 percent. Free HCN is reduced to very low levels in *atteke*, *plakari* and *gari* stored for four months. In *fufu* (Ghana) prepared through boiling followed by pounding, total HCN is reduced about 81 percent and free HCN 57 percent. Boiling tubers of high HCN varieties does not reduce HCN sufficiently. Therefore, this processing method should be used with low HCN varieties.

In Nigeria *fufu* obtained by soaking peeled fresh tubers for one day followed by steaming and pounding, total HCN is reduced 96 percent and free HCN 46 percent. In *konkonde* prepared by soaking fresh tubers which are then sun-dried, milled and cooked, total HCN is reduced by 96 percent and free HCN by 86 percent.

![Figure 6](image_url)  
**Figure 6.** Four-year average yield of cassava, yam and maize grown continuously on the same field for 20 years (1940-1960) at Umudike, Nigeria (After J.A. Obi and P. Tuley, 1973).

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Rate (kg/ha)</th>
<th>Time of application</th>
<th>Weeds controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluomaturon</td>
<td>2.0 - 3.0</td>
<td>PE*</td>
<td>Annual weeds, especially broad leaves.</td>
</tr>
<tr>
<td>Cotoran multi</td>
<td>4.0</td>
<td>PE</td>
<td>Annual weeds for 10-12 weeks in subhumid zones.</td>
</tr>
<tr>
<td>Diuron</td>
<td>2.0 - 3.0</td>
<td>PE</td>
<td>Annual broad leaves and some grasses</td>
</tr>
<tr>
<td>Primextra</td>
<td>2.0 - 3.0</td>
<td>PE</td>
<td>Annual grasses and broad leaves.</td>
</tr>
</tbody>
</table>

*PE* stands for pre-emergence.

**Note:** For cassava-maize intercropping, primextra as pre-emergence herbicide at the rate of 2.5 - 3.0 kg/ha is very effective for controlling the annual broad leaves (Akobundu et al., 1983).
When the sliced roots (3.5 x 5.8 x 6.9 mm) were sun-dried in perforated polythene bags, HCN was reduced progressively with time. Most of it came off within the first 8 hours in which 46 to 58 percent free and 69 to 74 percent bound HCN disappeared (Maduagwu and Adewale, 1980). *Pondu*, that is processed cassava leaves, had about 96 percent less total and no free HCN. Highest weight loss when processing *gari* came from peeling (41 percent) followed by dehydration (20 percent) and grating (11 percent)(Table 16).

Since garification rate is highly correlated with the percentage of dry matter it is possible to predict roughly the garification rate (y) with dry matter percentage (x) using the regression equation: 

$$y = 0.82 + 0.09 \times$$

Table 15: Hydrogen cyanide (HCN) content in traditional African cassava products (after IITA, 1982).

<table>
<thead>
<tr>
<th>Product</th>
<th>Total HCN, mg/100g of fresh weight</th>
<th>Free HCN, mg/100g of fresh weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean % reduction</td>
<td>Mean % reduction</td>
</tr>
<tr>
<td>Peeled, fresh tuberous roots</td>
<td></td>
<td>15.89 0.00</td>
</tr>
<tr>
<td>attieke</td>
<td>0.65 95.91</td>
<td>0.07 89.23</td>
</tr>
<tr>
<td>Boiled tuberous roots</td>
<td>4.79 69.85</td>
<td>0.70 7.69</td>
</tr>
<tr>
<td>chikwangue</td>
<td>- 100.00</td>
<td>- 100.00</td>
</tr>
<tr>
<td>eba</td>
<td>0.02 99.87</td>
<td>0.01 98.46</td>
</tr>
<tr>
<td>fufu (Ghana)</td>
<td>3.10 80.49</td>
<td>0.28 56.92</td>
</tr>
<tr>
<td>fufu (Nigeria)</td>
<td>0.72 95.47</td>
<td>0.35 46.15</td>
</tr>
<tr>
<td>fufu (Zaire)</td>
<td>0.02 99.87</td>
<td>- 100.00</td>
</tr>
<tr>
<td>gari (freshly fried)</td>
<td>2.66 83.26</td>
<td>1.22 +87.69</td>
</tr>
<tr>
<td>gari (after 4 months)</td>
<td>0.29 98.17</td>
<td>0.26 60.00</td>
</tr>
<tr>
<td>konkonde</td>
<td>0.72 95.47</td>
<td>0.09 86.15</td>
</tr>
<tr>
<td>ntuka</td>
<td>0.03 99.81</td>
<td>0.03 95.38</td>
</tr>
<tr>
<td>oyoko</td>
<td>1.46 90.81</td>
<td>0.68 +4.62</td>
</tr>
<tr>
<td>plakali</td>
<td>0.53 96.66</td>
<td>0.07 89.23</td>
</tr>
<tr>
<td>Fresh leaves</td>
<td>201.00 0.00</td>
<td>4.85 0.00</td>
</tr>
<tr>
<td>pondu (cooked leaves)</td>
<td>8.53 95.76</td>
<td>- 100.00</td>
</tr>
</tbody>
</table>

HCN content was analysed using an automated enzymatic assay method (Rao and Hahn, 1984).

Table 16: Some characteristics of tubers that affect and are related with garification rate (after IITA, 1980).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean %*</th>
<th>Loss %**</th>
<th>G.R. (r)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fresh tuberous roots (10 kg)</td>
<td>100</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>% peeled tuberous roots</td>
<td>59.0</td>
<td>41.0</td>
<td>0.40</td>
</tr>
<tr>
<td>% dehydrated tuberous roots</td>
<td>48.2</td>
<td>10.8</td>
<td>0.77</td>
</tr>
<tr>
<td>% dehydrated tuberous roots</td>
<td>28.0</td>
<td>20.2</td>
<td>0.94</td>
</tr>
<tr>
<td>% pulp after fermenting and removing chaff</td>
<td>25.2</td>
<td>2.8</td>
<td>0.96</td>
</tr>
<tr>
<td>% chaff</td>
<td>3.2</td>
<td>-0.36</td>
<td></td>
</tr>
<tr>
<td>% dry matter</td>
<td>25.5</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>% garification</td>
<td>13.5</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

*Average of 26 clones

**Loss stands for percent loss from one step to the next in garification process.

***G.R. stands for garification rate.
YAM

Yams are important in West Africa where ritualism has developed around their production and utilization (Onwueme, 1978). They are also an important staple food crop. The most economically important species grown in Africa are white yam Dioscorea rotundata, yellow yam D. cayenensis, trifoliate yam D. dumetorum and water yam D. alata. These yams are indigenous to West Africa except the water yam which originated in Asia. In Africa, it is white yam that is grown on the largest scale at the same time being the most preferred followed by water yam and yellow yam. Africa grows 96 percent of the world’s production (FAO, 1982).

Yams are grown in fairly high rainfall areas with a distinct dry season of not more than five months and a rain season not less than five months. The crop grows for six to ten months and is dormant for two to four months these phases corresponding to the wet and dry season (Coursey, 1967). Grown from tubers (300-600 g/sett), cultivated yams produce vines between 2 and 7 m long. Tubers are mature in 6 to 8 months after planting. The vines are usually supported on long poles (2-4 m). The male and female plants are separate. Yams are relatively tolerant to shade in the high rainfall forest regions (Table 17).

Constraints to production

Yam production requires high inputs and is labor intensive. In addition, the crop is difficult to grow because seed yams are expensive and often unavailable, seedbed preparation is laborious and tedious, staking is necessary and yet staking material is expensive and often not available, weeding is required for 4 to 5 months and harvesting needs special care. Of a total of 1,815 man hours/ha required for yam production, 49 percent goes to land preparation, 13 percent to planting, 5 percent to staking, 18 percent to weeding and 15 percent to harvesting. (Table 18).

For these reasons, yam production is declining which calls for research particularly to reduce production inputs and labor requirements.

Consumers prefer large tubers which implies that larger seedbeds should be prepared, larger planting sets used, plant population per unit area should be small, staking is necessary for leaf display, the number of tubers per plant should be small and there is greater

Table 18: Labor requirements for yam production in Nigeria (man hours/ha) (after Diehl, 1981).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Man hours/ha**</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land preparation*</td>
<td>882</td>
<td>49</td>
</tr>
<tr>
<td>Planting</td>
<td>235</td>
<td>13</td>
</tr>
<tr>
<td>Staking</td>
<td>93</td>
<td>5</td>
</tr>
<tr>
<td>Weeding</td>
<td>335</td>
<td>18</td>
</tr>
<tr>
<td>Harvesting</td>
<td>270</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>1815</td>
<td>100</td>
</tr>
</tbody>
</table>

*Land preparation includes seedbed preparation
**Average of 8 sites

Table 17: Effect of oil palm shade and fertilizer application on white yam yield (t/ha) in Eastern Nigeria (after IITA, 1974).

<table>
<thead>
<tr>
<th></th>
<th>Shade</th>
<th>No shade</th>
<th>Mean</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No fertilizer</td>
<td>8.38</td>
<td>9.15</td>
<td>8.77</td>
<td>100</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>9.42</td>
<td>12.08</td>
<td>10.75</td>
<td>123</td>
</tr>
<tr>
<td>Mean</td>
<td>8.90</td>
<td>10.62</td>
<td>9.76</td>
<td>100</td>
</tr>
<tr>
<td>%</td>
<td>84</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figures are averages from three villages.
chance of tubers getting damaged at harvest. In addition, nematodes cause severe pre-and postharvest damage to tubers, which reduces not only yield but also market and keeping quality. All these factors make yam production laborious, expensive and difficult.

**Approaches to overcoming the constraints**

**Germplasm evaluation and genetic improvement**

A total of 600 accessions of white yam and 40 accessions of water yam germplasm were collected in West Africa in the early 1970s. They were screened for desirable agronomic characteristics and several promising land races selected based on their performance. Using flowering habit, seed behavior, plant physiology and activity of pollinating agents under field conditions, the techniques for hybridization, seed germination, seedling establishment and rapid multiplication have been perfected for both white and water yam and several promising white yam clones have been produced. There are a number of water yam clones showing promise in terms of resistance to necrosis and yield potential — up to 40 tons/ha when staked and 20 tons/ha when unstaked. Their tubers are round and uniform in shape and size while the skin is so thick that tubers are seldom bruised during harvesting and postharvest handling. These tuber characteristics will be valuable for mechanical harvesting and processing. Several of the water yam clones can be pounded for food preparation which is important for consumer preference.

**Agronomic practices**

Characteristics influencing yield are size of mound or ridge, size and quality of planting sett, time of planting, weeding and staking (Enyi, 1977).

**Land preparation**

Like cassava, yams are normally grown on mounds or ridges when the soil water table is high or when the soils are poor and hard in texture. They are also grown on flat land. However, very little information is available about growing yams on large mounds. The few results available are summarized below.
Yield increases with mound size which appears to influence tuber yield more than fertilizer (Table 19).

The effect of mound size on tuber yield was most pronounced in soil with high bulk density. Yams grown on the flat in soil with gravel gave smaller, irregularly shaped tubers. Therefore, large mounds are essential for good tuber development, higher yield, smooth and large tubers, and easier harvesting (Kang and Wilson, 1981). However, if the soil is coarse-textured, well drained and relatively deep, it may be possible to get a good crop on a flat seedbed (IITA, 1981). On a large mound, yield was higher when yam setts were placed 80 cm above ground level compared to those at 20 cm and 40 cm (Table 20).

In addition, tuber shape improved and tuber rot decreased when setts were planted high up in the mound. Although there seems to be an advantage in growing yams the traditional way on large mounds, making the mound with traditional hand tools is very laborious. An alternative is to grow yams on ridges made by machines or animal traction (Onwueme, 1980).

**Sett size**

The yield for both the white and water yams increased with increased sett size at 8,000 and 10,000 plants/ha (Table 21). However, using large setts was uneconomic because of a low multiplication rate. To be profitable, sett size should not exceed 1 kg.

**Mulching**

Mulching with crop residue gave 20 percent more yield than no mulching (Table 22) and tubers were larger under mulch. Also mulching helped to reduce soil temperature resulting in good sprouting for setts (Lal and Hahn, 1973).

Plastic mulch significantly reduced necrosis of white yam and gave a fairly good yield (15 t/ha) of seed yam even when unstaked and small planting setts (20-50 g/sett) used (IITA 1982). Plastic mulch can also eliminate weeding, conserve soil moisture, reduced labor by 23 percent and prolong the growth period which can lead to higher yield.

**Table 19:** Effect of mound size and fertilizer on white yam tuber yield (t/ha) in three locations (after Kang and Wilson, 1981).

<table>
<thead>
<tr>
<th>Mound size*</th>
<th>No fertilizer</th>
<th>Fertilizer**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>7.83 (69%)</td>
<td>7.4 (66%)</td>
</tr>
<tr>
<td>Small mound</td>
<td>8.50 (75%)</td>
<td>9.1 (81%)</td>
</tr>
<tr>
<td>Medium mound</td>
<td>9.40 (83%)</td>
<td>10.0 (89%)</td>
</tr>
<tr>
<td>Large mound</td>
<td>9.46 (84%)</td>
<td>11.3 (100%)</td>
</tr>
</tbody>
</table>

*Small mound = 50 x 50 cm, medium mound = 100 x 100 cm, large mound = 150 x 150 cm.
**Fertilizer: 60N-13P-25K (in kg/ha).

**Table 20:** Effect of sett placement in the large mound seedbed at 20, 40 and 80 cm above the ground level on yield and general performance of white yams in hydromorphic soil (after IITA, 1974).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>20</th>
<th>40</th>
<th>80</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (kg/plant)</td>
<td>4.67</td>
<td>4.98</td>
<td>5.41</td>
<td>5.02</td>
</tr>
<tr>
<td>Tuber length (cm)</td>
<td>34.9</td>
<td>39.7</td>
<td>43.2</td>
<td>3.93</td>
</tr>
<tr>
<td>Tuber rot (%)</td>
<td>8.5</td>
<td>3.1</td>
<td>1.9</td>
<td>4.5</td>
</tr>
<tr>
<td>Shape</td>
<td>moderate</td>
<td>good</td>
<td>excellent</td>
<td></td>
</tr>
</tbody>
</table>
Staking

Normally, the leaf of unstaked white yam dies much earlier than when staked resulting in lower yields. For instance, staked white yam gave 48 to 62 percent higher yield than when unstaked. However, water yam showed insensitivity to staking (Table 23).

Although staking is beneficial, it is costly, laborious and difficult to mechanize (Onwueme, 1980). Furthermore, staking material is often not easily available.

There are several water yam clones (TDa 251, TDa 291, TDa 310, etc) that can be grown without staking and yet give reasonable yields (up to 20 t/ha). However, white yam clones suitable for growing without staking in high rainfall areas are yet to be found because white yam is generally highly susceptible to necrosis when unstaked. Selections of white yam clones for resistance to necrosis are being carried out.

Since yams are very slow in developing full canopy, their ability to cover the ground is limited (Onwueme, 1980). Staked yam vines leave the soil exposed to rain even when the canopy is fully developed making the soil more vulnerable to erosion (IITA, 1980).

Weed control

The inability of yam to completely shade the ground makes it susceptible to weed competition (IITA, 1977) which can reduce the yield of white yam by 43 percent and that of water yam by 61 percent (Table 24).

Herbicide recommendations for yams are the same as for cassava (IITA 1983, et al., 1983).

Table 21: Effects of sett size and spacing on yield (kg/plant) of yams at two different plant populations (after IITA, 1974).

<table>
<thead>
<tr>
<th>Sett size (kg)</th>
<th>10,000</th>
<th>8,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>White yam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.19</td>
<td>0.67 (2.5)</td>
<td>0.40 (1.1)</td>
</tr>
<tr>
<td>0.45</td>
<td>1.41 (2.1)</td>
<td>1.26 (1.8)</td>
</tr>
<tr>
<td>0.90</td>
<td>2.06 (1.3)</td>
<td>1.69 (0.9)</td>
</tr>
<tr>
<td>1.53</td>
<td>2.53 (0.7)</td>
<td>3.37 (1.2)</td>
</tr>
<tr>
<td>3.37</td>
<td>3.19 (-0.1)</td>
<td>4.11 (0.2)</td>
</tr>
<tr>
<td>Water yam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.21</td>
<td>1.81 (7.6)</td>
<td>2.40 (10.4)</td>
</tr>
<tr>
<td>0.45</td>
<td>2.93 (5.5)</td>
<td>3.54 (4.6)</td>
</tr>
<tr>
<td>0.92</td>
<td>3.71 (3.0)</td>
<td>4.26 (3.6)</td>
</tr>
<tr>
<td>1.78</td>
<td>3.56 (1.0)</td>
<td>4.23 (1.4)</td>
</tr>
<tr>
<td>4.01</td>
<td>4.21 (0.01)</td>
<td>4.31 (0.07)</td>
</tr>
</tbody>
</table>

Figures in parenthesis are multiplication rate calculated using \((Y-X)/X\), where \(X\) stands for sett size (in kg) and \(Y\) for tuber yield (in kg) produced with the sets.

Table 22: Effect of tillage methods and mulch on white yam yield (t/ha) at Onne, Nigeria (after IITA, 1980).

<table>
<thead>
<tr>
<th>Tuber characteristics</th>
<th>No mulch</th>
<th>Mulch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ridge</td>
<td>Flat</td>
</tr>
<tr>
<td>Tuber length (cm)</td>
<td>20.7</td>
<td>20.7</td>
</tr>
<tr>
<td>Tuber diameter (cm)</td>
<td>13.3</td>
<td>13.9</td>
</tr>
<tr>
<td>Yield (t/ha)</td>
<td>14.1</td>
<td>16.3</td>
</tr>
</tbody>
</table>
Intercropping

Yams are often grown in a mixture of other crops. When white yam was intercropped with maize or cowpea, its yield decreased by 33 percent (Table 25) and white yam yield seems to be affected more by maize and cowpea than by cassava.

Nematode control

The yam nematode and root-knot nematode cause great problems in yam reducing yield in white yam by 72 percent (IITA, 1980). Rotating yams with cover crops such as centro Centrosema pubescens, giant star grass Cynodon niemfuensis or stylo Stylosanthes gracillis would be helpful in controlling nematodes in yams. Among yam species, white yam is the most susceptible to nematodes. However, a land race of white yam, Abi, showed only light root-knot galling on the tubers for both Meloidogyne incognita race 2 and M. javanica (IITA, 1982). Water yam is fewer nematode problems.

Harvesting

Harvesting yam is done almost entirely with hand tools and farmers must be careful when lifting and handling tubers to avoid damage which would shorten the storage period. Yam consumers in Africa prefer the longer and larger tubers which grow at greater depths. This results in an increase in time required for harvesting (Onwueme, 1980). Alternatives to traditional harvesting should be sought through having varieties with round and uniform tubers as well as having a thick skin suited to manual or mechanical harvesting. Increased plant density reduces tuber size.

<table>
<thead>
<tr>
<th>Plants/ha (’000)</th>
<th>Staked</th>
<th>Unstaked</th>
<th>Difference</th>
<th>Yield reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White yam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1974</td>
<td>27.3</td>
<td>52.9</td>
<td>27.5</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>18.3</td>
<td>31.3</td>
<td>18.0</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>9.2</td>
<td>18.8</td>
<td>7.8</td>
<td>11.0</td>
</tr>
<tr>
<td>Mean</td>
<td>34.3</td>
<td>19.8</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>1978*</td>
<td>10.0</td>
<td>19.0</td>
<td>7.2</td>
<td>11.8</td>
</tr>
<tr>
<td><strong>Water yam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979*</td>
<td>10.0</td>
<td>11.7</td>
<td>12.8</td>
<td>-1.1</td>
</tr>
</tbody>
</table>

*Average of 24 replications.

Table 24: Effect of weeds on yield (t/ha) of yam (after IITA, 1976-1979).

<table>
<thead>
<tr>
<th>Weed free</th>
<th>Weedy</th>
<th>Yield reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White yam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>22.4</td>
<td>10.3</td>
</tr>
<tr>
<td>1977 (1)</td>
<td>28.6</td>
<td>22.5</td>
</tr>
<tr>
<td>1977 (2)</td>
<td>28.4</td>
<td>15.9</td>
</tr>
<tr>
<td>1979 (1)</td>
<td>14.2</td>
<td>3.3</td>
</tr>
<tr>
<td>unstaked</td>
<td></td>
<td></td>
</tr>
<tr>
<td>staked</td>
<td>24.3</td>
<td>15.6</td>
</tr>
<tr>
<td>1979 (2)</td>
<td>12.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Mean</td>
<td>21.7</td>
<td>12.3</td>
</tr>
<tr>
<td><strong>Water yam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>16.2</td>
<td>4.6</td>
</tr>
<tr>
<td>unstaked</td>
<td>14.2</td>
<td>7.1</td>
</tr>
<tr>
<td>staked</td>
<td>15.2</td>
<td>5.9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
and the depth tubers penetrate into the soil. These factors might make mechanical harvesting easier. Tubers of the water yam clones TDa 251, TDa 310, TDa 5 are uniformly round, are uniform in size and have a thick skin which could make them ideal for mechanical harvesting and processing.

Table 25: Yield (t/ha) of white yam when grown in association with other crops (after IITA, 1975; 1976).

<table>
<thead>
<tr>
<th>Year</th>
<th>Yam Sole with yam</th>
<th>Yam with maize</th>
<th>Yam with cowpea</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975 (1)</td>
<td>20.0</td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td>1975 (2)</td>
<td>23.1</td>
<td>13.0</td>
<td>10.9</td>
</tr>
<tr>
<td>1976</td>
<td>21.1</td>
<td>13.8</td>
<td>17.7</td>
</tr>
<tr>
<td>Mean</td>
<td>21.4</td>
<td>14.3</td>
<td>14.3</td>
</tr>
<tr>
<td>%</td>
<td>106</td>
<td>67</td>
<td>67</td>
</tr>
</tbody>
</table>

Storage

In the four to five months tubers are in storage they can lose up to 40 percent of their weight. The loss comes from sprouting, evaporation, respiration and rotting. It is mainly pathogens, mechanical damage, insect and nematode attack that cause rotting (Waitt, 1963). The principal factor responsible for poor yam storage is, however, preharvest nematode attack.

Another important factor responsible for poor storage is mechanical damage particularly when humidity and temperatures are high. Storage systems should be improved through structures that can provide adequate shade, light and ventilation varieties that can be stored longer and processing tubers into products such as yam flour that can be stored longer and are easier to transport.

"Seed" yam production

The cost of seed yam is approximately one-third of the total outlay of yam production (Nwosu, 1975, c.f. Okoli, 1980) which makes seed yam expensive and often unavailable to poor farmers. Yet what is available is often of inferior quality. Therefore, a system is needed for producing superior seed yam in greater quantities at a lower cost to farmers. In this line, Okoli (National Root Crops Research Institute, Umudike, Nigeria) developed a mini-sett (20-50 g) method by which yam can be rapidly multiplied. Using this method with plastic mulch (Alvarez and Hahn, 1982), it was possible to eliminate weeding and staking, to increase the multiplication ratio by 5 to 10 times over the traditional method and to produce about 15 tons/ha seed yam in four months. A net profit of approximately US$7,000 per hectare can be achieved from seed yam production using this system in Nigeria.
SWEET POTATO

Although among the root crops grown in the tropics sweet potato has the shortest growth cycle, four to five months, it has a high yield potential. For example, one improved clone yields 40 t/ha in four months without fertilizers, but with good management and good soils. Another characteristic of sweet potato is that it can adapt to a wide range of environmental conditions.

Constraints to production
For sweet potato in tropical Africa, weevils, nematodes and viruses often cause severe damage. Storage is also a problem. In areas where it is difficult to preserve planting material in the long dry season, late availability of planting material is an important factor limiting the highest production. This is particularly so where the rain season is short. In such areas, even when fields are suitable for planting after the first good rain, planting is delayed by two to three months. Sweet potato is, therefore, usually planted toward the end of the rain season in tropical Africa maturing in the dry season when the sweet potato weevil populations are largest so that damage to tubers is high. Weevils reduce yield, quality, market value and storability. Another important limiting factor is that farmers plant old vines instead of fresh, young, apical shoots which establish better, grow faster and give higher yields.

Approaches to overcoming the constraints
VARIETAL IMPROVEMENT
A large quantity of germplasm has been assembled in seed form from many different countries in Africa, Asia and the Americas. The germplasm has been evaluated for resistance to weevils, the sweet potato virus complex and other important agronomic characteristics. Sources of resistance to the insect and virus complex have been identified and incorporated into breeding populations. Using continuous cyclic recombination and selection, these populations have been further improved for yield potential and virus and weevil resistance as well as quality. Seed from these populations has been distributed to many national programs for selection and evaluation. Also, through tissue culture
followed by virus indexing, many improved clones have been sent to 30 countries in Africa for testing. As a result, local researchers have selected promising clones and have released them as their recommended varieties. By tissue culture, more than 600 accessions of sweet potato germplasm are being preserved in vitro.

**Resistance to sweet potato weevil**
Breeding clones have been screened for resistance to weevils in the field and in the laboratory. The resulting clones being used for recombination and reselection. Promising clones in terms of weevil resistance are TIS 3053, TIS 3030, TIS 3017, TIS 2532, TIS 8524, TIS 8266 and TIS 9172. There is strong indication that resistance to weevil is due to antibiosis (Hahn and Leuschner, 1981).

**Resistance to sweet potato virus complex**
The clones tested and found to be resistant are TIS 2498, TIS 3228, TIS 3053, TIS 2532, TIS 2534 and TIS 2544 (Hahn et al., 1981).

**Resistance to root-knot nematodes**
A total of 400 accessions of sweet potato germplasm have been screened for resistance to root-knot nematodes (Meloidogyne incognita race 2 and M. javanica) and 55 clones have shown resistance (IITA, 1982).

**Screening sweet potato for sink capacities and source potentials**
Forty clones were screened for sink capacities and source potentials by grafting them on each of the four tester varieties as stock or scion. The clones which showed large sink capacity are TIS 70683, TIS 71102, and TIS 70357. The clones which showed large source potential are TIS 2497, T1b 2, TIS 3295, TIS 70995 and TIS 71139 (IITA, 1981; Hahn, 1982).

**Yield potential**
Clones TIS 9265 and TIS 2498 gave average yields of 18 t/ha and 14 t/ha respectively in four months without fertilizers in conditions varying from high rainfall to sandy acid to semi-arid. TIS 9265 yielded 54 t/ha and TIS 2498 45 t/ha under good soil and management.

Resistant (left) and susceptible clones to sweet potato weevil
Agronomic practices

Soil erosion
Sweet potato provides effective ground cover early so that there is little erosion compared to other root crops (IITA, 1979; 1980).

Controlling weevils in the field and in storage

Cultural control in the field
Increase in plant population decreased root size which in turn decreased root exposure to weevil infestation on the soil surface (IITA, 1974). Earthing up the soil near the crown of sweet potato plants three months after planting helps reduce weevil damage to tubers in the field. When sweet potato is planted soon after the first good rain and harvested before the end of the rain season or immediately after, weevil damage is reduced.

Control in storage
When adult weevils were buried in the soil at 10, 15 and 20 cm below the surface, most of them died 8 days after burial. Also when tubers infested with weevils in the field were buried at more than 10 cm below ground for 10 days or longer, the weevils died. Therefore, underground storage for two to three months can be effective in controlling weevils.

Adult weevils immersed in water at 52°C, died within 10 minutes. Others died after 12 hours in tap water at room temperature. Hot water treatment at 52°C for 30-40 minutes controlled weevils, nematodes and storage rot associated pathogens. Low temperatures of 20°C to 23.5°C extended the period of development for weevils by 34 days and drastically affected their survival. At higher temperatures between 27°C and 34°C, the development period was shortened by 22 and 17 days respectively and survival rate increased. Therefore, sweet potato will have fewer weevil problems where the temperature is low.
COCOYAM

The cocoyams Colocasia spp. and Xanthosoma spp. are important staple food crops in many parts of Africa. Colocasia is indigenous to Southeast Asia and Xanthosoma to tropical America. Calocasia reached Africa earlier than Xanthosoma so that Colocasia is often called old cocoyam and Xanthosoma new cocoyam. They are essentially warm weather, lowland crops with the best yields obtained at a mean temperature above 21°C with annual rainfall exceeding 2,000 mm. Xanthosoma is preferred to Colocasia in West Africa because it has better yield, taste and adaptability. Within Colocasia eddoe and dasheen, are the two major types with eddoe performing better under drier conditions while dasheen grows better under flooding. Xanthosoma does better on deep, well drained soils. The corm and cormels are the edible parts of Colocasia and Xanthosoma while young leaves, petioles and flowers of Colocasia are often used as a vegetable. Cocoyam is propagated vegetatively using small corms, cormels and stem cuttings.

Constraints to production

A cocoyam root rot complex, principally caused by Pythium myriotylum, is the greatest limiting factor in Xanthosoma production in Africa. The plants infected with the disease develop chlorotic leaves. These show brown blight developing from the periphery and later extending toward the petiole. The petioles droop, the leaves dry up and are shed prematurely. Infested plants remain stunted with necrotic shrivelled leaves while the root system is greatly reduced by decay. In advanced stages, the cortical tissue turns brown and disintegrates leaving a nonfunctional vascular skeleton (IITA, 1981). Because of this disease, Xanthosoma is being replaced with root rot complex resistant Colocasia in the high rainfall areas of Cameroon.

Approaches to overcoming the constraints

Genetic improvement

GA at a concentration of 1500 ppm gave the best results for flower induction in
both *Colocasia* and *Xanthosoma* (IITA, 1978). In GA induced, hand-pollinated flowers, about 2 percent *Colocasia* and 38 percent *Xanthosoma* inflorescences set viable seed and a large number of viable seeds have been produced, seedlings established and selections made from them (IITA, 1979). The hybrids have been evaluated for resistance to cocoyam root rot complex and results are promising (IITA, 1982). Over one hundred *Xanthosoma* germ-

Germinating cocoyam seed in a petri dish

Cocoyam (*Colocasia* spp.) grown on a large scale in Cameroon. *Xanthosoma* spp. has been replaced by *Colocasia* spp. due to severe cocoyam root rot complex.
plasm accessions were introduced and evaluated in Cameroon. Cytogenetics and crossability of cocoyams have also been studied giving encouraging results for improvement.

Cultural control for cocoyam root rot complex

Foliar symptoms of cocoyam root rot complex were reduced by wider spacing (1.5 m) and early planting gave significantly higher yields regardless of the type of planting material used (Table 26) (IITA, 1981).

Table 26: Effect of time of planting and planting material on cormel yield (t/ha) of *Xanthosoma* spp. (IITA, 1981).

<table>
<thead>
<tr>
<th>Planting material</th>
<th>March 13</th>
<th>March 27</th>
<th>April 9</th>
<th>April 22</th>
<th>May 7</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corm head</td>
<td>3.73</td>
<td>1.44</td>
<td>3.69</td>
<td>1.78</td>
<td>0.48</td>
<td>2.22</td>
</tr>
<tr>
<td>Corm middle part</td>
<td>3.11</td>
<td>1.82</td>
<td>1.56</td>
<td>0.86</td>
<td>0.17</td>
<td>1.50</td>
</tr>
<tr>
<td>Mean</td>
<td>3.42</td>
<td>1.63</td>
<td>2.63</td>
<td>1.32</td>
<td>0.33</td>
<td></td>
</tr>
</tbody>
</table>

Cocoyam (*Xanthosoma* spp) suffering from damage by the cocoyam root rot complex in Cameroon.
References


