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Towards a New Green Revolution: from Chemicals to New Biological Techniques in the Improvement of Tropical African Agriculture (**)

INTRODUCTION

The greatest problem facing the world today is that of inequality in the capabilities of countries in different parts of the world to effectively tackle the problem of producing enough food to meet demands of their rapidly rising populations. Of major worldwide concern in this regard is the African food crisis which has arisen from the inability of most African countries south of the Sahara to produce enough food to satisfy demands of rapid population growth, urbanization and other pressures of modernization. The seriousness of the situation is often exacerbated by the drought which has been occurring off and on in different parts of Africa since the early 1970s, especially in the Sahel. Moreover, there is a general concensus among all recent reports on the present and future trends of events in Africa that concurrent with the agricultural, food and demographic crises are economic, political and ecological crises. The overall result is that most countries in Sub-Saharan Africa are increasingly relying on food imports and/or food aid to satisfy demands at a time when they lack foreign exchange and are bearing unprecedented heavy foreign debt burdens.

While in absolute terms agricultural and food production rates have been steadily going up at a reasonable rate of 1-2% per annum since the 1970s, the number of people to be fed is increasing at a faster rate than that of food production and averages 3% per annum (FAO, 1984, and Okigbo, 1986). This has resulted in per capita food production declining at a rate of 10% in the

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last decade — and food imports mainly cereals have been climbing at a 'dizzy speed' of more than 10% per annum since 1970 (Saouma, 1985). Cereal food import bill of Africa has increased nine-fold from U.S. $600 million in 1972 to U.S. $5.4 billion in 1983 (Brown *et al.*, 1986). Food aid amounted to 2-3 million tons in 1983 and was equivalent to about 11% of cereal imports in 1984/85 (FAO, 1984 and 1985).

African countries have been faring worse economically than most other LDCs. Thus the World Bank (1984), reported the per capita GDP of African countries in 1980 to be US $250 with a declining rate of from 2.1% in 1979 to −0.13 in 1983. Per capita income has declined since 1980 at an annual rate of 4.1% and average per capita income is now between 15 and 25% less than 15 years ago (Brown *et al.*, 1986). The annual growth rate of exports in Sub-Saharan Africa was 4.6% while that of imports was 7.1% in 1961/65-1973/77 (Swaminathan, 1983).

Other aspects of the African economic and environmental crises are best summed up by the Worldwatch Institute reports (Brown *et al.*, 1984 and 1986) as follows:

(i) Major elements of man's biological support system (forests, crop-lands, grasslands and fisheries) are under greater pressure of environmental decline than ever before. Excessive pressures of large numbers of cattle, sheep and goats cause overgrazing while droughts have resulted in dwindling animal populations. Desertification is increasing as a result of conversion of productive land into unproductive waste with total desertified area in Africa amounting to about 658 million ha in 1984.

(ii) Some 40% of Africans are living in countries where grain yields per hectare are lower now than they were 30 years ago with excessive soil erosion contributing to growth in external debt.

(iii) Africa is essentially agrarian, but it is losing the ability to feed itself — in 1984, 140 million of its 531 million people were fed with grain from abroad and in February 1985, according to a United Nations report, 10 million people left their villages in search of food.

(iv) One reason for Africa's agricultural disappointment is the expectation that the dramatic advances in grain production in Asia that began some two decades ago could be duplicated. Asian agriculture is dominated by wetland cultivation. A single package of successful yield raising technologies could be easily adapted for use throughout the region. Africa in contrast depends on several staples — maize, wheat, sorghum, millet, barley, and rice among cereals, plus cassava, yams, (other roots and tubers and plantains/starchy bananas) and a highly heterogeneous collection of farming systems.

Of the 31 least developed countries in the world at least 24 are located in Africa. With the exception of Ghana, Liberia and Ethiopia, most African countries got there independence in the 1960s and later under different colonial and historical backgrounds. They exhibit endemic political instability mostly under constantly changing military regimes. But political stability is imperative for effective planning, consistency in policies, strategies and programmes and meaningful rates of agricultural and economic development to be attained on a sustained basis.

It is on the basis of the above background that this paper reviews characteristics of African agricultural production systems, constraints to their improvement and inappropriateness of green revolution and 'modern' conventional agricultural productivity increasing technologies in providing solutions to the African food, ecological, economic and demographic crises. It recommends changes in strategies and technology characteristics for improvement of African agriculture based on biological and emerging technologies selectively integrated with compatible ecologically and scientifically sound, ecologically viable and socially acceptable components of traditional agricultural production technologies.

Characteristics of African Agricultural Production Systems and Constraints to Their Improvement

Despite the diversity that exists in African farming systems in which a mosaic of indigenous African and exotic crops of Asian and American origin are grown and various species of animals reared, the general characteristics of African agriculture based on Okigbo and Greenland (1976) and Okigbo (1933, 1984 and 1985) include:

(i) Objective for farming partly subsistence, but increasingly commercial so as to provide money for goods and services and various social obligations and requirements.

(ii) Farm sizes are usually small and over 80 percent of the farms are between less than 1 and 5 hectares, with farm sizes in the savanna zones usually larger than in the rainforest areas.

(iii) Land development and fertility maintenance involve a slash-and-burn clearance system before a cultivation phase followed by a fallow phase in which fertility is restored through nutrient recycling by plants. Manures and crop residues may be used, especially in compound farms and adjacent fields. Little fertilizer may be used for cash crops.

(iv) Labor is mainly manual and is accomplished with simple tools such as hoes and machetes. Limited use is made of livestock for work due to prevalence of trypanosomiasis, which limits rearing of cattle in some areas, in addition to cultural factors. Mechanization is very much limited and may only be partially employed in ploughing and/or primary processing such as threshing.

(v) Use of pesticides and other chemical inputs such as growth regulators and fertilizers is very much limited since farmers lack credit. Manual and cultural pest and disease control methods are widespread.

(vi) Cropping systems are usually very complex in terms of enterprise mix and range of commodities produced. Mixed cropping or intercropping is very common and serves to reduce risk of crop failure through increased frequency of harvesting without recourse to storage and processing. Very often crop production may be associated with animal rearing. The number of commodities is highest in the humid tropics and lowest in semi-arid areas.

(vii) Animal production systems involve mainly small livestock in the humid and subhumid areas where they serve as sources of manure, meat, and cash in times of emergency. Large animals are kept in the savanna by nomadic herdsmen (Fulani and Masai) who may also keep small livestock and may live in symbiotic relationship with agriculturists. Animals may be kept more for prestige and status than for sale.

(viii) Farming is often associated with hunting, fishing and gathering and sometimes also with a range of non-farm enterprises.

(ix) There is marked division of labor between the sexes and sometimes in terms of commodities produced.

(x) Traditional farming systems take advantage of microecological conditions and various components of the field system ensure that commodities grown are often located where they have obvious ecological advantage or are otherwise adapted.

(xi) Yields are usually low due to widespread use of unimproved crop varieties or breeds of animals and/or limited use of pesticides. Production per unit energy input is usually higher than in modern agriculture.

(xii) These farming systems, while ecologically sound and adapted to prevailing conditions and needs of the farmer when population density is low, are becoming increasingly out-moded and unable to meet demands of rapid population growth, high rates of urbanization, increased mobility, rising incomes and so on.

Typologically, African farming and agricultural production systems include:

(1) *Traditional and Transitional Farming Systems*:

- shifting cultivation and nomadic herding which are the most extensive.
- bush, woodland, thicket and grassland fallows.
- rudimentary sedentary agriculture or recurrent cultivation.
- intensive subsistence and partly commercial farming, e.g., compound gardens.
- specialized agriculture consisting of
  (a) terraced agriculture and
  (b) floodland and valley bottom agriculture.

(2) *'Modern' Farming Systems and Their Local Adaptations*:

- mixed farming (integrated crop and animal production, e.g., in the tropical highlands).
- livestock ranching.
- intensive livestock production (poultry, pigs, dairying).
- large-scale farms and plantations including rainfed farming and irrigated agriculture.
- specialized horticulture including market gardening, truck gardening and fruit orchards and commercial fruit and vegetable production for processing.

Constraints to Increased Agricultural Production in Sub-Saharan Africa

Constraints to increased agricultural production in tropical Africa consist of physico-chemical, biological and socio-economic factors, briefly listed as follows based on Okigbo (1984):

1. *Physico-Chemical Constraints*

(a) Climate

(i) unreliability of rainfall in onset, duration and intensity;

(ii) unpredictable periods of drought and flood;

(iii) reduced effective rainfall in sandy soils and steep slopes;

(iv) high soil temperature for some crops and biological processes (e.g., N fixation);

(v) high rates of decomposition and low OM level;

(vi) cloudiness and reduced photosynthetic efficiency in humid zones;

(vii) acute moisture deficits during several months of the year where dry months exceed 3 months;

(b) Soil: Most soils of the humid and sub-humid tropics are:

(i) highly weathered, sandy, low in clay;

(ii) of low CEC, hence colloidal complex is less active;

(iii) of low inherent fertility except on hydromorphic and young volcanic soils;

(iv) high in soil acidity;

(v) subject to multiple nutrient deficiencies and toxicities under continuous cultivation;

(vi) high in P-fixation;

(vii) subject to intense leaching and of high erosion hazards under prevailing rainstorms.

2. *Biological Constraints*

(a) unimproved crops and animals that exhibit:

(i) low yields and low yield potential;

(ii) susceptibility to diseases and pests;

(iii) unresponsiveness to some 'modern' inputs (e.g., fertilizers).

(b) high incidence of diseases, pests and weeds under favourable tropical environment.

(c) drastic environmental changes resulting from human activities (farming, overgrazing, burning, deforestation, etc.), with adverse effects on ecological equilibrium and balance in nature.

3. *Socio-Economic Constraints*

(a) small farm size more drastically reduced by population pressure;

(b) unfavourable land tenure systems often resulting in fragmentation of holdings;

(c) shortage of labour especially at seasonal peaks of demand;

(d) lack of credit, low income;

(e) poor marketing facilities and pricing structure;

(f) unavailability and high cost of inputs;

(g) poor extension services;

(h) illiteracy and superstition sometimes hampering adoption process;

(i) poor transportation facilities;

(j) shortage and inappropriateness of inputs;

(k) until recently, lack of package approach in technology, design, evaluation and use;

(l) lack of effective farmer organizations and political 'voice'.

Inappropriateness of Green Revolution and Conventional Modern Agricultural Technologies in the Improvement of African Agriculture

It is common knowledge that horizontal transfer of agricultural production systems or their component technologies from the temperate developed countries to tropical Africa has been either unsuccessful or woefully disappointing. The current African food crisis which is the result of failure of over half a century of agricultural research to produce significant impact on the productivity of the vast majority of Africa's small farmers. It is also partly attributable to over-emphasis on export crops during the colonial era and failure of farmers to adopt more risky monocultural production systems of temperate countries that depend on costly inputs and larger farm sizes to maintain high productivity. The failure of large scale farms such as the East African Groundnut Scheme in Tanzania and the Niger Agricultural Project in Nigeria (Baldwin, 1957), and strategies based on the western model of increasing agricultural production that neglect traditional strategies and technologies are reviewed by Eicher and Baker (1982) and UNESCO-UNEP (1978).

Briefly, the modern or conventional agricultural production systems usually rely on the following for increasing yields:

— Costly inputs such as fertilizers, and soil amendments, pesticides and growth regulators some of which may under certain conditions have adverse effects on the environments and living things.

— Mechanization especially with heavy machines and tractors which

- are beyond the means of most African farmers to own, maintain, repair or even hire.
- when used in vegetation removal, land development and conventional tillage often cause compaction and irreversible soil degradation in fragile tropical soils.
- depend a lot on excessive use of costly petroleum fuels which are increasingly becoming less cost-effective.
- have not been developed or adapted for the range of operations used on diverse crops encountered on African farms ranging from planting to harvesting and processing.

— are highly specialized, involving the growing of one or few crops and other commodities on large farms. (Such a system on small farms in Africa is froth with risk of failure and minimizes household food security).

— involve the growing of few crop varieties with narrow genetic base which when grown over large areas are subject to serious damage and losses as pests and disease organisms develop resistance.

— involve technologies that are developed on the basis of strategies that overlook the problems of division of labour between the sexes and growing of crops in mixtures in which some inputs such as herbicides and some machines are difficult to use.

— involve over-dependence on inputs that are not locally available and have to be imported at high cost.

The green revolution relies heavily on the use of fertilizers, pesticides and irrigation on cereals such as rice, wheat and maize which are different from the major African food crops such as roots and tubers, plantains and sorghum grown in different ecological zones in Africa. Moreover, even in such crops as rice, Africa relies on upland rice for over 64% of the crop produced. Also, there are several socio-economic and second generation problems associated with the green revolution in Asia such as those of input distribution, problems of storage,

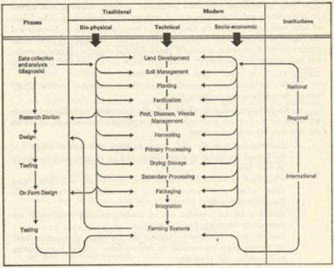


Fig. 1 - Interactions among various factors and institutions in different phases of farming systems design and testing. (*Source*: Okigbo, 1983).

marketing, handling and processing, inequities in income distribution which are socially undesirable.

The above are by no means exhaustive but do give a good picture of problems associated with green revolution and 'modern' conventional technologies.

Appropriate Strategies and Technologies for Improvement of African Agriculture

Concern about failure of technologies being developed on agricultural research stations to gain relatively rapid and widespread adoption by low-resource farmers in most developing countries and about the problems being encountered with the green revolution has resulted in a change in strategy in research aimed at developing appropriate technologies for the improvement of agricultural production in the tropics. This change in strategy led to evolution within the last 10-15 years of Farming Systems Research (FSR) — a holistic approach to agricultural research. FSR entails the study and understanding of the farmer's overall environment (physical, biological and socio-economic), his production systems, input/output relationships, household resource use dynamics and constraints to increased production and adoption of new technologies as a basis for determining strategies and priorities in research for finding more efficient alternatives to the increasingly out-model traditional production systems. Thus it enables due consideration of the farmer's needs and circumstances. Through FSR relevance of new technologies is achieved since it facilitates defining production system characteristics, commodity characteristics and technology characteristics that facilitate development of appropriate packages of technologies or input mixes and resource management systems for increased agricultural production by low-resource farmers. Apart from making research on component technologies more relevant, farming systems research involves a third phase of activities sometimes called on-farm adaptive research (OFAR) by which with the involvement of the farmer, promising technologies and subsystems of production are tested on the farmer's field and technology adoption monitored in such a way as to facilitate feedback to scientists on research stations (see Figure 1). At the same time, the various constraints including policies and rural infrastructure responsible for the yield gap usually observed between research station and the farmer's field can be identified and even quantified and significantly narrowed.

Through FSR it has become obvious that the best strategy to adopt in the improvement of traditional farming systems of tropical Africa is that of integrating desirable elements of modern production systems and emerging technologies with compatible, equally sound and adapted components of traditional African agricultural production systems and their component technologies.

The desirable characteristics of traditional African agricultural production systems that need to be considered in designing new and improved production systems for small farmers include:

(i) the diversification of production through temporal and spatial improvement of multiple cropping patterns that ensure satisfaction of the farmer's subsistence and increasing cash requirements, while maintaining stability of production and reducing risks;

(ii) integration of crop and animal production systems in addition to development of farming systems that involve components of improved agroforestry and agri-silvopastoral systems as circumstances permit;

(iii) the utilization of nutrient cycling and biological nitrogen fixation potentials of plants wherever possible in order to reduce the use of costly fertilizers;

(iv) cropping systems which make as much use as possible of indigenous and underutilized crop plants;

(v) the development of improved cropping patterns, grazing systems and technologies which ensure that the soil is kept adequately protected from erosion and degradation;

(vi) integrated watershed development including the development and utilization of relatively more fertile valley bottoms and hydromorphic soils for which solutions should be found to the various physical, biological and socio-economic constraints that limit their use.

Similarly, the various aspects of 'modern' agricultural production systems and their component technologies that should as far as practicable be incorporated into new improved farming systems for sustained yields include:

(i) mechanization and appropriate technology to minimize drudgery in farm-work while significantly increasing productivity;

(ii) integrated pest management to reduce losses in the field and in storage;

(iii) techniques and methods to increase the efficiency of those fertilizers which cannot yet be replaced by biological processes;

(iv) intensification of production and increased productivity per unit area of land in order to curtail drastically the reliance on expansion of area under cultivation as the main strategy for increasing production;

(v) increased use of irrigation and water harvesting in semi-arid and arid areas with measures taken to ensure adequate drainage and to minimize salinization;

(vi) methods for eliminating tillage altogether or minimizing it;

(vii) greater utilization of techniques and potentials of conventional genetic improvement of crops and animals;

(viii) judicious use of agricultural chemicals.

In realizing the potentials of the strategy of integration of traditional and modern technologies with greater cost-effectiveness and concern about the environment, the following emerging technologies may be taken advantage of:

(i) biotechnologies including tissue culture and related genetic manipulations;

(ii) appropriate use of soil conditioners, growth regulators, and related chemical substances;

(iii) novel food processing techniques;

(iv) new and renewable energy sources;

(v) computer techniques including modelling; and

(vi) collection and dissemination of agricultural data obtained from remote sensing.

Other Relevant Recommendations and Guidelines

To achieve more rapid progress in development of more appropriate technologies and efficient alternatives to prevailing farming systems in Africa, the following recommendations and guidelines are pertinent:

1. High priority should be given to the genetic improvement, production and utilization of roots and tubers, indigenous neglected crops, legumes and other crops that have not been involved in the green revolution.

2. Appropriate policies and institutional arrangements that should be used to facilitate progress in achieving desirable objectives within a given time-frame include:

(i) cooperation at national, institutional, regional and international levels;

(ii) cooperation and coordination of research and development at all levels and effective linkage of research, extension, training and the farmer;

(iii) adequate human resources development at various levels in different disciplines with provisions that ensure technical and practical competence in training and development of needed skills;

(iv) interdisciplinary cooperation of scientists in accordance with the increasing trend towards integrated approaches to agricultural problems;

(v) alerting of policy makers and politicians to the potential of the new agricultural strategies which more systematically utilize advances in science and technology — this should lead to the necessary political commitment to allocate adequate resources to promising research and development strategies;

(vi) last, but not least, effective communication among scientists, extension workers, farmers, policy makers, and the general public.

These recommendations and observations are based on Okigbo (1983) to which reference should be made for more detailed discussion.

Progress in the Development of Appropriate Technologies for Sustainable Farming Systems in Tropical Africa at IITA

The International Institute of Tropical Agriculture (IITA) is one of the 13 international agricultural research centers (IARCs), supported by the Consultative Group for International Agricultural Research (CGIAR). Four of these IARCs located in Africa include:

— IITA: International Institute of Tropical Agriculture at Ibadan in Nigeria (founded in 1967).

— ILCA: International Livestock Center for Africa at Addis Ababa, Ethiopia (founded in 1974).

— ILRAD: International Laboratory for Research in Animal Diseases at Nairobi, Kenya (founded in 1973).

— WARDA: West African Rice Development Association at Monrovia in Liberia (founded in 1971 with CGIAR co-financing in 1974).

All the IARCs have as their general objective the execution of mission-oriented research and training on CGIAR mandated commodities and/or problems that directly or indirectly contribute to the quantitative and qualitative improvement of food production in the major ecological zones in the developing countries of the world. More specifically, IITA's mandate calls for:

1. Quantitative and qualitative improvement of major crops of the lowland humid tropics including:

— Rice for tropical Africa.

— Maize for tropical Africa.

— *Grain Legumes*
- cowpea worldwide.
- soybeans for tropical Africa.

— *Roots and Tubers*
- cassava for tropical Africa.
- yams worldwide.
- sweet potato.
- cocoyams worldwide.

2. Development of improved farming systems for sustained productivity in the lowland tropics of the world as alternatives to shifting cultivation and related fallow systems. The IITA's work in farming systems, which is mainly restricted to cropping systems for major crops of the lowland humid tropics, included a special research and training programme on plantains and starchy banana production systems. In its Africa mandated or oriented research and training activities, IITA collaborates with and receives effective support of IARCs that have the world mandate. For example, in rice IITA receives support from IRRI.

To achieve the above objectives, IITA's research and training activities are organized into the following programs:

1 - Rice (*Oriza sativa*) Research Programme (RRP)

2 - Maize (*Zea mays*) Research Programme (MRP)

3 - Grain Legumes Improvement Programme (GLIP):

— cowpeas (*Vigna unguiculata*)
— soybeans (*Glycine max*)

4 - Roots and Tubers Improvement Programme (RTIP):

- cassava (*Manihot esculenta*)
- yams (*Dioscorea* species)
- sweet potato (*Ipomoea batatas*)
- aroids (*Colocasia esculenta* and *Xanthosoma saggitifolium*)

5 - Farming Systems Programme (FSP):

- Land development and soil management.
- Cropping systems for major food crops plus plantan and starchy bananas.
- Socio-economic studies - production economics and fain and starchy bananas.
- Mechanization and appropriate technology for small farmers.
- Socio-economic studies - production economics and farming systems research (FSR).

6 - International Cooperation and Training Programme (ICTP):

- Special cooperative projects with national institutions.
- Research, production and special training activities.

7 - Document, Information and Library Programme (DIL):

- Library and documentation.
- Publications and audio-visuals.
- Mailing and distribution of publications.
- Conferences, workshops and seminars.

8 - Research Support Units:

- Virology Unit (VU)
- Germplasm Resources Unit (GRU)
- Africawide Biological Control Programme (ABCP)
- Demonstration Unit.

The above include research programmes and activities (nos. 1-5 plus 8 in part) and the other units, whose activities provide back-up for research or otherwise, contribute to IITA's technology testing and adoption processes.

In all the research programs of IITA, 'integrated' approach strategies are adopted which minimize reliance on chemicals and costly inputs while giving high priority to technologies that have minimum adverse effects on the environment. Details of the objectives, priorities and focus which reflect this overall strategy of de-emphasising inappropriate green revolution technologies can be identified in the following objectives of IITA's research programs.

Objectives of IITA's Crop Improvement Programs

All IITA's crop improvement programs give priority to:

- increased yield;

— improved quality (e.g., reduction in content of toxic constituents);
— resistance to diseases and pests;
— adaptation or tolerance to environmental stresses;
— adaptation to different cropping systems;
— adaptation to mechanization;
— meeting preferences of consumers and suitability for certain food preparations;
— reduction of some post-harvest losses and suitability for processing.

Many new crop varieties produced by IITA have increasingly wider genetic base and possess several traits that satisfy more than one of the above objectives.

Objectives of IITA's Farming Systems Program

In its overall objective of developing more efficient farming systems for sustained yields that constitute suitable alternatives to the prevailing fallow systems, due consideration is given to the various desirable and undesirable characteristics of traditional African and 'modern' or conventional component technologies and systems of production. Consequently, objectives and characteristics of technologies, to which high priority is being giving by the Institute's FSP include:

— potentiality for increasing production per unit area and input;
— reduction of drudgery in farming and minimizing rural-urban migration;
— reduced cost of inputs;
— labour-saving potential of operations ranging from land clearing and planting to harvesting;
— minimization of hazard to man ad, animals and environment;
— suitability for fulfilling the differential needs and roles of women and men.
— overall economic viability, ecological soundness and suitability and cultural acceptability.

The various sub-systems and systems of production and associated practices to which IITA is giving high priority are those that fulfill objectives of the farmer and those outlined above, including:

— Improved and more efficient cropping patterns and systems in terms of
 · crop combinations and spatial arrangements (sole to mixed, two or more).
 · suitable sequences and rotations, e.g., relay intercropping, sole and/or intercrop rotations.
 · improved land development and tillage practices (shear blade clearing and no-till planting).
 · improved soils, soil cover and plant residue management (dead mulch and living mulch).

— Integration of arable crops and suitable shrubs/trees with or without animals
- alley cropping.
- alley cropping with animals.
- plantain-based cropping systems.

— Integrated watershed management in which cropping and/or land use is adapted to different topo-sequences or places in landscape (Figure 2).

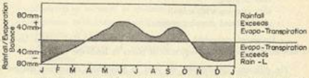
The different toposequences are used to grow those crops best adapted to the prevailing soil conditions and water table. The lowest valley bottom areas are wetland that can be used for rice-based cropping systems and aquaculture. The highest contours are used for tree crops or pasture. Several arable upland crops are grown in-between these zones (Figure 2).

Progress in IITA Towards a New Green Revolution in Tropical Lowland Africa

Considerable progress has been made in IITA in crop improvement and the development of technologies, practices and production systems that minimize use of chemical inputs and/or eliminate some undesirable characteristics and problems associated with the 'first green revolution'. In the crop improvement programs of IITA improved varieties of rice, maize, cowpeas, soybeans, cassava and sweet potatoes have been selected and developed that significantly give higher yields than the local or popular varieties grown by most farmers and at the same time possess a wider spectrum of other desirable characteristics. These are briefly reviewed below.

Rice Improvement

About 60% of rice grown in tropical Africa is upland. Consequently, IITA gives priority to improvement of upland rice, hydromorphic or lowland and irrigated rice varieties varying in yield from 1.5 to 3.5 t/ha, height from 78-120 cm, maturity from 100-130 days, tolerant to drought and resistant to blast, sheath rot and glume discoloration have been developed. Local upland rice varieties rarely give yields of more than 1 t/ha. Improved high yielding long grain irrigated rice varieties developed at IITA yield from 3.5-7.5 t/ha as compared to 1-2 t/ha for local varieties. These vary in height from 80-136 cm, in growth duration from 105-138 days, with varying degrees of tolerance or resistance to lodging and iron toxicity. Some of the lowland rice varieties developed at IITA give yield of 4-6 t/ha and exhibited resistance to sheath blight, sheath rot, *Diopsis* (stalked eye fly) and rice yellow mottle virus (RYMV).



Illustrates above the pattern of Rainfall providing two Rain-Fed seasons and also a patentially more productive dry season. F excess Rainfall is conserved in Tanks (I-E-Water harvesting) to extend the growing season.

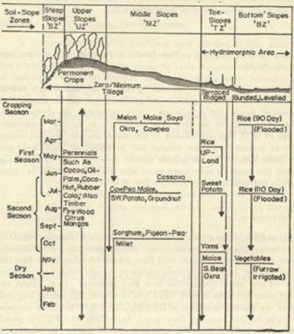


Fig. 2 - (*Source*: Okigbo, 1984).

Maize Improvement

Marked progress has been made in development of improved maize varieties (open pollinated and hybrids) with priority given to development of maize varieties for (1) mid-altitudes of 1000-1500 m and 150-180 days full season, (2) lowland tropics of 110-120 days full season, (3) lowland tropics early maturing varieties of about 90 days duration, (4) highland tropics early maturing types of 150-170 days duration and full season types of 180-240 days and (5) tropical mid-altitudes early maturity of 110-120 days.

In all varieties, yellow and white varieties are developed for poultry and human consumption with priority given to development of varieties resistant to the maize streak virus, maize mottle virus, rust, ear and stalk rots, downy mildew, stem borers (Sesamia, Eldana and Busseola species), lowland blight, striga, and environmental stresses such as drought. The most important break-through is the development of streak resistant early, medium and late maturing composites and hybrids. The early maturing varieties yield 2-4 t/ha as compared to less than 1 t/ha for local varieties and medium to late varieties with yields of from 3-7 t/h as compared to 1-2 t/ha for open-pollinated varieties. There are now hybrids that give up to 4-7 t/ha in the humid lowlands and more than 6-10 t/ha in the savanna zones. IITA maize varieties now cover over 75% of the cultivated maize area in Nigeria.

Grain Legume Improvement

The cowpea constitutes Africa's most important indigenous legume but is bedevilled by a host of diseases and there are insect pests that attack the crop at every stage of its life cycle. Of the cowpea diseases, sources for resistance have been identified for cowpea mosaic virus, aphid borne mosaic, golden yellow mosaic, cowpea aphid borne mosaic, cowpea yellow mottle, anthracnose, rust, bacterial blight, *Cercospora*, *Fusarium* wilt, scab, brown blotch, *Phythophthora* stem rot, *Septoria*, root knot nematodes, etc. Similarly, sources of resistance have been identified for leaf hoppers, aphids, *Maruca* pod borers, flower thrips, bruchid weevils and so on. These various sources of resistance have been combined in varying degrees in improved high yielding varieties which are now available in extra early (55-60 days maturity), early (60-70 days) and medium maturity (75-85 days) lines. The new cowpea varieties give yields of 1-2 t/ha as compared to 600-800 kg/ha for local varieties. In the past, 6 or more sprays were required for good yields but now with improved and insect resistant varieties 2-5 well timed sprays are necessary depending on variety, nature and severity of insect attack. Resistance to bruchids in cowpeas has reduced losses in storage while plant characteristics such as growth duration and plant type have adapted some cultivars to different cropping systems. For example, the early maturing varieties are suitable for both intercropping and relay or rotational cropping sequencies in which they utilize residual moisture after a longer duration crop such as rice.

Soybeans

Soybeans are a new crop in tropical Africa. Although areas of Sub-Saharan Africa suitable for soybeans vary from 140-270 million hectares, less than 5% of this area is currently being utilized. Early attempts to grow soybeans from colder climates in the tropics encountered problems of low seed viability, low yields, inability to nodulate with indigenous rhyzobia, shattering, stink bug and virus damage. Improved soybeans adapted to the tropics have been developed at IITA with satisfactory levels of storability, ability to nodulate with indigenous rhizobia and yields of 1.5-3.5 t/ha.

Roots and Tubers Improvement Program

Cassava is one of the major starchy staples on which millions of people in the humid and subhumid regions depend. Africa accounts for over 39% of the world's cassava and cassava is a crop which is adapted to marginal soils and even in the cereal dominant drier areas, cassava is grown as a famine relief crop. Improved cassava varieties developed at IITA give yields 20-50 t/ha in 12-15 months as compared to 6-10 t/ha in farmers' fields. Many of the improved varieties possess resistance to cassava bacterial blight, cassava mosaic disease and anthracnose and tolerance to cassava mealybug and cassava green mite. Other characteristics of IITA cassava varieties include good leaf yield and canopy retention, which suppresses weeds, low hydrocyanic acid content and suitability for several food preparations.

Sweet potato is a minor crop in tropical Africa but its consumption is increasing especially in urban areas. Sweet potato also has a high industrial potential which is not being realized. IITA has developed some varieties of sweet potato that are resistant to the sweet potato weevil and virus disease with yields ranging from 15-50 t/ha. Some possess good leaf yield and canopy cover for suppressing weeds.

Yams and Aroids

Limited progress has been made in the genetic improvement of these vegetatively propagated root and tuber crops. However, much progress has been made in identifying and selecting yam varieties that produce seeds and developing methods for breaking dormancy of yam seeds thus facilitating their genetic improvement. However, much progress has been made in development of micro-propagation and multiplication of yam tubers, especially by the mini-set technique which reduces yam set shortage and cost of sets. Yam varieties with spherical tubers that can be more easily harvested by mechanical means have been identified.

Less progress has been made in aroids as compared to yams. But by treatment with gibberelic acid flowering can be induced especially in *Xanthosoma species* and crosses have been made that resulted in varieties with some resistance to cocoyam blight.

Progress in Farming Systems and Development of Appropriate Technologies for Low Resource-Farmers

The mechanical and appropriate technologies developed for small farmers in tropical Africa include:

— CDA sprayers which are solar or battery powered and hand or tractor carried. This facilitates effective killing of weeds and crop residues to facilitate no-till seeding.

— Jab planters that are hand-fed or autofed which facilitate seeding through thick cover of crop residues.

— Rolling injection planter which may be hand-carried or tractor mounted and also facilitates planting through crop residues (Figure 3).

— Hand-operated cassava harvester or harvesting lever.

— Cowpea harvester.

— Cheap, simple maize storage cribs that can be constructed from locally available materials.

— Maize shellers (hand-operated).

— Rice threshing machine.

The above are by no means exhaustive but one or more of them can be used in different cropping or farming systems some of which have been listed above. With these, yields can be increased per unit area and sustained from year to year. They include:

— intercropping and relay cropping which usually give higher total yields per unit area of land.

— cropping sequences and rotation in short-term and long-term situations.

— mulching, which increases yields and soil fertility, minimizes erosion while increasing water-infiltration and reduces soil temperature and its fluctuations. Both dead and living mulches can be used. Living mulches have the additional potential of facilitating crop production on steep slopes.

Of the production systems of high sustainability, IITA has developed the alley cropping technique by which arable food crops are grown in rotations in-between hedgerows that are periodically pruned to supply mulch, nutrients and fuelwood (Figure 4). Advantages of alley cropping include:

— supply of mulch which prevents erosion, increases water infiltration and supplies soil organic matter.

— increase and maintenance of soil fertility, especially where leguminous shrubs or trees are used.

— reduction of amplitude of soil temperature/fluctuation and provision of favorable environment for soil organisms, e.g., earthworms.

— supply of fuelwood or charcoal.

Fig. 3 - Rolling injection planter: an appropriate technology for low-resource farmers developed at IITA: manually operated, it facilitates sowing of seeds through thick plant residues.

Fig. 4 - Alley cropping - a sustainable cropping system by which food crops are grown in-between hedge rows of woody trees and shrubs which are periodically pruned to obtain mulch, food, fuelwood, etc. Here cowpeas are growing between alleys of *Leucaena leucocephalia.*

— supply of stakes for viney crops.

— supply of fodder for livestock.

— supply a range of raw materials as sources of drugs, structural materials, fibre, biomass for feed stocks, etc. (Figure 5).

Any of the above technologies can be used in association with integrated watershed management systems which ensure sustainability of yield, especially where soil conservation measures are taken.

Emerging Technologies which have been Found to Facilitate Better Use of Technologies Developed at IITA

Tissue culture is one of the emerging technologies that has proved useful to IITA in accomplishing the following:

— germplasm maintenance.

— production of disease-free clones which facilitates distribution and exchange of germplasm.

— micro-propagation and multiplication of improved material of low multiplication ratio.

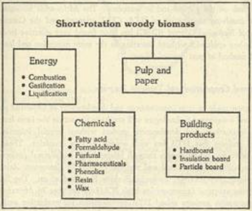


Fig. 5 - Biomass from trees grown in short rotations is a source of many products, including chemical feedstocks. Phenolics are used in the manufacture of adhesives, fungicides, and plastics. Furfural is used in making industrial solvents. (*Source*: Chow *et al.*, 1983).

— various genetic manipulations such as mutagenesis, protoplast fusion, organelle transfer, wide crosses, etc.

The use of tissue culture to facilitate distribution of disease-free improved planting materials and various genetic manipulations in cassava, sweet potato, yams, cocoyams and plantains, and use of biological control as a component of integrated pest management are illustrations of how emerging technologies can be integrated in a most cost-effective way in boosting food production in developing countries. With little investment in training and facilities in national institutions, capabilities can be developed for taking advantage of by-no-means sophisticated and expensive technologies. It is however necessary that both IARCs and national research institutions develop a critical mass of manpower and facilities that ensure that they keep abreast of developments in biotechnology and other emerging technologies in institutions in developed countries so that they can make use of the relevant results of research without major investments in basic and more sophisticated research.

A recent development is that of the Africa-wide biological control programme to combat the cassava mealy-bug caused by *Phenococcus maniboti* and cassava green mite caused by *Mononychellus spp.* which spread over large areas of tropical Africa between 1970 and 1982 (Figure 6). Apart from identifying sources of genetic resistance, natural enemies of which the most effective is *Epidinocarsis lopezi*, an exotic parasitoid of the mealy-bug and predators such as *Diomis spp.* have been introduced from Latin America, reared en masse under laboratory conditions and released both on the ground and by aeroplane. The Africa-wide biological control program, involving cooperation of IITA, CIAT scientists and the Commonwealth Institute of Biological Control (CIBC) has been found very effective in combating the mealy-bug epidemics without resorting to the more expensive and less-effective chemical method of pest control (Figure 7).

International Cooperation and Training Program

Progress made in crop improvement and development of improved production systems and component technologies will not have impact on the farm level and on national institutions and development project without special international co-operative projects that IITA has with several African countries. These projects that are often funded by donors through bilateral and multilateral projects involve 42 off-site scientists in national and regional projects in Cameroun, Zaire, Kenya, Ghana, Niger, Sierra Leone, Tanzania, Burkina Faso and so on. The SAFGRAD project being executed in cooperation with ICRISAT involves 26 African countries. These cooperative projects afford IITA opportunities for evaluation and adoption of improved varieties of the Institute's mandate crops and improved farming systems technology.

Training which is associated with these special projects enables IITA to

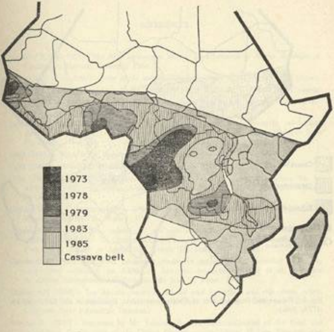


Fig. 6 - Spread of *Phenacoccus manihoti* (cassava mealybug) between 1973-1985. Origin of *P. manihoti*: South America. (IITA, 1986).

assist national institutions develop capabilities in research and production. Since its inception, IITA has altogether trained about 4,000 participants with 3,530 from Africa, 136 from Asia, 104 from Europe, 77 from Latin America and 9 from Oceania. Altogether 204 research scholars and 114 research fellows have been involved in thesis-related research training for the M.Sc. and Ph.D. degree equivalents, respectively. Group courses for production training have been taken by 3076 participants while non-degree training has been given to 230 vacation students and 311 research associates. In 1985 alone, 678 participants were involved in group production courses and 62 in degree-related training. In a country such as Zaire alone, 153 nationals have received IITA training including 19 M.Sc.

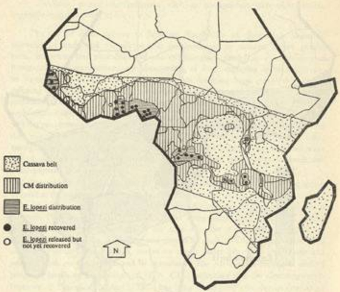


Fig. 7 - Release and Dispersal Area of *Epidinocarsis lopezi*, Parasitoid of the CM in Africa. (IITA, 1986).

and 11 Ph.D. holders all of which are now totally responsible for the country's cassava research and production program. Some training programs have been extended to Luzophone African countries.

Conclusion

With the strategies which IITA is adopting in research and training programs which involve many non-cereals unaffected by the first green revolution and priorities being given to minimization of chemicals and problems associated with the first green revolution in Africa, it is hoped that a second green revolution based more on biological innovations than chemical ones will soon occur in Africa. This development will benefit the majority low resources farmers as well as the few large scale ones, in Africa.

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