RCMP Research Monograph No. 7

ANNUAL REPORT 1990

Highlights of Scientific Findings

Resource and Crop Management Program
International Institute of Tropical Agriculture

The International Institute of Tropical Agriculture (IITA) is an autonomous nonprofit institution, with headquarters on a 1,000-hectare experimental farm at Ibadan, Nigeria. It was established in 1967 as the first major African link in an integrated network of international agricultural research and training centers located in the major developing regions of the world.

Funding for IITA came initially from the Ford and Rockefeller foundations. Land for the experimental farm was allocated by the Government of the Federal Republic of Nigeria. Principal financing has been arranged since 1971 through the Consultative Group on International Agricultural Research (CGIAR).

The Resource and Crop Management Program (RCMP) is concerned with two of the three main thrusts of IITA research, namely: resource management research, which is the study of the natural resource base with a view to refining existing resource management technologies and devising new ones, and crop management research which aims at the synthesis of the products of resource management research and plant breeding into sustainable and productive cropping systems.

The goal of RCMP is to develop economically and ecologically viable farming systems for increased and sustainable production by the smallholder or family farmer of Africa, while conserving the natural resource base.

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Preface

The RCMP Research Monograph series is designed to widely disseminate results of research on the resource and crop management problems of smallholder farmers in sub-Saharan Africa, including socioeconomic and policy-related issues, and to contribute to existing knowledge on improved agricultural principles and policies and the effect they have on the sustainability of small-scale food production systems. These monographs summarize results of studies by IITA researchers and their collaborators; they are generally more substantial in content than journal articles.

The monographs are aimed at scientists and researchers within the national agricultural research systems of Africa, the international research community, policy makers, donors, and international development agencies.

Individuals and institutions in Africa may receive single copies free of charge by writing to:

The Director
Resource and Crop Management Program.

Resource and Crop Management Program
International Institute of Tropical Agriculture
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I. Introduction

Goal of RCMP

Our goal in RCMP is to develop economically and ecologically viable farming systems for increased and sustainable production by small-scale family farmers while conserving the natural resource base.

The resources with which we are most concerned are soil, water, interception of solar radiation, labor and other energy resources, crop and fallow vegetation, and material inputs (fertilizers and chemicals, among others).

Conceptual Framework of RCMP

We distinguish two closely related areas of research - resource management research and crop management research.

Resource Management Research (RMR) involves three linked phases of activity:

a. Diagnosis: measurement of the physical, chemical and biological elements of the natural resource base and of the socioeconomic implications of its exploitation.

b. Analysis: examination of the determinants of stability and degradation of the resource base by studying the dynamic interactions of these elements.

c. Design: modification of existing resource management practices or the design of new ones capable of stabilizing or increasing output while avoiding the degradation of the resource base.

The focus of Crop Management Research (CMR) is to understand the constraints and potentials of selected farming systems and to devise appropriate technologies for their improvement.

CMR also involves three linked activities:

a. Diagnosis: characterization of mandated cropping systems areas, the description and analysis of constraints, and the impact of new technology.

b. Validation and adaptation: on-farm screening, testing, and evaluation of technologies generated during experiment station research. Adjustment or adaptation of existing technology to a particular set of environmental conditions, either agroecological or socioeconomic, through on-farm research.

c. Feedback: relevant information from farm level characterization, diagnosis and adaptive research reported back to scientists developing resource management technologies or breeding improved varieties at IITA's research stations.

The selected farming systems on which RCMP concentrates, based on IITA's mandate and focus, are cassava-based systems in the forest zone, maize-based systems in the transition and savanna zones, and rice-based systems in the inland valley agroecosystems.

RCMP is organized into a Resource Management Research Unit and three Systems-based Working Groups which conduct crop management research.

II. Resource Management Research

Agroclimatology

Up to date machine readable climatic data for Africa are rare. Significant steps were taken in 1990 to correct this situation. For Nigeria, daily climatic data were computerized from 44 stations and monthly data from 108 stations. Long-term climatic normals for countries in Africa, South America, and for India were obtained. Software for data quality control and analysis was developed.

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) maize model was tested for IITA maize variety TZSRW. Since the genetic coefficients were not available for this variety, it was necessary to develop a genetic coefficient calculator as a substitute. Using this substitute, it was found that the maize model simulated field performance of maize under sole cropping in Nigeria. The model needs modification to take account of nutrient contribution from *Leucaena leucocephala*, in alley cropping systems.

A modern geographical information system (GIS) laboratory with sufficient hardware, software and data bases was established. A computerized resource information system (RIS) was developed to:

- Allow the overlay of an unspecified number of layers of information.
- Generate maps of areas with specified environmental conditions.
- Allow zooming for a detailed look at any selected area.
- Determine the agroecological conditions of a region or location. Cooperative working arrangements were established with national and international institutions.

Soil Physics

Experiments started on the acid ultisol (typic kandiudult) of the humid forest research station in Mbalmayo, Cameroon. In an experiment on the quantification of soil physical changes under no-tillage and alley cropping with *Cassia spectabilis*, no-tillage increased the crop yield of maize and plant height of *C. spectabilis*. Soil bulk density and infiltration rate were not affected by tillage or cropping system. Lower soil temperatures were observed in mixtures of cassava + maize + melon during the period of melon growth.

When the site was cleared, the vegetation was burnt in piles 1-1.5m high and 1-2m in diameter. It was established that this burning resulted in moderate soil compaction to a depth of 0.15m but that this was not sufficient to eliminate plant growth. The observed absence of plant growth may, therefore, be due to chemical imbalances created. These are being investigated further.

Soil erosion studies continued under the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) collaborative project on ultisols in Cameroon and alfisols in Nigeria. Soil loss under the ultisols is much greater than that recorded for the alfisols. For example, in ultisols in Cameroon, soil loss was 42 tons ha^{-1} compared to 0.1 ton ha^{-1} on the alfisols in Nigeria in the no-till treatment. After plowing, soil loss was 150 tons ha^{-1} on the ultisols compared with 2.5 tons ha^{-1} in the alfisols. In the bare fallow treatment, the losses were about 644 tons ha^{-1} on the ultisols and 140 tons ha^{-1} on the alfisols. The smaller soil losses and disturbances in the no-tillage treatment resulted in higher soil fertility status, as measured by higher organic carbon and other major nutrient contents. However, in neither the alfisols nor the ultisol does this higher soil fertility status result in larger maize, groundnut or cowpea yields. After 5-7 years of continuous cultivation, crops yields declined but they were higher in plowed plots compared with no-till plots. Plowing of the no-till plots after five years of cultivation resulted in a significant increase in maize grain yield from 1.9 tons in 1989 to 4.3 tons. Mineralization of the organic matter increased the active organic matter pool. This resulted in a much higher yield than that recorded in the plots which had been previously tilled.

Weed Science Research

Pseudovigna argentea is a herbaceous legume which has a reduced climbing habit compared with other herbaceous legumes and is being assessed as a live-mulch cover crop in maize production systems. Results in 1990 showed that *P. argentea* controls weeds adequately in monocrop maize systems. There was no significant effect on maize growth and grain yield between unweeded plots and those weeded once or twice for all levels of fertilizer application. However, maize responded significantly to applications of fertilizer.

In an experiment on weed control in alley cropping systems in the sub-humid zone on alfisols, alley cropping *per se* did not have any significant effect on weed density or biomass. However, it caused a shift in weed flora from perennial grass weeds and *Euphorbia heterophylla*, present in no-tillage plots cultivated every year, to *Synedrella nodiflora* (a shade tolerant weed), with no perennial grass weeds in *Leucaena* plots cropped every other year. Maize grain yield was significantly higher in the *Leucaena* alley system that was cropped every other year than in plots cropped yearly, or in no-tillage plots cropped continuously (no-alley crop). However, the increased yield would not be sufficient to cover the output loss during the year of fallow. Also, mean yields across weed control treatments were significantly higher in plots that were weeded once or twice than in unweeded maize plots.

Weeds are suppressed in arable crops intercropped with *Crotalaria verrucosa*. Maize grown in the subsequent year requires less weeding and less nitrogen fertilizer than plots without a previous history of *Crotalaria* use.

Studies on the chemical control of weeds showed that maize grown in *Imperata* infested fields requires 4-5 weedings before crop harvest. However, only 2 weedings are needed where the *Imperata* is sprayed the preceding year with glyphosate at 1.8 or 3.6kg ha^{-1}, fluazifop-butyl at 2.0kg ha^{-1}, or imazapyr at 1.25kg ha^{-1}. Also, several herbicides that do not contain hydrazine were identified for weed control in maize.

Soil Microbiology

Research work in soil microbiology was carried out in the areas of:

- soil organic matter
- N cycling
- mycorrhizae
- establishment of hedgerow trees.

The emphasis was on the quantification of soil and vegetation (essentially trees) parameters that interact with (i.e., that determine or are influenced by) soil productivity and plant biomass production. The focus was on: (i) soil organic matter fractions and their response to management practices (ii) the symbiotic properties of trees used in alley cropping and in improved fallow systems as an important feature that determines tree biomass production and nutrients acquisition in poor and stressed soils.

Amounts of soil organic matter (SOM) fractions, in particular the size of the "floating" (i.e., small particles derived from decomposition of plant materials) and the light (active) fractions, were determined in soils of different pH, cropping systems and vegetations. The largest amount was found in the 0-5cm soil layer where organic inputs such as plant litter and tree prunings are undergoing decomposition. Differences in the active SOM fraction between the 0-5cm and the 5-10cm soil layers were, however, not always significant. Fallowing for 1 to 5 years generally increased the levels of the active SOM fraction, with some correlation with fallow length. The "floating" and light fractions were larger on mounds at 0-10cm than in the space between mounds. In fallow plots planted with *Acioa*, soil contained more "floating" materials than in plots where *Acioa*, *Dialium* and *Anthonata* were the protected fallow species. Also soil (0-5cm) under the non-leguminous species *Acioa* and *Dialium* contained larger amounts of "floating" and active SOM than the soil under the legume *Anthonata*. This indicates the influence of vegetation on soil organic matter. Nitrogen fertilization did not influence the size of SOM fractions (in an experiment at IITA), but soil fertility status was significantly correlated with the amounts of SOM fractions (at Niaouli, Benin).

Leaves containing relatively high amounts of lignin decomposed at slower rates than leaves with low lignin content. This principle was used to reduce the rate of decomposition of *Gliricidia* and *Leucaena* leaves (about 15% lignin) by mixing them with *Acioa* leaves containing about 35% lignin. Leaf decomposition measured as CO_2 release was also found to be much influenced by soil moisture and rainfall frequency. During decomposition of *Gliricidia* leaves, we recorded N losses through volatilization up to 4% of the N applied. No significant N volatilization was detected from *Cassia* leaves.

Nitrogen fixed from the atmosphere defines N_2 gains in cropping systems. There is a need to estimate how much N_2 is fixed. We found a close agreement between the difference method and the more accurate but expensive ^{15}N dilution method to estimate N_2 fixed by 1-year-old woody species. We used more than one reference tree and found that N uptake of some non N_2 fixing species can be higher than that of N_2 fixing species. Selection of

reference trees is thus critical for the accuracy of methods used to estimate N_2 fixation. Inoculation of *Leucaena leucocephala* with rhizobium resulted in N_2 fixations of more than 300kg ha^{-1} $year^{-1}$. Uninoculated *Albizia lebbeck, A. saman, Gliricidia sepium, Leucaena leucocephala, Calliandra calothyrsus* and *Cajanus cajan* fixed on average 200kg N ha^{-1} $year^{-1}$ in microplots. We also found differences in the partitioning of fixed N_2 in plant organs. Unlike *Leucaena* which stored most of its fixed N_2 in leaves and pods, *Gliricidia* directed to the roots about 40% of the N_2 fixed. These observations have implications in alley cropping. In this system, trees are pruned periodically. The prunings constitute a source of nutrients. When pruning is done at short intervals, it reduces the production of above- and below-ground biomass, but not the ability to fix N_2, though the total amount of N_2 fixed is less in pruned trees.

Mycorrhizal infection increased the shoot P and dry weight, and/or uptake of immobile molecules such as Zn and Cu by all woody species studied. It promoted the nodulation of *Faidherbia albida* and *Acacia nilotica*, and reduced the effects of drought stress on the growth of *Gliricidia sepium* and *Leucaena leucocephala*. Mycorrhizal symbiosis is thus beneficial during tree establishment and for plant biomass production.

Requirements of N, P and K for increased growth and nodulation were defined for 11 woody species. These requirements were diverse, with differences between tree genera, species and cultivars. Radiation data suggested competition for light at spacings shorter than 75cm. To obtain similar above-ground biomass for 75cm spacing between *Leucaena* and maize as for sole *Leucaena*, it was necessary to apply 120kg N ha^{-1}. At shorter spacings, fertilizer N application increased tree biomass but not significantly, and radiations received by *Leucaena* were low.

Soil Fertility—Non Acid Alfisols

In the ninth year of continuous cultivation of maize followed by cowpea in alley cropping plots established on a degraded alfisol, maize grain yield in plots without nitrogen fertilizer application was the same in plots alley cropped with *Acioa, Alchornea*, and the control plot (no hedgerow). In alley cropped plots with *Gliricidia* and *Leucaena* but with no applied nitrogen, the yields were the same as those in the control (no hedgerow), *Acioa* or *Alchornea* plots receiving 45kg N ha^{-1}. With 45kg N ha^{-1}, application to alley cropped plots with *Gliricidia* and *Leucaena*, maize grain yield was as high as those in the control plots (no hedgerow) receiving 90 or 135kg N ha^{-1}. Maize plants had adequate micronutrient levels in all the treaments. However, it emerged that hedgerow prunings of *Alchornea, Gliricidia* and *Leucaena* recycle significant amounts of Cu, Fe, Mn and Zn compared with *Acioa*. Repeated additions of these prunings increase surface soil Zn status under *Gliricidia* and *Leucaena* and may, in the long run, affect the performance of maize plants.

In another long-term alley cropping trial with *Leucaena* grown at 2m inter-hedgerow spacing with alternate year cropping, it was confirmed that 2 hand weedings, the normal practice among farmers, would be sufficient to control volunteer *Leucaena* and result in optimum maize yield.

In the long-term alley cropping trial with *Gliricidia* and *Leucaena* on land with a 70% slope established in 1982, a switch was made from sole crop maize to maize intercropped with

cassava. The pattern of water run-off and erosion was the same as that recorded in previous years with sole crop maize. Run-off and erosion were greatest in tilled plots without hedgerows and lowest in *Leucaena* plots planted at 2m. Maize grain yield was also lowest in the tilled non-alley cropped plots and highest in the *Leucaena* 4m alley cropping plots.

In studies to determine the nutrient requirements for the establishment and growth of *Leucaena* and *Gliricidia* in non-acidic soils, it was shown that both species responded significantly to rhizobium inoculation and N-fertilizer application at half of the test sites in the derived and guinea savanna, with positive interactions between both treatments. *Gliricidia* produced a higher biomass yield during early growth than *Leucaena*.

In a study of the effect of plant residues with different chemical composition on soil fauna activities and subsequent maize crop yield, it was shown that nitrogen application and mulching on Egbeda soil, which has been under grass fallow for 6 years, increased earthworm population, biomass yield, and maize grain yield. Application of nitrogen and slowly decomposing mulch increased termite population. Ant population increased with N application and *Leucaena* mulch. Myriapod population was not affected by the application of either N or mulch.

In an alley cropping trial with *Leucaena* and *Cajanus cajan* in a degraded nitosol in the Republic of Benin, yields of maize, either as sole crop or intercropped with cassava in the fifth cropping year, were lower in the alley cropped than the non-alley cropped plots. Fertilizer response was significant, particularly in the alley cropped plots. Results suggest that there is competition between crops and hedgerow species for moisture and nutrients in this soil under the agroclimatic conditions of southern Benin.

In the long-term fallow management trial on land cleared from secondary forest in which we are comparing the effect of bush fallow, *Pueraria* cover crop, and alley cropping with *Leucaena* using fallow periods ranging from 0-4 years, and intercropping with maize and cassava, maize grain yields in the second year of cropping were lowest in the *Pueraria* plot. There was no significant difference in maize yield between bush fallow and *Leucaena* alley cropped plots. There was also no significant difference in soil physical, chemical, or microbial properties between the different treatments. The major differences were between the different soil types (alfisols and entisols) on which the trial is established, with structural degradation being least under natural fallow.

Effects of woody species on soil fertility are being studied at the arborata in Ibadan in the sub-humid forest-savanna transition zone (alfisol) and at Onne in the high rainfall humid-forest zone (ultisol derived from sedimentary sand) in relation to their potential for use in alley cropping and agroforestry systems. Growth measurements on some of the species after 10 years show that *Pterocarpus soyaxii* and *Leucaena leucocephala* perform better in Ibadan, while *Irvingia gabonensis*, *Treculia africana* and *Gmelina arborea* perform better at Onne. *Dialium guineense* and *Cordea alliodora* perform equally well at both locations.

Soil Fertility—Acid Ultisol

Long-term alley cropping trials with *Acioa bateri* (non-legume, non-nitrogen fixing), *Cassia siamea* (legume, non-nitrogen fixing) and *Flemingia macrophylla* (legume, nitrogen fixing)

have shown promising results. However, alley cropping with *Gmelina arborea* (non-legume, non-nitrogen fixing) tends to have a negative effect on crop yield. Maize and cassava yield are highest under *Acioa* and *Flemingia* with and without fertilizer application. Application of fertilizer N and K increase maize grain yield in all treatments. Fallowing for one year resulted in an improved cassava tuber yield. However, maize grain yield was reduced by fallowing, because of the great amount of mulch produced in the alley cropping plots, resulting in poor maize stand establishment.

Evaluation of the rooting patterns of the potential tree species for alley cropping on the acid soil showed that *Acioa bateri* has the most favorable rooting pattern for alley cropping. It has more abundant roots in deeper horizons compared with other species. This makes it more suitable for recycling nutrients from deeper soil layers while avoiding competition with food crops planted in the alleys.

Tephrosia candida is showing promise as a species for use in improved fallows for the regeneration of degraded lands. It showed effective weed control and appeared to improve soil fertility as indicated by better maize growth after a one year fallow, compared with natural bush fallow.

The oil bean, *Pentaclethra macrophylla*, has shown favorable characteristics for agroforestry and alley cropping, i.e., it has relatively rapid growth, continuous litter drop, and the capacity to coppice well. In addition, it produces edible fruits when left unpruned. The rooting pattern of this species will be evaluated for its suitability in alley cropping systems.

Plantains in *Acioa bateri* alley cropping plots and elephant grass (*Pennisetum purpureum*) mulch plots performed better than in treatments in which other hedgerow species were used. Although plantain yields were slightly lower on the alley cropped *Acioa* plots than in the control grass mulch plots (14.5 vs 16.5 tons ha^{-1}) the *Acioa* plots only required 2 prunings. The control treatment needed 80 tons of fresh elephant grass ha^{-1} to be cut and carried in 2 split applications. Alley cropping with *Acioa* is, therefore, likely to be a more profitable system for field production of plantains than systems in which mulch has to be cut and carried.

Resource Management Economics

We have established that village studies using group interviews are effective means for classifying resource management systems, identifying regions suitable for an increase in agricultural production, and identifying research issues in soil and resource management.

In a study in southeastern Nigeria, we concluded that although population density is an important factor in changes in agricultural production, other mechanisms, such as reduced access to common lands, affect resource degradation. In addition, other factors may contribute to shortened fallow, e.g., access to urban markets, and high opportunity cost of labor.

In an on-farm study to identify constraints on the adoption of alley cropping, we concluded that the "first" constraint will be the failure of hedgerows on-farm to produce enough biomass for mulching in order to produce significant crop yield increases. From

among the farmers who were introduced to alley farming in 1987/88 in one village in southwestern Nigeria, only one farmer has planted an alley farm "on his own". No other farmers have extended alleys or planted new alleys, nor have any family members or neighbors. Only one alley farmer from those in all trials was cultivating crops on his alley farm in the 1990 cropping season. From existing trials, it is not possible to completely specify high potential regions/cropping systems for alley farming in West and Central Africa. Additional research is required on the systems themselves, farmers' perceived needs, and on the on-farm performance of alley farming. The latter must be based on experiments which permit extrapolation across locations, environmental conditions, and farmer circumstances.

Using existing data and a simulation model, we evaluated the relative economic benefits of controlling soil erosion in southwestern Nigeria in 4 systems: alley cropping with *Leucaena* (2m and 4m widths between hedgerows), no-till, and bush fallow systems (3 years cropping followed by 3 years fallow, and 3 years cropping followed by 9 years fallow). The study uses a capital budgeting approach to determine the profitability of the alternative land use systems, taking into account the short- and long-run impact of soil erosion on agricultural productivity. Using a 10% interest charge, when no yield penalties are imposed (reflecting the case of low population density), the 9-year fallow system is most profitable, followed by the 4m alley cropping, the no-till, the 2m alley cropping, and the 3-year fallow system. When penalties are imposed on yields due to land being taken out of production because of fallow vegetation (reflecting the case of rising land values), the 4m wide alleys are most profitable, followed by the no-till, the 2m wide alleys, and the 9- and 3- year bush fallow systems. Thus, where access to new forest land is "costless", high yield damage from erosion will not detract significantly from the immediate profit advantage of traditional bush fallow systems, with long fallow periods.

III. Crop Management Research

Savanna Systems Group

The objective is to characterize and delineate the major maize-growing sites, and this complements the work being carried out on maize characterization. Work has started to test the usefulness of the Crop Environment Resource Synthesis (CERES) maize crop growth model with 6 IITA varieties in the forest and northern guinea savanna (NGS) of Nigeria in collaboration with the Maize Research Program (MRP). At present, the crop model cannot simulate the site specific behavior of varieties.

In collaboration with MRP, 26 international maize variety trials from all over West and Central Africa for the period 1985-1988 were analyzed for genotype x environment (G x E) interactions. The clustering of experiment sites according to G x E effects indicates that the clusters quite often do not coincide with the present definitions of maize growing environments according to rainfall, growing season length, temperature and altitude. Soil fertility, water retention characteristics, and some field management practices seem to influence varietal performance strongly at some sites. This information is being used in redefining the characteristics and some field management practices to be used for site selection in varietal testing in West and Central Africa.

In collaboration with the Institute of Agricultural Research (IAR), Samaru, Zaria and MRP, 63 farmers fields in 5 different villages in the NGS of Nigeria are being intensively monitored in order to determine the effect of the parasitic weed *Striga* on the evolving maize production systems. Very preliminary analysis indicates that 5 factors will have a major impact on the incidence of *Striga* in the field:

a. The frequency of sorghum cropping in the field—*Striga*, originally a pest of sorghum, builds up the longer and the more frequently sorghum has been cropped in the field. The predominant system of sorghum/maize intercropping is, therefore, highly favorable to *Striga* increase.

b. The frequency of maize cropping in field—*Striga* severity is higher, the longer maize has been cropped in the field, indicating that the weed is slowly adapting to maize from its natural host, sorghum.

c. The planting time of maize—The risk of *Striga* infestation is higher, the later the planting date of maize. Early planted maize escapes early *Striga* attack.

d. The weeding practice—Farmers weeding from the furrow to the row seem to have less *Striga* than those weeding from the row to the furrow.

e. Relay planting of cowpeas or cotton—At the time of relay planting, most farmers do a lot of weeding, thereby destroying *Striga* plants that have emerged, and thus reducing *Striga* build up. Such practices are especially important in combination with tolerant maize varieties.

Results of the major study of the spread of maize in the NGS of Nigeria are as follows: Maize is an important food crop in the humid and sub-humid tropics as well as in the drier areas. Recent surveys by IITA and the Institute for Agricultural Research (IAR) of Ahmadu Bello University in the Guinea savanna of northern Nigeria have shown an increased use of improved maize, fertilizer, and improved management practices, such as animal traction and effective weeding, as fallow periods have become abbreviated. Farmers have asserted that they are better off than before, attributing their well-being to the greater profitability of farming.

Several elements combined to prime the agricultural "take-off" in northern Nigeria. A good road network, linking the northern and southern parts of the country, was built with revenues from oil production during the 1970s. During the same period, an extension program was organized as part of the World Bank-assisted agricultural development projects, initially in the north at three centers. With an extension system in place to introduce new technologies and supply fertilizer to farmers, and with roads to bring in the inputs and deliver the produce to markets in the populous south, all that remained to trigger growth was the right crop technology.

The traditional cash crops of the north were groundnuts and cotton. Both were not profitable enough to attract farmers' interest in expanding production. But by late in the 1970s, IITA had developed a high-yielding maize variety, TZB, by building on two composite breeding lines of Nigeria's Federal Department of Agricultural Research. In experimental trials, the new variety yielded 150-200% more than local varieties. Also, it was resistant to the fungal diseases of rust, blight, and ear rot, and highly adapted to growing conditions in the savanna. Its white color had a consumer appeal. Experiments on farmers fields showed that it yields 21-115% more than local maize.

The agricultural development projects introduced TZB to northern farmers and demonstrated how to obtain high yields using fertilizer. When the farmers found that the maize gave them a far more profitable return than other cash crops, they began to expand production rapidly.

During the next decade, the spread of maize in the moist savanna was phenomenal. According to IAR and IITA research, maize had been grown in that zone as a backyard crop in the 1970s. By 1989, maize had become a major food crop in virtually all villages, and a major cash crop in more than two-thirds of them. Most of this maize was the high-yielding TZB. In over half of the villages surveyed by IAR and IITA, hardly any local maize varieties were being cultivated. Improved maize had overtaken and changed the role of its predecessor.

Sorghum, traditionally the favorite food crop, is still planted over a greater area than maize. However, since TZB outyields local varieties of sorghum and millet, the other staple cereal in the region, TZB can reduce the land requirement for feeding farmers' families. Many farmers have found that by growing TZB for household consumption, they can free additional land for cash crops. With the surplus over food needs being marketed, farmers have increased their cash income which they can use to reinvest in cash crop production.

However, there are concerns about the sustainability of the phenomenon. Successful maize cultivation is highly dependent on good soil fertility. With the virtual elimination of fallows, the soil organic matter status (SOM) of the soils has declined, micro-nutrient differences are becoming more evident, and weed pressure, especially the parastic weed *Striga*, which has moved to maize from sorghum, is increasing. Furthermore, with the increase in cost and reduction of the subsidies, the use of fertilizers is declining. More biologically sustainable farming systems involving the use of legumes, more nitrogen efficient maize varieties which are tolerant to *Striga*, and cultural control methods for *Striga* need to be developed.

Humid Forest Systems

Data from the study of the role of maize storage practices as a constraint to increased maize production in the forest zone show that storage damage varies widely from year to year, and within a sample of farmers in the same year, depending on rainfall during the period of maturity of the maize crop. In 1990, maize samples from farmers' stores showed minimal damage (less than 15% after 6-8 months of storage). Harvesting occurred during the dry spell. This contrasts greatly with the previous year, when there was heavy damage in storage from maize which was harvested during a period of continuous rainfall. The results indicate that the development of an appropriate drying technology could largely eliminate storage damage.

In a study of the potential of second season maize in the forest zone, it was revealed that second season maize is presently a minor crop. It is always planted with cassava, and yields are low, ranging from 150 to 500kg ha^{-1}. Farmers seem to consider it a bonus whenever it happens to succeed in addition to the more secure cassava. On-farm trials showed that the introduction of stem borer resistance in maize could increase pure crop maize yield to about 1,200kg ha^{-1}—a 2.4-fold to 8-fold yield increase. However, under farmers' intercropping systems, reduction in the unit cost of production is expected to be only 17 to 25%, indicating that second season maize is not likely to be viable in the forest fringe even with stem borer control. However, final conclusions must await on-going work with a programming model, which would include farmers' decision making in terms of second season maize, in order to predict whether maize will continue to be intercropped with cassava, and to quantify the increase in production which will be induced by the fall in the unit cost of production.

On-farm trials have shown that mean yield from cowpeas grown in the second season is 600-800kg ha^{-1} with 3 to 4 insecticide sprays. Where farmers are able to obtain sprayers and insecticides this is therefore a viable crop in the second season. The average yield potential of soybean was recorded as 700-800kg ha^{-1}. Because of minimal crop protection problems, this is proving to be a very viable second season crop and marketing facilities seem to be developing satisfactorily.

Trials continue on the incorporation of pigeon pea into the cassava + maize intercropping in order to improve the productivity and sustainability of the system. Growth of pigeon pea interplanted with cassava and maize must be limited during the first year to avoid competition with cassava. Pigeon pea must, therefore, be pruned at least once, and probably twice, after the maize harvest. Pruning at 1m height was found earlier to be inadequate. In 1990, the

comparative trial indicated that the growth height of pigeon pea can be significantly reduced with maximum survival, if the pigeon pea is pruned as low as 30cm.

Farmer-managed on-farm trials with 3 hybrid maize varieties confirm findings in earlier years that, under present farmer management, hybrid maize does not show a significant yield advantage in the forest fringe area of southwestern Nigeria.

In a study of tillage system (no-tillage-and hoe tillage) and cropping system (maize + cassava intercropping or maize + cassava + egusi melon) the greatest yields occurred when no-tillage was combined with a maize + cassava mixture. Maize and cassava yields did not differ significantly between other treatments. Maize yields were, however, greater in no-till plots.

The effects of cassava-based intercropping systems and rotations on the physical and chemical properties of earthworm casts and the adjacent soil were studied on an Oxic paleustalf in southwestern Nigeria. Earthworm activity was greater with intercropping, although it was not significantly affected by the number of component crops in a mixture. The particle size distribution, bulk density, exchangeable cations, Bray-I-P, pH and effective cation exchange capacity (CEC) of soil and earthworm casts did not differ among the cassava-based cropping systems investigated. Cropping systems may influence soil fertility indirectly by changing water infiltration characteristics and hence, nutrient losses in run-off and erosion.

The adoption decisions of subsistence multicrop producers regarding an improved cassava variety (TMS 30572) in the humid tropical rainforest ecosystem of southwestern Nigeria were analyzed within a qualitative choice framework. The empirical results revealed that younger farmers producing marketable surpluses on holdings in excess of the mean farm size of 0.6 ha were more likely to adopt TMS 30572, compared with farmers producing primarily for household consumption. The activities of extension agents among subsistence producers were statistically significant in the technology adoption process. Migrant farmers were identified as early adopters by the empirical model. These results have significant implications for extension personnel, research scientists, and policy makers, and provide further justification for strengthening the extension capacities of the national research programs within the cassava belt of the humid forest zone of West and Central Africa.

Cassava is a basic component of the farming system in many areas of Africa because of its adaptability to relatively marginal soils and erratic rainfall conditions, its high productivity per unit of land/labor, the certainty of obtaining some yield even under the most adverse conditions, and the possibility of maintaining continuity of supply throughout the year. Famine rarely occurs in areas where cassava is widely grown, since it provides a stable base to the food production system. This indicates that cassava has the potential to bridge the food gap. However, the full realization of this potential depends on obtaining more detailed information about cassava growing conditions, production systems, processing methods, marketing, and urban consumption patterns. Authoritative information on these issues is lacking and even the production statistics that are available are, at best, educated guesses. The Collaborative Study of Cassava in Africa (COSCA) project was, therefore, initiated to correct these information deficiencies.

COSCA is an inter-institutional effort in which national and international agricultural research centers are collaborating. The broad objective of COSCA is to improve the relevance and impact of agricultural research on cassava by international agricultural research centers (IARC) in Africa in order to realize the potential of cassava in raising food production and incomes in Africa. A multidisciplinary team is constituted in each country to conduct COSCA surveys. The collaborating international institutions include international agricultural research centers, development agencies, and advanced country universities which carry out research on cassava in Africa. Some of them provide facilities, such as advanced laboratories and geographic information system (GIS), while others provide scientists with expertise which may not be available in the national institutions.

COSCA surveys are being conducted in 250 representative villages distributed in the cassava growing areas of Cote d'Ivoire, Ghana, Nigeria, Tanzania, Uganda, and Zaire. These six countries are responsible for about 70% of cassava production in Africa. They provide the wide range of variations in climate, population density, and market access which are thought to influence cassava production. Significant findings emerged from the study during 1990.

Cassava production was reported to be increasing in the last 20 years in 70% of the representative villages visited in Africa. Favorable market, famine and hunger, population growth, declining soil fertility and drought are the major reasons provided by the farmers for the increase. Thus, the key determinants of this increase include climate, demographic pressure, and availability of market access. Cassava production is increasing in relatively more villages in the humid than non-humid climate zones. Within the humid climate zones, production is increasing in relatively more villages in zones where population pressure is high than where it is low, and in zones where market access is good rather than where it is poor. Where cassava production is increasing, it is replacing mainly other arable crops, although in some places it is also replacing fallow or tree crops. Cassava is replacing other crops where fallow periods are declining leading to a decline in soil fertility.

Cassava is widely produced with purchased inputs such as hired labor, improved inputs, and the mechanization of land preparation. These practices are, however, found more in areas of high population density and good market access infrastructure. Among the improved inputs are fertilizers and improved cassava planting materials. In Nigeria, where improved cassava varieties have been multiplied and made available to farmers, they are present in nearly 90% of 64 representative villages visited and are grown by many or most farmers in nearly 60% of the villages. The situation is, however, different in the five other countries visited (Cote d'Ivoire, Ghana, Tanzania, Uganda, and Zaire) essentially because the required investment in adaptive research, and planting materials multiplication and distribution have not been made.

Although over 70% of cassava varieties grown in the 250 representative villages visited are low cyanide type, the roots of which can be eaten raw, boiled, or roasted without preprocessing yet, in relative terms, the number of the low cyanide varieties grown by the farmers has been declining, while the number of high cyanide varieties is increasing over time. The high cyanide varieties are judged by the farmers to be superior in pest resistance, yield, and in in-ground storability, although not early in maturity.

Health problems of goitre, paralysis of both legs, and intoxication after meals exist but it is not certain that they are caused by cassava consumption.

There is a significant degree of turn over in the cassava varieties which farmers grow, as they replace existing varieties with new ones that may possess desired attributes such as pest resistance, high yield, and early maturity.

The need for early-maturing cassava varieties increases as population density increases or as market access improves while the need declines for varieties that store longer in the ground. In areas of high population density, farmers reported that they harvest their cassava at or before 12 months after planting. Similarly, nearly 45% of farmers in good market access areas reported that they harvest their cassava at less than 12 months after planting, compared with less than 10% in poor market access zones.

These observations suggest the need for research to develop varieties that are high-yielding, early-maturing, and disease and pest resistant. The needs for varieties that store long in the ground or that are low in cyanide do not seem to be critical. However, these preliminary conclusions will be investigated further in later phases of the study.

The processing of cassava roots before consumption is widespread. Cassava roots are processed into a wide range of products including flours, granules, pastes, starch, alchoholic beverages, and medicines. The processing of each product passes through many stages during which fermentation may take place. The processing of cassava roots eliminates cyanide, reduces bulk, and extends shelf life.

Marketing of cassava products is widespread. Farmers reported that they did not market cassava in only one out of the 250 representative villages visited in Africa; farmers in 45% of the villages marketed three or four cassava products, and in 20% of the villages they marketed five or more different cassava products.

Inland Valley Systems

A medium term research strategy was developed for the group. This calls for:

- Measurement of the land area occupied by Inland Valley Swamps (IVS) in West and Central Africa, the percentage and physical location of those IVS which are used for agricultural production.
- Identification of the factors which lead to a low rate of utilization of IVS for agricultural production and the changes which have occurred over time in land uses in IVS, and the factors which trigger changes in land use patterns in IVS.
- Classification of IVS of West and Central Africa and selection of representative experimental sites within the principal categories of IVS.
- Identification and quantification of constraints to different land uses for the principal categories of IVS in terms of ecological and economic sustainability, and farmers' welfare.

- Development of integrated models of biophysical and socioeconomic processes in the principal categories of IVS agroecosystems, validation of the models developed on the basis of the results obtained, and extrapolation of the results to other categories of IVS.
- Design of feasible improvements in land-use and/or management practices for different categories of IVS agroecosystems and testing of modifications at representative sites.

A detailed review of the research literature on the agronomy of rice-based cropping systems in IVS of West Africa confirmed that the availability of adequate rice germplasm is only a minor constraint to increased production. Major constraints to rice production which must be addressed in future are weed competition, low soil fertility, and variable water conditions. There is every indication that major increases in farm income and resource conservation in rice-based cropping systems in these valleys may come from diversified cropping in which crops grown in the dry season play a significant part.

Trials continued to understand factors contributing to rice yield variations along the toposequence in IVS, and to identify varieties with high and stable yields across the toposequence. In the high rainfall area of Makeni in Sierra Leone, analysis of variance of grain yields indicated no significant interaction between position in toposequence and variety. This means that all of the varieties tested responded to position in the toposequence in roughly the same manner. Mean grain yields from 10 varieties were 1.7 tons ha^{-1} on the valley fringe, 2.9 tons ha^{-1} on the middle slope, and 4.4 tons ha^{-1} in the valley bottom. Mean grain yields of most of the varieties were more than 3 tons ha^{-1} with the local check producing 2.6 tons ha^{-1}. In the Bida area, in the moist savanna of Nigeria, tests were conducted on the valley fringe and valley bottom using both small unleveled and unpuddled paddies, representative of the farmers' system, and large leveled puddled paddies, representative of an improved water management system. Contrary to expectations, it was shown that land improvement resulted in a yield decrease of about 2.5 tons ha^{-1} on the valley fringe, and a yield increase of up to 3.2 tons ha^{-1} in the valley bottom. Clearly, leveling of large paddies involving substantial topsoil movement resulted in poor soil conditions in the fringes. Toposequence position and variety had an interactive effect on grain yield which they did not have in the high rainfall area of Makeni. A new improved variety, TOX3118-E2, performed better along the valley fringes than the highest-yielding existing IITA variety, ITA306, although it gave slightly lower yields in the valley bottom. However, improved varieties performed better than the local check at all levels along the toposequence.

Screening of upland crops along the toposequence in inland valleys aimed at developing a methodology for selecting appropriate germplasm. Strong relationships were observed between ground water depth and the yield of cassava and sweet potato. There was also some indication of deferential response of sweet potato clones to ground water depth.

Trials of *Sesbania* as a potential green manure crop in rice-based systems in IVS indicated that *Sesbania* does best when planted between late February and early May at Bida, in the savanna of Nigeria. Pruning to 25cm height resulted in greater total pruning biomass production than pruning to 50cm.

The leaves of cassava and sweet potato play an important role in many African diets, so the agronomic and economic effects of leaf harvest on tuber production are being explored.

The results of a trial in a small valley during the dry season, comparing recommended low planting densities to the farmers' normal practices of a higher planting density, validated the recommended low density for increased tuber production. A limited degree of leaf harvesting appears to stimulate tuber production. Revenue from leaves and tubers decreased with increasing plant density and increased with increasing leaf harvest. The only positive yield effect of increased planting density was observed to be leaf yield at first leaf harvest when fresh vegetables are scarce in the market. This effect may be enough to explain why farmers tend to plant cassava and sweet potato at a density higher than recommended.

Mounds and ridges are common seedbed preparation methods for upland crops grown during the dry season in IVS. In a trial to study the effect of this seedbed preparation method on the soil physical and chemical properties and on crop yield, it was revealed that there was no difference in seedbed resulting from either method. Both created a loose uncompacted and fertile seedbed, highly conducive to crop growth.

Annex 1

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