Resource and Crop Management Research Monograph No.

RESOURCE AND CROP MANAGEMENT PROGRAM

ANNUAL REPORT 1991

Highlights of Scientific Findings

Resource and Crop Management Division
International Institute of Tropical Agriculture

The International Institute of Tropical Agriculture (IITA) is an autonomous non-profit 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 Division (RCMD) 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 RCMD 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 Resource and Crop Management Research Monograph series is designed for the wide dissemination of results of research about the resource and crop management problems of smallholder farmers in sub-Saharan Africa, including socioeconomic and policy-related issues. The range of subject matter is intended 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:

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I. Introduction

Goal of RCMP

The goal of the Resource and Crop Management Program (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. Research is conducted at research stations in Ibadan in the Savanna/Humid Forest transition zone of Nigeria, (bimodal annual rainfall 1200mm), Onne in the forest zone of Nigeria (unimodal 2841mm rainfall) and at Mbalmayo in the Forest zone of Cameroon (pseudo biomodal, 1530mm rainfall). In addition, research is conducted in collaboration with National Agricultural Research Systems (NARS) in over 50 sites located in about 20 countries in sub-Saharan Africa.

II. Resource Management Research

Characterization of environments, resources and constraints

The objectives of activities aimed at mapping the ecological and economic resources and productive potential of West and Central Africa are to develop a geographically-related database of environmental and resource information relevant to crop production; to classify the region in terms of ecological and economic zones; and to use models in linkage with Geographical Information Systems (GIS) to determine the productive potential of the IITA mandate zone.

In 1991, applications of the Resource Information System (RIS), a GIS system developed in-house, substantially increased. Several new data bases were added making a total of 70 to support various characterization needs. A model was developed to compute the length of growing season based on rainfall, evapotranspiration, soil water balance, and an assumed 100mm soil water holding capacity. This model was also used to determine rainfall pattern (unimodal or bimodal). Characterization maps were prepared of inland valley agroecosystems, and humid forests of Cameroon. A site selection scheme based on biophysical and socioeconomic characteristics was developed to guide the banana weevil project in East Africa which is now being field tested in Uganda. A case study of Northern Cameroon is underway to determine water limited sorghum production.

Daily weather data was analyzed for 42 stations in Nigeria to characterize climatic risks as indicated by (a) length of dry spells at different rainfall thresholds, (b) annual rainfall probability, (c) mean rainfall at 10-day periods during the growing season, and (d) monthly mean rainfall in 10-year intervals. Preliminary analysis has indicated a pattern of declining rainfall, shorter growing seasons, fewer rainy days, and increased rainfall intensity.

The objectives of activities aimed at the characterization of resources and resource management in indigenous farming systems are to describe the farming systems of West and Central Africa with particular respect to the management of resources, and to identify at the farm level the major constraints to production and sustainability.

In a resource survey of fallow management systems in Imo State, Nigeria, soil and vegetation are being studied in farmers' fields in two contrasting locations. In Mbaise, three-year fallows are found of *Dactyladenia barteri* (Hook) (syn *Acioa barteri)*; in Umuahia, five-year "natural bush" fallows are common. Maize yield is greater in Mbaise than Umuahia. However, soil chemical factors do not satisfactorily explain this result. The fallows in Mbaise, although shorter, have more litterfall and broadleaf weeds are dominant, rather than grasses.

A broader survey of farmers' management of their natural resources was carried out in southeastern Nigeria, partly to provide a context for the evaluation of the Mbaise and Umuahia study sites. It showed that, relative to the rest of southeastern Nigeria, the Mbaise and Umuahia sites are periurban, with ultra-high transport and market networks, and high population densities. High-value labor-and input-intensive gardening is combined with oil palm harvesting and processing. The region has been food-importing for over 40 years. Income for food imports is derived from commerce and oil palm processing. Existing *D. barteri* fields in Mbaise are generations old.

In a collaborative study with a visiting scientist, the general features and terminology of Hausa, Kulere, Yoruba and Nupe soil taxonomies and soil management and conservation practices were documented. The main results among the Yoruba show that soil is classified according to texture, color and fertility. Each soil type has limitations and risks and there are clear soil/crop relationships. Terms for land forms and erosion also exist. The Kulere system is based on texture, water retention and color. Erosion awareness and soil conservation practices are impressive. Particularly notable is the construction of stone terraces for erosion control and fertility enhancement. Soil type influences crop choice and planting date. Hausa terms for land farms and soils were also collected. Again, soil classification relies on texture, color, and soil moisture characteristics. Hausa farmers have very detailed terminology for soil amendments and detailed information on soil fertility management practices. Crop, soil associations are as strong as in Yoruba and Kulere systems.

Work continued on the characterization and development of the Humid Forest Station (HFS) site at Mbalmayo, Cameroon. The aim is to develop a database of the quantity, quality, and spatial distribution of natural resources at the HFS, to determine the representativeness of the site, and to utilize the database in developing the research agenda and land management policy for the station.

A topographic map of most of the site was completed together with a preliminary vegetation survey. A soil survey of 200 sites in Southern Cameroon revealed the presence of five main "profile classes" of which two, comprising about 50% of the humid forest zone of the Cameroon, are to be found at the HFS.

Since April, we have been carrying out an anthropological study of the farming systems around the HFS. Conducted in four villages in the Mbalmayo area, the study seeks to model resource management strategies of small farmers focusing on land tenure, the organization of labor, investment and knowledge systems. Major methodologies used are archival research and literature review, participant observation, key informant interviews, field mapping, village meetings, censuses and questionnaires.

Key findings to date are that the cocoa crisis has contributed to changing resource management strategies as people shift to food crops and plant larger fields. While population densities are high enough to degrade the resource base, perceived labor scarcities impede the adoption of more intensive technology. Land tenure is still regulated at the village level but land is increasingly partitioned on the death of the head of household. Farmers have a complex system of classifying trees in relation to soil fertility.

Adaptability and adoptability of alley cropping systems

The general aim is to determine the environments and farming systems for which alley cropping is likely to be a productive, sustainable and socioeconomically acceptable cropping system.

The specific objectives of studies to determine the adaptive capabilities of hedgerow trees are to determine the response of hedgerow trees (HRT) to pruning and other management practices, to determine the performance of HRT and alley cropping systems in relation to the climate and soil conditions.

Results from a study of the effect of pruning on non-structural carbohydrates in HRT showed that *Gliricidia sepium* uses stem starch to support initial sprout growth and this starch fraction is present in sufficient concentrations to preclude use of root reserve carbohydrates. Data obtained also showed the trend of accumulation of reserve carbohydrates early in the dry season.

In a study of the effect of pruning on intercrop performance, delayed pruning of hedgerows was found to affect maize grain yield more than stover yield. Delaying hedgerow pruning till eight weeks after planting maize and cassava had no pronounced effect on maize grain yield. Maize grain yield was reduced in a 10 weeks pruning cycle but significant reduction was only observed with no hedgerow pruning. Growth measurements of the cassava crop showed taller and thinner cassava plants with delayed pruning, particularly on the unpruned treatment. The amount of light interception by cassava canopy is very much affected by pruning intensity of the hedgerow.

In a study of root competition in alley cropping, soil moisture, light interception, root dynamics, and maize crop performance were investigated under alley cropping with *Leucaena leucocephala*. Plant biomass and grain yield were higher in alley cropped plots than in plots with no hedgerows, with significant yield differences observed 68 days after maize was planted. Pruning increased soil moisture retention by an average of 6.4% within the top 50 cm of the soil during the first 50 days after planting. Hedgerow shading affected maize yield. Photosynthetically active radiation (PAR) indicated that crops planted at distances less than 50cm from the hedgerow received less than 77% of the incoming PAR. The minirhizotron method can be used to estimate the development of roots within the alley cropping management system. The minirhizotron data suggest that less than 50% of *L. leucocephala* roots are located in the 0-20cm region of the soil profile.

In a study of the effect of light interception on HRT establishment, *L. leucocephala* shoot fresh weight and height were highest under 75% of the incoming PAR. The smallest amount of shoot biomass was observed under 25% PAR. Nitrogen fixation as assessed by nitrogenase activity was highest at 100% light exposure. The results, therefore, showed that some amount of shading can be beneficial for *L. leucocephala* establishment. The growth parameters such as height, biomass production, and microbial activities, e.g., nodulation, increased as the light intensity received by the tree increased. Solar energy availability is thus crucial to tree establishment in intercropping with food crops.

Intra-specific variation of *Gliricidia sepium* for tolerance to low P soil was confirmed in field experiments. The P uptake and use efficiency of *G. sepium* provenances was more influenced by plant growth habit and availability of P in soil than by morphological characteristics such as root length and percentage mycorrhiza infection. The percentage of N_2 derived from the atmosphere was about half of that measured in pot experiments.

The objective of weed management research in alley cropping is to assess the interaction between hedgerow trees, weeds, and crop. In a study of the effect of weeding regime on tree establishment, the nitrogen and potassium status of the soil three weeks after weeding was higher than that at weeding. This showed that weeds were holding back some nutrient elements during growth which were mineralized after three weeks when the area was weeded. This was probably responsible for the increase in tree biomass under frequent weeding as compared with unweeded plots where weeds reduced tree nutrient uptake. For good HRT establishment when N. fertilizer is not used *Senna siamea* (syn. *Cassia siamea)* trees should be kept weed free while *G. sepium* and *L. leucocephala* can be weeded once in every four weeks. When N. fertilizer is used, *S. siamea* trees can be weeded once in eight weeks.

In an experiment at Ibadan station, uncontrolled weed growth reduced maize grain yield by 52% in no-tillage plots and 33% in a continuously cropped *L. leucocephala* alley system in which maize was also planted without tillage. Alley cropping with one weeding resulted in 15% maize yield reduction compared with a yield reduction of 41% in no-tillage system with one weeding. Similarly, chemical weed control was superior in alley cropping than in the no-tillage system without alley cropping.

There were significantly more annual weeds in the no-tillage plots than in *L. leucocephala* plots, irrespective of whether the plot was cropped yearly or every other year. Weed biomass was also significantly higher in the no-tillage maize plot than in the *L. leucocephala* plot at six weeks after planting and at maize harvest, indicating that alley cropping had a depressing effect on weed growth. Weeding by all methods was more effective in alley cropping than in no-tillage plots. This is possibly because of lower weed pressure in the alley crop. There were significantly more perennial weeds in *L. leucocephala* plots than in the no-tillage plot.

Alley cropped and no-tillage plots started with the same weed flora in 1988. In 1991, there were more annual broadleaf weeds in no-tillage plots than in the alley cropped plots. The lowest weed density was in the alley plots that were cropped every two years. Annual grasses and sedges were more numerous in the no-tillage plots than in the alley cropped plots, an indication that declining fertility causes a shift to annual grass weeds. Total perennial weed density was significantly higher in alley cropped plots, than in the no-tillage plots possibly because of the effect of *L. leucocephala* volunteers.

The Alley Farming Network for Tropical Africa (AFNETA) provides a major avenue for assessing the adaptability and adoptability of alley cropping. The objective of AFNETA is to promote research on alley farming systems in the National Agricultural Research Systems (NARS) and to accelerate adoption of the technology in different agroecological zones of sub-Saharan Africa. Collaborative research has been initiated in 32 NARS from 20 African countries. Experiments are being conducted on screening and management of HFTs for alley farming, livestock integration in alley farming, on-farm and socioeconomic research in 54 sites in the humid (17 sites), sub-humid (20 sites), and semi-arid zones (17 sites). Seventy percent of the sites are in lowlands and 30% in highlands of tropical sub-Saharan Africa.

In screening trials in the semi-arid zone, all the MPTs tested recorded high survival rates up to 12 months after planting, and grew well except for *G. sepium*, *Calliandra calothyrsus* and *Prosopis juliflora* in a few sites. In the sub-humid zone, *S. siamia*, *L. leucocephala*, *G. sepium*, *S. spectabilis* and *Acacia auriculiformis* are among the species that perfomed well. *Faidherbia albida*, *P. juliflora*, *Albizia zygia*, *A. adantifolia* and some *G. sepium* accessions performed poorly.

In management trials, cassava yield declined by about 32% for an average of 10 trials, cotton yields declined by an average of 20% in 4 trials, while on the average, maize yield increased by 180% in 44 trials. *Phaseolus vulgaris* yields increased an average of 12% in three trials while rice yields increased an average of 14% and *Vigna unguiculata* yields increased an average of 16% in nine trials. These trials conducted all over Africa confirm that maize and legumes respond positively in alley cropping systems, while cassava yields tend to decline. The yields recorded are field yields, i.e., they are the yields of the entire field including the area occupied by the hedgerows.

Shortage of good quality feed is a major constraint to livestock productivity in many regions. The objectives of trials integrating livestock into alley farming are to assess the effect of quality and quantity of fodder production when grass and trees are cultivated together. Grass yields decline slightly when intercropped with *L. leucocephala* and *G. sepium*. However, foliar and wood biomass resulting from the trees provided an additional forage output from the systems.

Other trials on the digestibility and palatability of the resulting forage showed that the best feed consumption was obtained in the treatment including 75% of grass and 25% of the tree legume.

Most AFNETA projects are conducted on-station as this is the first experience of many NARS scientists with this technology. However, on-farm trials were conducted in about 12 sites in 1991. Since most of the trials are recently established, yield data do not show the effect of the hedgerows, except in Benin Republic where maize grain yield was increased by alley cropping.

Adaptability and adoptability of legume-based cropping systems in the moist savanna zone

The objectives of these projects are to determine the effectiveness of herbaceous and shrub legumes for controlling weeds and improving soil fertility, and to determine the adaptability and adoptability of herbaceous and shrub legume-based technology in the moist savanna zone.

In an experiment at the Ibadan station comparing continuously cropped *Pseudovigna argentea* live mulch system with a no-tillage system, there was no significant effect of N-fertilizer on maize yield in *P. argentea* plots. On the other hand, maize responded positively to N-fertilizer and to weed control treatments in the no-tillage system with no cover crop. Maize yield (2.0 t ha^{-1}) in the no-tillage experiment that received 90 kg N ha^{-1} and was kept weed-free was significantly lower than maize yield in the live mulch plot without N-fertilizer (2.3 t ha^{-1}). Maize yield in an unweeded live mulch plot without nitrogen was 1.5 t ha^{-1} while a no-till maize weeded once and receiving no nitrogen (a situation often encountered by farmers) had a yield of only 0.5 t ha^{-1}. Nematode population was significantly higher in the no-till plots than in the live mulch plots. *P. argentea* live mulch appears to suppress the population of plant parasitic nematodes. However, stem borer incidence was higher in live mulch than in no-till plots. Earworm problem on maize cobs was higher in no-till plots.

Crotolaria verrucosa L. suppresses weeds when intercropped with arable crops. Its canopy prevents weeds from going to seed after the arable crop is harvested. Results from a study involving interplanting *C. verrucosa* in maize show that *C. verrucosa* planted not later than two weeks after maize was effective in suppressing weeds without adverse effect on maize yield. Also, it is possible to reduce weeding frequency to one without the usual yield reduction caused by weed interference at low weeding frequencies. Beneficial residual effects of *C. verrucosa* include (i) reduced weeding frequency during subsequent cropping in plots that had *C. verrucosa* in the previous growing season, (ii) reduced demand for N-fertilizer, and (iii) low weed infestation in spite of increased cropping intensity. The best time to plant *C. verrucosa* appears to be at the same time as maize and cassava.

Development of Resource Management Systems for the humid forest—acid soil environment

The objective of this project is to develop sustainable and adoptable cropping systems for the acid-soil humid-forest environment which can effectively augment or replace traditional fallow-based systems.

Alley cropping on coastal ultisols at the Onne station with *Dactyladenia barteri* (Hook). (syn. *Acioa barteri)* has consistently shown positive results for both cassava/maize and plantain cropping systems in terms of biomass yield, decomposition of prunings, source of good quality fuelwood after a fallow period, and effects on soil productivity. Yield decline has, however, been observed in continuously cropped treatments. This has cast doubt on the sustainability of the system.

One year of fallow increased the yield of both maize and cassava. The reduction in maize grain yield after fallowing because of the great amount of mulch produced was not observed this year. Highest yields were obtained with a combination of fallow and fertilizer application. It is becoming evident that continuous maize and cassava cropping may not be sustainable on the soils even with alley cropping and fertilizer application. Also, pruning yield for *Flemingia macrophylla* was reduced in the one year fallow plot, compared with the continuously cropped plot, because it tended to dry up during the fallow cycle. Coupled with the decline over time in its pruning yield, this species may not be suitable for long-time alley cropping. Since *Gmelina arborea* has consistently shown a negative effect on maize and cassava yield, *D. barteri* and *Senna siamea* (syn *Cassia siamea*) are the prominent tree species emerging from this experiment.

In an experiment on spacing of *F. macrophylla*, direct seeding resulted in generally good establishment but initial growth was poor. No significant differences in prunings yield due to hedgerow spacing were observed.

In another spacing trial with *D. barteri* and *S. siamea*, no apparent differences due to inter-row spacing were observed but wider inter-row spacing increased the pruning yield per tree. *D. barteri* produced more biomass than *S. siamea*. However, crop performance was uniformly poor even after a one year fallow cycle, which indicates that the site could not be regenerated by a short fallow, using the species.

In order to expand our capacity to use multipurpose trees (MPTs) in the development of sustainable farming systems particularly on the acid soils, a major collaborative project has been launched with International Centre for Research in Agroforestry (ICRAF) and Oregon State University (OSU). First, an ethno-botanical survey was conducted in southeastern Nigeria. About 285 MPTs and shrubs were identified as useful for soil enrichment, food/fruit, medicine, ornament and other indigenous uses. Most of these species have been planted in three large arboreta at Onne and Ibadan in Nigeria and Mbalmayo in Cameroon. About 40 are being intensively studied for use in agroforestry systems. From field exploration, 366 accessions (seed) of various multipurpose tree species have been stored at the IITA Genetic Resources Unit (GRU). Further to this, 50 accessions of *Vernonia amygdalina* (Bitter leaf) germplasm (vegetative cuttings) have been collected and established at the IITA arboretum. Morphological characterization has commenced. This bank is the first of its type.

Preliminary results from technology specific screening on an alfisol at Ibadan, in which the species are put under alley cropping indicate that *Enterolobium cyclocarpum, Albizia caribbasa, Millettia thonningii* and *Alchornea cordifolia* have good growth.

On the acid ultisols at Onne, tree growth of *E. cyclocarpum* (2.3m) and *Senna spectabilis* (var. *Cassia spectabilis*) (1.7m) was greater than that of indigenous species such as *M. thonningii* (0.8m), *Dialium guineense*, *M. griffionanus* (0.9m) and *Pterocarpus santalinoides* (Lam). *L. leucocephala* and *G. sepium* which are acid-soil sensitive species, have been included for comparative purposes. Although growth of *L. leucocephala* was 1.7m, its shallow rooting pattern is unacceptable in alley cropping systems on these soils.

Determinants of sustainability in cropping systems

The objectives of this project are to develop methods for assessing the sustainability of cropping systems by long-term comparative system studies, and to investigate the interactive effects of introducing component technologies into indigenous cropping systems.

Research continued on the development of appropriate measures of sustainability. Despite the vast amount of literature that now exists on the definition of sustainability, there is a distinct scarcity of literature on how to operationalize and measure the concept. We have proposed the use of a total factor productivity index which combines biological, physical, and economic factors to measure the sustainability of a crop or farming system. Also, work continues on organic matter dynamics as an indicator of sustainable resource conservation and on the role of biodiversity in ecosystem functions in agricultural systems.

Long-term studies continue on the sustainability of alley cropping systems on non-acid alfisols at the Ibadan station. The objectives are to access the sustainability of alley cropping as a low input production system, evaluate the long-term performance of exotic and indigenous hedgerow species, evaluate the potential of alley cropping for rejuvenation of degraded soils and land infested with *Imperata cylindrica*, and to evaluate the potential of alley cropping in controlling erosion on sloping land.

In the tenth year of an alley cropping trial with hedgerows of *D. barteri, Alchornia cordifolia, G. sepium*, and *L. leucocephala* planted 4m apart and pruned at a height of 75cm during the cropping season, the yield of maize in *L. leucocephala* and *G. sepium* plots without N application (3119 and 2574 kg ha^{-1}) were higher than in control plots receiving 45 kg N ha^{-1} (1912 kg ha^{-1}). Alley cropping plots receiving 45 kg N ha^{-1} give higher maize grain yield (3484 and 3104 kg ha^{-1}) than non-alley crop plots receiving 135 kg ha^{-1} (2594 kg ha^{-1}).

In long-term comparative whole system studies, we aim to compare traditional fallow management systems with promising food production technologies (alley cropping with *L. leucocephala*, and *Pueraria phaseoloides* cover crop) for sustained and low input crop production, to investigate the effect of fallowing in sustainability of crop production, and to evaluate the cost effectiveness of the systems. In the third year of the trial planted after 23 years forest fallow on entisols and alfisols on the Ibadan experimental station, soil microbial biomass was observed in the following order: *P. phaseoloides* plots> bush fallow = *L. leucocephala* plots. Biomass carbon was higher under bush fallow and *Pueraria* plots than in *L. leucocephala* plots.

Assessment of earthworm casting activity in 1991 showed that casting activity under bush fallow > *P. phaseoloides* > *L. leucocephala*. Casting decreased each year under *L. leucocephala* and to a lesser extent under *P. phaseoloides* .

Fallowing affected the infection rate of maize by arbuscular and versicular mycorrhiza. Continuous cropping reduced mycorrhizal infection as compared with fallow treatments. Indigenous and introduced inoculum are effective in promoting mycorrhizal infection.

During the rainy season soil water tension was low and did not differ between treatments. At the beginning of the rainy season soil water tension increased faster only in the bush fallow and *P. phaseoloides* plots. In general, soil water tension reached the highest values in continuously cropped *P. phaseoloides* plots. The heterogeneous plant cover in alley cropped plots affects the soil water regime, with higher water tensions observed near hedgerows than in the center of the alleys below 70cm depth.

Regrowth biomass increased with length of fallow period and was highest in bush fallow plots > *L. leucocephala* plots > *P. phaseoloides* plots. It is estimated that in a one year bush fallow (mainly of *Chromolaena odorata)* about 218 N, 17.6 P, 217 K, 156 Ca and 39 mg in kg ha^{-1} was recycled.

Maize yield increased with length of fallow period. For a given fallow length it was observed in following order *L. leucocephala* plots > bush fallow > *P. phaseoloides* plots. Plot management was most difficult under *P. phaseoloides* because of its climbing nature.

Development of Resource Management models and decision support systems

The objectives of this project are to develop interactive models of the relationships between soil constraints, soil processes, and soil management interventions, and to develop information systems and decision support tools for resource management in tropical Africa.

The CERES maize model of International Benchmark Sites Network for Agro-technology Transfer (IBSNAT) was tested for adaptation to conditions in southeastern Nigeria. The maize model is designed to simulate plant physiological processes (nutrient and water uptake, transpiration, photosynthesis, organogenesis, biomass partitioning), and to predict growth, development and yield in daily time steps. Genetic constants were estimated using observed silking and maturity dates, grains per plant and weight per grain at harvest for each replication using 1990 data. The mean values of genetic constants were used for simulation of the 1991 growing season. No other adjustments were made in the model. Two years of intensive field monitoring of sole maize crop and its comparison with simulations using the IBSNAT CERES maize model have shown that the simulated results were within 10% of those observed. Also, excellent agreement between above ground biomass, stem, and leaf weights throughout the season showed that built-in partitioning rules in the models were robust and adequate. The validated crop model with known genetic constants for varieties could be a time and money saving tool, useful for studying the response of varieties in contrasting environments and management practices.

In collaboration with the University of Hawaii, a decision aid based on IF.. THEN rules provided by an expert system shell is being developed to aid in the design of new alley farming systems. Results so far indicate inadequate data on measures of benefits of alley farming systems. Sufficient reliable data are needed to economically evaluate a proposed system. Better information is needed on the uses and suitability of the various species for the farmers' intended purposes. Also information is needed on species such as their requirements for water, nutrients, and management for satisfactory or maximum production. It has become clear that for application to specific sites, the required soil data may not be widely available. To overcome this, nutrient cycling data should be collected in all alley farming trials.

A model of the economics of shifting cultivation systems has been developed. The model provides a basis for an economic characterization of shifting cultivation systems as a complement to characterizations based on fallow vegetation or soils. The model results are consistent with many of the features of shifting agricultural systems reported in the literature. The model demonstrates that in some shifting cultivation systems, sustainability may be fortuitous, in that declining productivity of weeding labor induces cultivators to abandon cultivation before irreversible soil or vegetation degradation have taken place.

Biology and fertility of soils

The objective of this project is to develop a functional understanding of the relationships between the biological processes in soil, the dynamics of organic matter, and the physical and chemical basis of soil fertility.

Soil organic matter (SOM) is a labile resource, declining rapidly with cultivation. This pattern of change is the opposite of that required for sustainable agriculture. In a collaborative project with Katholik University Leuven (KUL), Belgium, dynamics of SOM are being studied. The target is to devise systems that will replenish SOM from one crop cycle to another.

In 1991, we described the relationship between quantity of organic inputs (litterfall and tree prunings) and levels of SOM active fractions in farmers' fields and on station, at various sites in West and Central Africa from the humid area to dry savanna. Fertility of soils was also correlated to soil humic (HA) and fulvic (FA) acids and to the humin content (HN). Total C and N in FA and HN were found to follow the order forest > newly cleared land > degraded land, but HA tended to remain constant. Vegetation greatly influenced SOM chemical fractions. Humic acid was 29% in plots without vegetation, 40% under maize, 42% under *Panicum maximum*, and 45% under *L. leucocephala* or *Mucuna pruriens* var *utilis*.

In collaboration with the Institute of Soil Fertility in the Netherlands (IB Haren) work on the role of soil fauna in nutrient dynamics has just been started with the assessment of factors affecting decomposition rates and studies on effects of plant residues of contrasting chemical compositions on maize crop performance and soil faunal activities. The objective is to understand the role of soil fauna in nutrient cycling and soil physical changes, and to devise ways to manipulate this soil component for increased and sustained agricultural production.

In one experiment, decomposition was affected in decreasing order by C/N ratio > lignin content > polyphenol content > soil faunal activity. Earthworm and millipedes had preference for *G. sepium* and *L. leucocephala* mulches as compared with leaves of non legumes such as *D. barteri*. Earthworm casting activities were also monitored in various alley cropping experiments and planted fallows.

In collaboration with Michigan State University in the USA, we are quantifying root competition between hedgerow species and associated crops in alley cropping systems and determining the nutrient contribution from the roots of the hedgerows. Minirhizotron and the video camera system as well as root crop sampling have been used. Our preliminary result from the first year's experience with the minirhizotron method shows that it can be used to estimate root development. More than 30,000 roots were identified within the top 10cm of soil by 42 days after planting maize, and 70-79% of the roots are located in the top 14cm of soil.

To test and devise alternative technologies that will restore soil fertility in degraded lands, *Tephrosia candida* was planted in an attempt to regenerate a degraded ultisol at Onne. It controlled weeds effectively and improved soil physical and chemical properties when compared with the use of *Chromolaena odorata* and grasses in the natural fallow. The result shows that *T. candida* improved the re-cycling of nutrients, particularly calcium, in addition to nitrogen input from N-fixation.

Biology and control of *Imperata cylindrica*

The objectives of this project are to develop methods for controlling *Imperata cylindrica* (speargrass) and to recover land, abandoned because of speargrass infestation, for productive and sustainable crop production.

In 1991, studies consisted of both habitat management and evaluation of herbicides. Shading by *G. sepium* hedgerows reduced the density of speargrass by 67%, while shading by *L. leucocephala* reduced it by 51%. Shoot biomass of speargrass decreased by 81% in the *G. sepium* hedgerows and by 78% in the *L. leucocephala* hedgerows. Reduction in speargrass rhizome biomass was 96% while rhizome reduction in the *L. leucocephala* plots was nearly 90%. Rhizome mortality was significantly higher in *G. sepium* plots than in *L. leucocephala* and control plots. *G. sepium* was, therefore, better than *L. leucocephala* hedgerow species in suppressing speargrass.

Significant reduction in the density of living speargrass shoots was observed in plots treated with glyphosate, fluazifop-butyl and imazapyr relative to the control plot. These treatments caused the highest tiller mortality. The greatest reduction in speargrass shoot density occurred in plots treated with varying rates of imazapyr. Imazapyr at 0.5 kg ha^{-1} caused more reduction in shoot density than glyphosate at 1.8 kg ha^{-1}. No regrowth of speargrass shoots was observed in plots treated with imazapyr at 1.25 kg ha^{-1} at 15 weeks after treatment while shoot regrowth was observed in all other plots including those treated with the recommended rate of glyphosate (3.6 kg ha^{-1}).

III. Crop Management Research

Savanna Systems

In broad terms the objectives of the Savanna Systems group are to provide feedback to IARCs and NARS in the mandate area in order to guide research priorities, to integrate technologies developed by IARCs and NARS in order to improve the productivity, stability and sustainability of savanna ecosystems in the region, and to develop the research capacity of NARS.

In studying the sustainability of intensifying systems, the objectives are to identify determinants of intensification, study the impact of intensification on natural resource base, and investigate the economic viability of intensifying maize-based systems.

Activities in 1991 included the identification of sustainability issues in the savanna and the development of a strategy on sustainability for the research group, the analysis of the contribution of zinc to the fertilizer response of maize in farmers' fields (collaboration with soil science section, Institute of Agricultural Research, (IAR), Ahmadu Bello University Zaria, Nigeria), as well as completion of the survey on costs and returns of farmers' current cropping patterns.

Based on the results obtained, a "systems" as opposed to a "component" concept of sustainability has been adopted. Degradation in one component of a system may not be considered unsustainable if improvements in the productivity of other components of the system can compensate for it. Two driving forces of intensification were recognized: population and market-related factors. An analysis of the impact of these driving forces on cropping patterns, and the physical and socioeconomic resource base was used to identify priority sustainability problems and the types of solutions likely to be acceptable to farmers under each type of intensification.

In the Northern Guinea Savanna (NGS) of Nigeria, top priority will be given to preventing soil degradation and the build-up of cereal pests and diseases. An ex-ante analysis of the effectiveness of possible solutions, and their acceptability to farmers indicated that our major focus should be on developing a more balanced cropping system, with legumes playing a larger role than they do currently. A variety of traditional and non-traditional legumes will be characterized for the contributions they can make to solving these problems and the resources required for their adoption. Characterization of environments in terms of their resource base will then be used to match technologies and environments.

It was also recognized that economic sustainability of maize-based systems was threatened by the planned removal of fertilizer subsidies by many governments in Africa. Another major focus, therefore, will be on increasing the efficiency of soil and fertilizer nutrients, through crop genetic improvements, improvement of soil quality (where legumes could again play a role), and improved crop management practices.

On-station trials over three years done by IAR showed significant responses of maize to zinc applications, if available Zn is below 2 ppm. Soil data collected from farmers' fields in 1990 showed some fields to be below the critical level and many fields showed Zn deficiency symptoms on the plants. In on-farm trials on 28 farmers fields in 4 villages we compared 20-10-10 (N-P-K) and 20-10-10 + 2+1 (N-P-K + S + Zn). There was a wide variability of responses, showing that further analysis is needed to differentiate responsive from non-responsive fields/management practices.

Studies of legumes as components of cereal-based cropping systems aim at analyzing the constraints and opportunities of legumes to contribute to the sustainablility of cropping systems in the savannas. Activities in 1991 included the evaluation of some fodder legume species for their suitability to be integrated into maize-based farming systems in collaboration with International Livestock Centre for Africa (ILCA), Kaduna; testing of selected species on farmers' fields in collaboration with IAR and National Animal Production Institute (NAPRI), Samaru; the start of intensive cowpea monitoring in collaboration with Grain Legume Improvement Program and Plant Health Program (GLIP/PHP), IAR and University of Bauchi; and a study of the market for soybeans in collaboration with GLIP.

The following criteria were defined for the selection of promising legume species, that might be suitable for the present cereal-based cropping systems in the NGS: climatic adaptation, soil adaptation (pH, P, water logging, drought) growth type (preferably erect), fodder value (green and as hay) aggressiveness (preferably low initial aggressiveness) diseases and pests (should not have diseases and pests in common with current crops), contribution to soil improvement (N - fixation, organic matter, root type), contribution to pest reduction (Striga, nematodes). Several species were selected (Aeschynomene, Centrosema, Stylosanthes, Senna), but Aeschynomene seemed to have the best fit. It was the only species found to stimulate suicidal germination of Striga, has good fodder value, erect growth type and slow early growth. It has no insects or diseases in common with cowpea.

Consequently, Aeschynomene plots were established in farmers' fields, that are seriously affected by Striga or nematodes. The legume's contribution to pest control in the major crops, maize and sorghum, is being tested in addition to its soil improving ability and fodder value.

Soybean is a potentially useful component of savanna systems because of its ability to withstand insects and weeds. Soybean, however, is a relatively new crop and its adoptability will depend on whether farmers can find a market for their soybean. A first step towards investigating this was taken in 1991. There has been a recent dramatic expansion of soybean production in Benue State, Nigeria. This phenomenon was analyzed to draw out implications for the market for soybean. Results showed that the expansion of soybean was being driven by the market for soybean oil. Oil producers were obtaining soybeans locally because Nigerian farmers were able to produce soybean at a price competitive with imports. Production was expanding and market channels were well developed. As a result industrial users were not experiencing the supply problems commonly associated with many agricultural commodities. This had led to the substitution of soybean for groundnut in oil/feedcake production. There is, however, a ban on the import of edible oils into Nigeria. It will be important to investigate whether the domestic oil/feedcake industry would remain competitive if the ban were lifted. This aspect will be studied next year.

A major objective of our characterization studies of maize-based systems is to develop a methodology which can be used by NARS and IITA for agroecological/ socioeconomic characterization of maize-based systems in West and Central Africa. In 1991 the characterization of maize-growing environments on the basis of G x E interaction was continued, constraints of maize-based systems in the NGS of Nigeria were analyzed and described, and criteria for the characterization of production systems were developed. The comparison of G x E clusters from IITA's international maize variety trials showed inconsistency in the clustering over years. Additionally, many sites were not used in all years and some varieties changed over the years.

Several constraints affecting maize in the NGS are known to scientists working on-station, but their analysis on farmers' fields is more complicated. A key is necessary to differentiate symptoms of different constraints in the field. Subsequently, incidence and severity of major constraints have to be translated into estimates of yield loss, which are the most relevant criteria for the farmer. Differential keys are being developed in order to differentiate between problems of Striga, nematodes, fusarium, streak, deficiencies in zinc and sulfur, which seem to be factors frequently confounded in the field.

Multivariate analysis of diagnostic trials and surveys, aims at improving the efficiency of farming systems research by describing the diversity of existing systems and identifying constraints and opportunities for technology development and transfer. In 1991, programs of cluster analysis and contribution analysis developed by the University of Queensland, Australia, were adapted to our needs and tested. Weed and nematode populations in the savanna were well described by cluster analysis. The contribution analysis indicates the importance of different species to the differentiation of groups. The size of the program had to be changed for the weed data set. The user interface is, however, still too complicated.

Principal component analysis was used to conceptualize the information on soils from farmers' fields. Cation exchange capacity (with Ca and Mg), the organic matter factor, the pH and soil texture explain about 75% of the variability between soils.

In our on-going studies of the impact of evolving crop production systems on Striga, our comprehensive field monitoring methodology was tested on 70 farmers' fields in six villages. We concluded that three field visits are sufficient to analyze the farming system and to estimate the yield loss from it.

NARS in Cameroon (Institut de recherches agronomique, IRA, Maroua) and Ghana (Agricultural Experiment Station, Nyankpala) started to characterize Striga in the farming system of their areas. Part of their methodology was developed by IITA in collaboration with IAR, Samaru. The experiences from these sites will expand on our efforts to develop a useful methodology.

In the field, differences in the virulence of Striga on sorghum, maize and millet were observed, but the pattern of virulence and the involuntary forces behind it have not been analyzed. Laboratory research by our Plant Health Management Division (PHMD) has contributed to developing a methodology for the differentiation of Striga populations. Preliminary trials showed clear differences in the virulence of Striga populations to the cereal hosts.

New maize varieties with tolerance of Striga were tested in farmers' fields using the farmers' maize/sorghum intercropping system and leaving all field management practices to the farmer. The observations of 1990 trials were confirmed: tolerant maize varieties have increased yield under Striga infestation. The reduced count of Striga incidence on some of these varieties also suggests the presence of true resistance to Striga rather than just tolerance in these varieties. Most farmers practiced late remoulding, thus there was almost no *Striga* reproduction on maize. However, sorghum stayed in the field for 6-8 weeks after the maize harvest and allowed substantial Striga reproduction. The trials confirmed that the presence of sorghum in the farming system is at present the major cause of Striga proliferation.

Consequently, the presence of sorghum in farmers' fields was quantified. Survey data from five villages in the NGS of Nigeria showed that sorghum was present as a major or minor crop in 66% of the cultivated area. Sorghum/maize intercrops were present in 42% of the area. These intercropped fields would allow substantial Striga reproduction even if technologies for controlling Striga on maize were adopted. Data also showed that sorghum was planted in two or more consecutive years in the same field in 52% of surveyed plots. This indicated that reduction of the Striga seed bank would be difficult to achieve, unless Striga-resistant sorghum varieties acceptable to farmers could be developed.

Survey data was also used to analyze farmers' crop choice decisions. Crop choice decisions related to cereals and legumes were particularly important since the domination of cereals leads to the build up of cereal pests such as Striga. Rotation with legumes can contribute towards reducing the build up. In-depth interviews with farmers illustrated that producing a sufficient quantity of staple foods to feed the family, and obtaining some variety in the types of staples consumed, were primary objectives, followed by the production of cash crops to meet family and farm cash requirements and social obligations. Analysis of farmers' cropping patterns showed that, on average, farmers devoted 62% of their cultivated area to cereals and only 14% to legumes. Within the cereals, sorghum which is mainly a food crop, and maize which is both a food and cash crop, each occupied 28% of cultivated area.

Farms in the sample included those managed by household heads, and those managed by junior members of the household. Since household heads are usually responsible for supplying staples for the family, they were hypothesized to devote a larger area of their farms to cereals, and particularly to sorghum Results showed that household heads planted a significantly greater proportion of their farms to cereals (68%), compared with non-household heads (53%). However, when broken down by crop, the proportion planted to sorghum was found not to be significantly different. The difference in the area devoted to maize (32% vs 21%), was however significantly larger for household heads. Maize is intensive in purchased inputs and this pattern could reflect the better financial status of household heads. The only other crop in which a significant difference was found was cotton, with non-household heads planting a larger proportion of their farms (18%) than household heads (7%).

Cotton is the only non-food crop cultivated in the area and its greater cultivation by non-household heads may reflect their relative freedom from obligations to supply food for the family. Cotton is also cultivated in the area with minimal purchased inputs. It may therefore be more suitable than maize as a cash crop for non-household heads.

Differences between household heads of different wealth categories showed that wealthier farmers devoted a larger share of their farms to cereals and poorer farmers had a larger proportion of their farms planted to legumes. Differences were not, however, statistically significant, except in the case of maize, which occupied a smaller share of the farm in the case of the poorest farmers (21% vs 37%), and millet, of which poorer farmers planted significantly more than the wealthiest farmers. Sorghum showed no systematic pattern in relation to wealth, indicating that other factors such as family food requirements may be more important.

The results so far appear to indicate that to add variety to the consumption of sorghum, wealthier farmers cultivate maize for consumption, while those who cannot afford the inputs cultivate millet. Maize is the preferred cash crop for those who have the required cash to purchase inputs. Others cultivate cotton. Legumes do not appear to feature as either

major food or cash crops. Legume consumption levels are very low. Therefore, if they are to increase their role in the production system, they will have to increase their attractiveness as cash crops. The results indicate that considerable increases in the productivity of legumes will be required before this can be achieved. Analysis of farmers' crop choice decisions will continue in 1992.

The farming systems in the semi-deciduous forest zone of southwestern Nigeria, present characteristics of a system in the early stages of population-driven land intensification. They are characterized by declining fallow periods, low levels of use of hired labor and material inputs due to cash constraints, declining soil fertility, and a switch to crops which can maintain calorie production per land area under conditions of low soil fertility.

In order to investigate whether the farming systems in the area are compatible with the characterization criteria being developed in the NGS, analysis of data from an intensive survey in 1988/89 of all income generating activities of 39 randomly selected households in three villages in the area was carried out, supplemented with in-depth informal interviews. Analysis of land use patterns showed that although fallow periods were declining, fallowing was still widespread. On average, 20% of the land area of farmers was left fallow, 40% contained tree crops (mainly cocoa and oil palm). Less than a third was planted to annual food crops, with 81% of food crop area occupied by intercropped cassava and maize. While the average size of the tree crop fields was around 1 ha, the average food crop plot was only 0.2 ha. Fertilizer application levels were very low, averaging 10 kg N/ha on food crop fields.

Field inspection showed that standards of weed control on food crop fields were poor. This was supported by survey data which showed that, on average, fields were weeded for the first time 10 weeks after planting, whereas the recommended practice is 3 - 4 weeks after planting. Farmers regarded weed control as the major constraint on food crop fields and claimed the reason was the lack of cash to hire laborers for weeding. Two thirds of the labor used for food crop production was supplied by the family, and the operations which used the highest proportion of hired labor were heaping (53% hired labor) and weeding (46% hired labor).

An analysis of the cash profile showed that 87% of net cash income was derived from non-farm activities, mainly trading. Tree crops contributed 19%. Food crop expenses were higher than sales. Thus, cash expenses for food crop production (of which 89% was hired labor) were being financed from other activities, mainly trading. The seasonal distribution of net cash income showed that the last three months of the year were the most liquid, with cash receipts coming in from tree crop products and trading. This was used to finance land clearing and land preparation for food crop fields in the following year. March to June, the period when weeding labor would be required, were periods of negligible or negative net cash incomes.

Costs and returns analyses and discussions with farmers showed that returns to both land and labor for established cocoa farms was 96% higher than for food crop production and 500% higher for oil palm fields. Labor requirements for established tree crops were only 23% of the labor required for food crops. However, the long gestation period, particularly of oil palm (which in fact was more profitable than cocoa) held back expansion.

Soil fertility was not overtly mentioned as a problem. However, discussions revealed that the area had converted from a yam-based system to a cassava-based system because of declining soil fertility. In this situation, technologies for increasing soil fertility are unlikely to be adopted unless they have a substantial impact on either the cropping system (for example, by permitting yam cultivation), or on the yields of existing crops. Such

technologies are likely to require cash expenses, (for example for labor and fertilizer) and therefore are unlikely to be adopted, given current cash constraints.* This appears to be confirmed by the lack of adoption of alley cropping in the area.

Since the area is served by good roads, and appears to have a comparative advantage in tree crops, it may be possible to convert the area to market-driven intensification, through improved tree crop technologies. Short duration, high-yielding oil palm varieties, when introduced to farmers on a limited basis, were very favorably received. Their widespread adoption could inject more cash into the system and therefore make soil management techniques more adoptable, while contributing at the same time to the weed control problem.

A study of institutional constraints to the adoption of hybrid maize was conducted in four Local Government Areas in Kaduna State, Nigeria, an area which has a comparative advantage in maize production and has witnessed a major expansion of open-pollinated maize in the last 15 years. Within the study area, around 40 villages had hybrid maize adopters. In most villages, less than 5% of farmers were adopters. In no village did adoption exceed 26%. Certain village level characteristics appeared to favor adoption. Villages with adopters were clustered around the major markets in the area, indicating that input supply and ease of output disposal could be important factors. Virtually all villages with adopters had resident extension agents or were frequently visited by extension agents. The villages with relatively higher rates of adoption had resident or nearby hybrid seed distributors. There was no connection between adoption and the location of official input distribution outlets (farm service centers). This was not surprising since farm service centers were often empty, and inputs were procured by farmers from major markets.

The most important reasons given by farmers for adopting hybrids were high yield and high profitability. The overwhelming reason given for non-adoption was that hybrids required high dosages of fertilizer. This could reflect cash constraints or difficulties in procuring sufficient fertilizer.

Turning next to farmer characteristics that influence adoption, a probit analysis revealed the most important determinant of adoption was the ability of farmers to procure enough fertilizer, and on time. A higher level of education was also a significant factor. The cost at which fertilizer could be procured was not a significant determinant.

Interpretation of the results and discussions with farmers indicate that in the perceptions of farmers, the efforts required annually to obtain hybrid seeds are worthwhile only if high levels of fertilizer can be used, because it is only then that the advantage of hybrids over open-pollinated varieties (OPV) is sufficiently expressed to make seed procurement worthwhile. If a farmer is in a situation where he cannot procure enough fertilizer (whether for cash or distribution problems) he will prefer to grow OPV. Also timeliness is important. If, at the beginning of the season, he cannot be sure of being able to procure sufficient fertilizer, OPV are considered a safer bet.

These results indicate that it will be important to investigate whether currently available hybrids require high dosages of fertilizer to express sufficient advantage over OPV. It will also be necessary to investigate whether this is a characteristic of heterozygosity. This is particularly important since fertilizer application levels are likely to decline, given the commitment of governments in SSA to the removal of fertilizer subsidies.

A Collaborative Group on Maize-Based Systems Research (COMBS) established in 1989 includes on-farm research teams from the six major maize-producing countries in the region. Declining soil fertility and increasing weed infestation, and the methodological problem of farmer participation in on-farm experimentation are being addressed by all teams. At the same time, a computerized decision-support system is being developed for the integration of appropriate legume-based technologies into maize-based farming systems that allow the NARS scientists to easily access information on appropriate legumes and the management techniques for any particular ecozone they want to address.

Humid Forest Systems

The objectives of the Humid Forest Systems research are:

- to characterize major cassava-based production systems in the humid forest zone of West and Central Africa from an ecological and socioeconomic perspective;
- to evaluate constraints and potentials for crop production and utilization in selected cassava-based systems in the humid forest zone of West and Central Africa;
- to generate and evaluate improved crop management components of selected cropping systems;
- to design and evaluate improved cropping and utilization systems for smallholder farmers;
- to provide feedback on production and utilization constraints of smallholder farmers which can be incorporated into crop management and resource management research, and strengthen links between IITA, NARS and international institutes on research and training related to major cassava-based crop systems.

Characterization research is carried out under the Collaborative Study of Cassava in Africa (COSCA). COSCA is conducted in three phases. Phase I was a broad characterization survey conducted in 1989, Phase II was a detailed production survey conducted in 1991 and Phase III is a postharvest study to be carried out in 1992.

The goal of Phase II of COSCA is to collect detailed information on production practices at the farm level over a wide area. This information was collected in 1991 from 275 villages selected statistically in such a way as to represent the cassava-producing zones of six countries which together produce 70% of cassava in Africa. These countries are Côte d'Ivoire, Ghana, Nigeria, Tanzania, Uganda and Zaire. In each of the 275 representative villages, three farmers were selected (again by a statistical method) and information was taken from all the fields, (cassava and non-cassava fields), carrying crops in the 1991 crop season. The information collected from each field included field area obtained by measurement using compass, tape and ranging poles, cassava yield taken from all mature cassava fields by the yield sample plot method, proportion of total output of each cassava field meant for sale, and proportion of total output of each cassava field that would be processed before use by farmers. Data was also collected on methods of cultivation not only of cassava but also of all major crops including maize, rice, beans/peas, banana, yam, cocoyam and potatoes in the humid and subhumid areas. Information is provided for diverse conditions of market infrastructure, demographic pressure, climate, and agricultural intensification. It is integrated with

information collected in the broad characterization survey of Phase I conducted in 1989. Phase 1 data showed the need of farmers in areas of dense population and with a relatively good market access infrastructure for early-maturing, high-yielding, pest and disease resistant cassava varieties with good processing qualities. Farmers who produce predominantly sweet cassava types are also seeking cassava varieties which are suitable for in-ground storability and have good cooking qualities. Farmers who practice intercropping are additionally seeking certain growth habits which are suitable for intercropping, such as high branching types. But they would delay planting to later in the season in order to use low branching types which give a high root yield.

The mean fresh root yield for the 275 representative villages in Phase II of COSCA is above 12 t ha^{-1} with a range of less than 1 t ha^{-1} to more than 50 t ha^{-1}. Weighted average of FAO information for the same countries is about 8 t ha^{-1}. The difference between the two estimates is likely to result from differences in the data quality. Bitter varieties give a higher yield than sweet types especially under more adverse conditions. Low branching varieties give a higher yield than high or no branching types, and broad leaf types give a higher yield than narrow leaf types.

The yield is significantly higher in the subhumid than in the humid climate areas but higher in the humid than in the dry areas sampled. The sampled areas do not represent all dry areas, since they include only such areas where cassava is important. Yield is directly related to plant population density which is lower in the humid than in the subhumid climate areas. Yield is maintained at an average level with organic manuring, livestock grazing, and the use of improved planting materials in areas of intensive production such as areas of reduced fallow period or where purchased inputs are used, (chemical fertilizers, hired labor and mechanization of land preparation and transportation.) Improved cassava varieties yield substantially more fresh roots, (an average of about 20 t ha^{-1}), than local varieties, (an average of about 11 t ha^{-1}). The improved varieties are widely grown by farmers in Nigeria and occupy more than 60% of the land planted to cassava in the humid areas and 40% in the dry areas.

Distribution of mature cassava fields by age shows that above 15 months after planting (MAP) cassava fields diminish rapidly. This trend is more pronounced in areas (1) of intensive agriculture, (2) of high demographic pressure, (3) of relatively good market access, and (4) where varieties grown are predominantly sweet. The sweet types are harvested earlier because of their relatively poor in-ground storage quality as there is no evidence that they bulk faster than the bitter types. Improved varieties perform better than local varieties in terms of early maturity. The improved varieties have attained maximum bulking at 10-12 MAP and the yield stays stable for above 36 MAP. The local varieties, on the other hand, do not reach maximum bulking before 18 MAP.

The importance of cassava declines from the humid through subhumid to dry climate areas, defined in terms of the percentage of arable cropped land. However, cassava is still the most important crop in the subhumid areas and second only to maize in the dry areas sampled. The importance of cassava also declines as agricultural intensification increases from shifting cultivation through fallow rotation to continuous cropping. Yet cassava is still the most important crop in areas of both shifting cultivation and fallow rotation and surpassed only by maize in areas of continuous cropping. In the humid climate areas, the importance of cassava appears to be driven by both demographic and market forces. But outside the humid climate areas, market forces become more important than population as the driving force behind the

importance of cassava. The evidence does not show that cassava is more important in the areas of use of purchased inputs than in areas where such inputs are not used.

The production trends for cassava are increasing in approximately two thirds of the 275 representative villages. Cassava is replacing fallow in 40% of the villages, pasture in 30%, arable crops in 28%, and tree crops in only 2% of the villages. The proportion of the villages where cassava production trend is increasing is above average in areas where banana/plantain, rice and millet/sorghum are the most important crops; the proportion is close to 100% in areas where yam is the most important crop in terms of land area. The increasing trend is driven by famine caused mainly by drought in 30% of the villages, by demographic pressure in 25%, by market availability in 20%, and by other factors in 25% of the villages. Evidence shows that cassava production is increasing in more villages

- in the areas of intensive agricultural production and of high use of purchased inputs.
- in the subhumid compared with the humid climate zones.
- in the humid compared with the dry climate areas sampled. Where it is increasing in the dry climate areas, however, it is driven more by market forces than by agricultural intensification, famine or demographic pressure.
- in the low altitude rather than in the mid altitude villages. Within the mid altitude villages where cassava production is increasing, the trend is driven more by demographic pressure and famine than by market forces.

About 70% of total cassava production is processed into a wide range of products including pastes, chips/flours, granules, starch, and alcoholic beverages. The proportion processed is positively and significantly related to the importance of cassava in terms of percentage of arable crop land and also to demographic pressure. It is significantly higher in the subhumid (80%) than in the humid (65%) and the dry (60%) climate zones. It is also significantly higher among villages which produce only bitter cassava types (80%) than among others (60%) which produce only sweet cassava types. The proportion processed is, however, negatively and significantly related to market access infrastructure conditions, being lower in areas close to markets (60%) than in others not close to market centers (70%). The objectives of processing cassava roots include bulk reduction and shelf life extension in order to facilitate marketing. Therefore, the need for processing is greater in areas further away from markets than in others close to market centers.

The transformation is done following a wide range of traditional technological pathways adapted to the use of locally available processing resources such as fuelwood, sunlight, and water. The main steps include peeling, crushing, cooking/toasting which are labor, fuelwood and/ or sunlight use-intensive. It also includes fermentation which may or may not be water use-intensive depending on the technological pathway adopted. The processors desire attractive color, texture and taste qualities, in that order, in the processed products. Chips/flours are the most widely used cassava product in 45% of the 275 villages, granules in 22%, fresh roots in 21%, and pastes in 12% of the representative villages.

Water supply determines the type of product made with cassava roots. The number of villages where chips/flours are the major processed cassava products increases from 25% in the humid through 60% in the subhumid to 85% in the dry climate zones. On the other hand, the number of villages which use pastes as the major product decreases from 20% in the humid to 15% in the subhumid to none in the dry climate zones. Technological pathways

include sun drying for chips/flours and soaking in water for pastes. Sun-drying is more efficient in the dry than in the humid climate areas, while water supply is more abundant in the humid than in the dry areas. Water supply does not, however, affect the proportion of total production processed. Among villages which depend on rivers for water supply and therefore do not face a water scarcity, the proportion of total production processed is 67%. In comparison, among other villages which depend on boreholes for water supply and therefore face a relative water scarcity, the proportion of total production processed is nearly 80%

Although some traditional processing techniques involve steps which are fuelwood use-intensive, yet fuelwood supply does not seem to influence the product made. Making gari, a granule, involves the toasting step which is very fuelwood use-intensive. But in areas where nobody buys fuelwood because of an abundant supply, only about 15% of the villages make granules as their major processed product. On the other hand, in the commercialized areas where most people buy fuelwood and hence fuelwood supply is low, about 35% of the villages make granules as their major cassava product. Gari is an attractive processed cassava product which has a higher expenditure elasticity of demand than other cassava products at high expenditure level. It is produced irrespective of high fuelwood cost for the high income consumers. The fuelwood supply situation also does not constrain the proportion of total production of cassava processed; in the villages where nobody buys fuelwood because of abundant supply, about 65% of total production is processed; in comparison, in the villages where most people buy fuelwood, more than 70% of total production of cassava is processed.

Labor use-intensity is the major constraint in traditional cassava processing. Peeling, crushing and toasting are extremely labor-intensive, to the extent that root yields attained through the use of the improved cassava varieties would not lead to expanded production to a significant degree because of labor constraints at the processing stages. However, the crushing step has been mechanized in some areas of commercial production, mostly in West Africa. The number of villages where cassava production is increasing is 100% where the crushing step has been mechanized in gari making, compared with only 45% of the villages where no processing step is mechanized. The result is that the importance of cassava in terms of percentage of arable land increases from less than 35% in villages where no processing step is mechanized to more than 75% in villages where the grating step in gari making is mechanized, with cassava displacing cocoyam, millet /sorghum and rice.

Other objectives in cassava processing include the reduction of the hydrocyanic acid potential of the roots and imparting of desired taste in the final product. These two objectives are attained at the fermentation step of processing. However, nearly 20% of the villages which produce fermented processed products reported a decline in the length of the fermentation period. The number of villages where cassava fermentation trend is declining is significantly higher in areas where the grating step is mechanized (60%) than in areas where no processing step is mechanized (10%); the number is higher in areas of good market access (25%), than poor (15%); it is also higher in areas of high demographic pressure.(25%) than in low (10%)

In southwestern Nigeria cassava+maize+egusi melon intercrop is the predominant cropping system. Cassava is usually the main crop. Optimum fertilizer rates for such a crop mixture are not available and fertilizer practices based on sole crop studies have proved inadequate. In trials carried out in Ayepe in Oyo state and Ohosu, in Edo state, Nigeria, fertilizer rates were based on soil analysis, assumed potential uptake and two blanket rates. The highest crop yields were obtained when fertilizer was applied to fully compensate for

potential uptake. Nutrient uptake was linear. The point of maximum nutrient accumulation was established at 8 weeks after planting (WAP) for egusi, 8-12 WAP for maize, and 24 to 36 WAP for cassava.

In a study to quantify tillage effects on run-off and yield of cassava+maize intercrop, results showed that in the short term, inclusion of melon in a maize+cassava mixture depressed maize and cassava yield by 16 to 32%. However, because of the favorable effect of melon on water infiltration, run-off and erosion, compaction and soil fertility, especially under no-tillage conditions, the combination maize+cassava+melon is expected to be more sustainable in the long run than maize+cassava alone.

In a study aimed at quantifying plant interaction in the cassava+maize mixture, identifying key plant parameters for intercrop optimization, and examining the medium- and long-term dynamics of cropping systems, results indicated that a simple equation for plant interaction can be used to simulate crop growth in a population based on individual plant growth curves. The model interfaces with well-established modules for the calculation of potential crop growth as a function of light and water.

A literature review of the research results of intercropping with cassava shows that the temporal complementarity of these species mainly accounts for the greater biological advantages over sole cropping of combining cassava with maize or grain legumes. The slow-growing cassava provides a niche early in the season, which can be occupied by a faster-growing and earlier-maturing crop. Though cassava growth is inhibited by competition with the associated crop, it may partially compensate for this loss after the latter has been harvested. In general, the result is better land utilization than when the crops are grown separately.

The size of this advantage depends very much on the associated crop. Low-growing legumes compete with cassava to such an extent that the consequences of this stress persists even after the legume has been harvested. Maize is less likely to have an effect, since it generally reduces cassava growth early enough in the season to permit adequate recovery afterwards. But even so, the advantage of the cassava+maize mixture may be greatly diminished if the vigor of the maize crop exceeds a certain threshold (corresponding to a maize yield of 3-3.5 t ha^{-1}), in which case subsequent cassava growth is severely reduced and the plant does not recover from the stress of early competition. Cassava+maize intercropping thus involves a somewhat delicate compromise, in which the growth of each crop is sacrificed to some extent for the sake of greater efficiency overall.

These insights have a number of implications for plant breeding. In the case of grain legumes, for example, it is preferable, at least for the purposes of intercropping with cassava, that varieties be of relatively low vigor and mature in less than 90 days. Likewise, the ideal cassava clone for a mixture with maize is one that has low or moderate vigor early in the cropping cycle (and thus exerts only a minimal effect on maize growth) but can recover afterwards from stress caused by competition with this cereal.

Another implication is the seemingly contradictory point that selection of maize for increased yield under high plant density in sole stands is the approach most likely to generate varieties that are more suitable for intercropping with cassava. Much experience in maize improvement has shown that selection under these conditions raises its harvest index, resulting in genotypes that are efficient in producing grain but less vigorous in their vegetative growth. Such plants are not only the best grain producers in combination with

cassava, but should also be the least likely to suppress cassava yields. This is one case in which genetic improvements needed to raise production of the sole crop can be nicely reconciled with the demands of the crop mixture.

That is not necessarily true, though, of the implications for crop management. Agronomic practices that are designed to exploit the higher yield potential of improved maize may be so detrimental to cassava (particularly if they push maize yields over 3 t ha^{-1}) as to eliminate the advantage of intercropping. The cassava+maize mixture is therefore unsuitable for high-input agriculture or very fertile soils, unless maize is planted at low density.

In continued analysis of the productivity and constraints in farmers' cassava+maize system, an intensive field-level diagnostic study was conducted in Ayepe in the forest-savanna transition zone of Nigeria to quantify the causes of yield differences among farmers, combined with a modeling exercise on potential maize yields. The results showed that shade (22.6%) and weed infestation (31.6%) together accounted for 54% of farmers' yield variation. Differences in soil fertility appear to play a role but could not be captured by the laboratory-determined soil parameters.

Research continued on the incorporation of pigeon pea into the cassava+maize intercropping system in order to improve the productivity and sustainability of the system. A trial was conducted at the Ibadan station with three factors: cassava varieties (TMS 30572 and Odongbo) pigeon pea plant arrangements, and pigeon pea cutting heights (30, 50 and 70cm). Pigeon pea was cut back after the maize harvest. Maize yields averaged 1.45 t ha^{-1} with no significant differences between treatments, showing no adverse effects of pigeon pea on the maize.

Cutting back of the pigeon pea resulted in significant mortality. This was not observed in an exploratory observation in 1990, which was, however, conducted during the second rainy season with much less vigorous cassava growth after the maize harvest. Pigeon pea mortality was significantly higher when cut back at 30cm (29%) than at 50cm (20.3%) or 75cms (16.1%) and also higher in association with the vigorous TMS 30572 (24.6%) than with Odongbo (10.9%). Mortality also correlated significantly with canopy volume of the cassava. It was suspected that part of the mortality was related to root snapping in the process of pruning. This would also increase with the stem diameter to be cut, which was higher at the lower cutting heights. Further investigations will be needed on appropriate management techniques for pigeon pea to prevent mortality.

In the popular cassava-based cropping system in the southern Nigeria, cassava is either relayed into early planted egusi melon and maize or planted practically sole (with low density maize). The sole cassava pattern would benefit from an associated legume such as groundnut.

A simple exploratory trial was conducted by 20 farmers in the Ohosu area of Edo state. Farmers were given seed of a small seeded erect and a large seeded spreading variety of groundnut, for interplanting into their cassava or yam fields. The fields were monitored for rodent attacks and stand at harvest and dry pod yields were measured. In most fields, farmers planted the groundnut well before the cassava or the yams. Planting densities varied from 20,000-120,000 plants ha^{-1}. Rodent attack was severe in many of the fields. The average groundnut pod yields ranged from 200-1600 kg ha^{-1}. Farmers' opinions ranged from "not interested" to "keen to try again". In 1992, a researcher/farmer managed trial will be conducted to study timing of groundnut introduction as well as plant arrangement.

In our constant effort to strengthen co-operation with NARS cropping system research teams in key institutes, a joint meeting was held in June between NARS collaborators in cropping systems research and those in root and tuber crops improvement. The group adopted the name CORTIS, i.e., Collaborative Group for Root and Tuber Crops Improvement and Systems. A plan of action was developed for mutual technical support among the groups, collaborative research projects, and interfacing between crop breeding and cropping systems research.

Two major research issues have been identified by the group namely: development of collaborative research on the introduction of (grain) legumes in farmers' systems, and development of procedures for evaluation and on-farm testing of improved varieties.

Inland Valley Systems

A five-year research plan was recently developed by the group. This plan spells out the methodological framework of research activities on inland valley (IV) systems at IITA. These activities fall into three broad categories: inventory - classification, diagnosis - modeling, and development of improved technologies. In 1991, the group gave priority to inventory - classification and diagnosis - modeling activities.

Level 1 characterization was initiated and completed in 1991. It consisted of the mapping of broad agroecological and economic zones throughout West and Central Africa at a scale of 1:5,000,000. The ecological and economic parameters used in this mapping are soils (FAO classification), length of the growing season (based on rainfall data and potential evapotranspiration), population density (more than or less than 30 persons km^{-2}), income per capita (more than or less than \$350 $year^{-1}$), altitude (less than 800m).

Secondary data banks were obtained and entered into IITA's GIS. The map produced enabled 11 large agroecological and economic zones to be identified, cutting across West and Central Africa. Each zone covers more than 10 million ha. Areas will be chosen within these zones for characterization, constraints identification and quantification in subsequent years.

The objectives of diagnosis research are to develop methods of data collection for measuring ecological and economic constraints in IV agroecosystems. Previous work had identified weeds as a primary constraint in these systems. The methods of data collection developed thus focused on farmers' weed management practices.

The objectives of the research activities on weeds were to quantity yield losses due to weed infestation, understand farmers' weed management practices, understand the interactions between farmers' water management, soil fertility management and weed management practices, and to understand farmers decision-making procedures.

An interdisciplinary and systems approach was devised and two sites were utilized to test this approach (Bida located in the Southern Guinea Savanna of Nigeria and Makeni located in the humid forest zone of Sierra Leone). A random sample of 60 farmers having IV fields was chosen at each site. Trials were conducted on one of the IV fields of each farmer during two rainy seasons. In conjunction with these trials and observations, each farmer was interviewed eight times. The questionnaires developed used principally, but not exclusively, open-ended questions which aimed at throwing light on the motivations and perceptions of the farmers.

All 57 farmers in Bida weeded their lowland rice fields at least once, compared with Makeni where only seven out of 60 farmers weeded their fields. Of the farmers in Bida who

weeded, 36% did so within the first 28 days following transplanting, 20% weeded between 29 and 35 days following transplanting, 33% weeded between 36 and 49 days following transplanting and 5% farmers weeded more than 50 days following transplanting. There was a significant reduction in rice yield because of the failure to weed in both Bida and Makeni. A single weeding within 36 to 49 days after transplanting resulted in yields comparable to two hand weedings at four and six weeks after transplanting or to total weed removal. However, a single hand weeding in Makeni was not sufficient to prevent significant yield reduction.

The magnitudes of the interelationships between rice varieties, seedling densities, seedling age, weed density and biomass, and water levels were examined. Under farmer weed management (one weeding spread over three- week interval), mean grain yield ranged from 1-3 t ha^{-1} and was mainly influenced by seedling age, transplanting density and type of variety.

In Makeni, farmers' yields in their unweeded fields averaged 1.2 t ha^{-1}. The yields were negatively correlated with levels of weed infestation (weed density and weed biomass), seedling age, and mean depth to ground water over the season.

The analysis of the trials results, measurements and answers to the questionnaires showed that using data derived solely from on-farm trials or questionnaires would have given us a narrow understanding of weed problems in IVs. It was the interactive and inter disciplinary design and implementation of trials and questionnaires which gave a more complete understanding of these problems and of the agroecosystems in which they occur.

Bida IV farmers belong to a relatively traditional society in so far as they give priority to social relationships and human values over commercial and financial values. By opposition, Makeni farmers belong to a society where the concept of profit is a dominant value. These farmers are also more integrated in the market system than Bida farmers.

Furthermore, staple foods are different in the two locations (rice in Makeni, millet and sorghum in Bida). Bida farmers consume rice relatively rarely, almost uniquely during their religious and social ceremonies and celebrations. They thus consider their IV fields as complementary, but not essential to their upland fields. In Makeni, IV fields are considered as prime farming environments by comparison with upland fields. IVs thus play an entirely different role in the farming systems in the two locations. It follows that needs in improved technologies concerning weed management as well as other cultural practices will be different.

The information obtained at the two sites led us to the realization that it is essential to collect data on upland fields in a research project dealing with IV systems. It is indeed necessary to have a minimum knowledge of upland farming activities in order to understand farmers priorities and trade offs between upland and IV fields.

The results obtained also show that farmers are very aware of the interactions which exist between their various practices. They are aware of the fact that fertilizer applications will generate different rice yields, depending upon the water status of a field, its rate of infestation by weeds and pests, and its soil fertility. Farmers make decisions concerning weeding frequency and total number of weedings on the basis of the physical characteristics of their upland and lowland fields (e.g., growth cycle of weeds, ease/difficulty of weeding) and of

their production objectives. The combination of these two factors determines farmers' trade offs between upland and IV fields. Labor allocation (family, hired and communal) to upland and IV fields is made according to these trade offs. This allocation, in turn, dictates the number of weedings which is feasible for IV fields.

Any improved technology introduced in IV agroecosystems will have direct and indirect consequences for upland farming practices, through the above interactions. It will thus be necessary to identify and evaluate these consequences when testing these technologies in IV systems.

The inventory - classification work undertaken by the group so far, not only provides the relevant and necessary framework for extrapolation of results to large geographical areas, but is also leading to an in-depth understanding of IV systems by facilitating comparisons of results from sites representative of different categories of IVs.

Annex 1

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MSc/MPhil.

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"Survey on impact of fertilizer use on ground and surface water quality in the Northern Guinea Savanna (NGS) region of Nigeria"

Thomas, Vinod George (India) University of Ibadan, Nigeria.
"Forms of phosphorus in soil under alley cropping with different woody species in South-West Nigeria".

Welkie, Sylvia (Canada) University of British Columbia, Canada.
"The relationship between leucaena hedgerow pruning intensity on performance of associated mixed cropped maize and cassava"

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PhD

Abolaji, Grace T. (Nigeria) Southern Illinois University, USA.
"An analysis of the impact of research-extension farming linkages on small farmers' adoption of improved cassava varieties in Nigeria"

Ahmed, Benjamin (Nigeria) Ahmadu Bello University, Zaria, Nigeria.
"Economic analysis of the potentials for sustained maize production in the Northern Guinea Savanna of Nigeria"

Akinnifesi, Kehinde (Nigeria) University of Ibadan, Nigeria.
"Adaptive performance of selected hedgerow trees in major agro-climatic zones in Nigeria"

Akonde, Pierre T. (Benin) University of Hohenheim, Germany.
"Effects of long term alley cropping systems on food crops productivity in southern Benin Republic"

Ambassa-Kiki, L. R. (Cameroon) University of Ibadan, Nigeria.
"Rehabilitation of a degraded ultisol in central Cameroon, at Minkoameyos"

Atayese, M. O. (Nigeria) University of Ibadan, Nigeria.
"Screening of leguminous woody seedlings for ectomycorrhizal benefits"

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"Screening of leguminous woody seedlings for vescular-arbuscular mycorrhiza"

Bakare, Olasinde M. (Nigeria) University of Ibadan, Nigeria.
"Effect of seasonal variation on mycorrhizal spore production"

Boehringer, Andreas (Germany) University of Hohenheim, Germany.
"Simultaneous fallow systems in southern Benin"

Bohlinger, Brigitte (Germany) University of Hohenheim, Germany.
"The aspects of fallow plant management during the cropping cycle"

Chineke, Theodore C. (Nigeria) University of Ibadan, Nigeria.
"Agricultural climatology of the Nigerian environment"

Egbe, A. (Nigeria) University of Ibadan, Nigeria.
"Comparative development of two indigenous multipurpose trees for agroforestry"

Ezedinma, C. I. (Nigeria) University of Nigeria, Nsukka, Nigeria.
"Availability and use of farm labor in food crop production in cassava-producing zones of tropical Africa"

Freeman, Horatio A. (Sierra Leone) University of Minnesota, USA.
"A model of agricultural intensification in semi-subsistence agriculture in Nigeria"

Huwer, Gerlinde Maria (Germany) University of Hohenheim, Germany.
"Soil fertility and water conservation"

Kadiata, B. D. (Zaire) Institut Facultaire des Sciences Agronomiques, Zaire.
"Biological nitrogen fixation and management of an alley cropping system"

Kaleem, Fezrat Z. (Ghana) University of Science and Technology, Ghana.
"Nitrogen fixation in soybeans under sole crop and maize intercrop and residual effect on a following maize crop"

Kormawa, Patrick (Sierra Leone) University of Hohenheim, Germany.
"The potential for production and marketing of soybean in West Africa".

Kunda, K. Ndolumingu (Zaire) Université Catholique de Louvain-la-Neuve, Belgium.
"Matière organique du sol et cinétique de minéralisation de la matière organique azotée du sol dans les jachères naturelles et dans les parcelles cultivées"

Latt, Christopher (USA) University of Florida, USA.
"The interactions among reserve carbohydrates, pruning strategies and biomass production of hedgerow tree species"

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"Nitrogen fixation and release by leguminous trees used for alley cropping"

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"Root and nutrient distribution patterns in an acid soil under selected hedgerow tree species"

Whittome, Mike Peter (England) University of Cambridge, UK.
"The current level of research into the adoption of alley cropping in Nigeria"

Annex 2

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