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INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

Annual Report 1991

DAVE GIBSON

INTERNATIONAL
RESEARCH IN

Annual Report 1991

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Cover: This nitrogen-fixing *Inga Species* is an indigenous forest tree in Latin America with considerable potential for agroforestry. Farm families in Peru collect the seed pods, whose inner portion is edible. Photo: Gustav Böklin.

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Photo: A Njenga

Dr Pedro Sanchez (right) addresses the audience during the dedication of Lundgren Auditorium at ICRAF headquarters. Seated, left to right, are Dr George Holmes, Chairperson of ICRAF's Board of Trustees, Mr Jeremiah Nyagah, Minister in the Kenya Government, and Dr Björn Lundgren.

The year 1991 marked several important transitions for ICRAF. In March, the Board of Trustees elected George Holmes, a distinguished forester from the United Kingdom, as chairperson. He succeeded ICRAF's long-standing friend and supporter, Howard Steppler of Canada. In April, the Board appointed me as ICRAF's third Director General, following 10 years of outstanding leadership by Björn Lundgren. I assumed the post on 1 October.

In May, ICRAF joined the Consultative Group on International Agricultural Research (CGIAR) with global responsibility for research on agroforestry. In June, the first draft of ICRAF's new strategic plan, *The Way Ahead*, was presented to the Technical Advisory Committee (TAC) of the CGIAR. A second version, approved by ICRAF's Board of Trustees, was submitted to the CGIAR at International Centres Week in October. The strong focus on areas of grave environmental and human concern won a positive response from the scientific and donor communities.

Also in October, the Board of Trustees changed ICRAF's name—from International *Council* to International *Centre* for Research in Agroforestry. This shift from a body that gives advice (council) to the group right in the middle of things (the centre) reflects several important changes at ICRAF.

For one thing, the change in name indicates ICRAF's responsibility within the CGIAR to act as a real focal point for agroforestry research, both strategic and applied. Secondly, we are now more fully implementing ICRAF's global mandate. Collaborative research projects will start in 1992 at sites in Latin America and Asia, and training courses are being conducted in Brazil and Indonesia.

ICRAF's institutional goal has been rephrased as follows: 'To mitigate tropical deforestation, land depletion and rural poverty through improved agroforestry systems'. Research focuses on three agro-ecological zones: the humid, subhumid and semi-arid tropics.

In the humid tropics, work will concentrate on agroforestry alternatives to slash-and-burn cultivation and agroforestry systems for the reclamation of abandoned land. In the subhumid and semi-arid tropics, the focus will be on

agroforestry systems to overcome land depletion, soil fertility loss, erosion, and loss of fodder and fuelwood.

Work in areas suffering land depletion will continue to focus on Africa, where problems are most serious. Collaborative research will continue through the four existing Agroforestry Research Networks for Africa (AFRENAs)—the Southern Africa and the Eastern and Central Africa programmes for the subhumid tropics and the semi-arid lowlands of West Africa (SALWA) programme for the semi-arid tropics.

Research in the humid tropics will continue within the AFRENA programme for the humid lowlands of West Africa and will expand to the humid tropics of Latin America and Southeast Asia, focusing on alternatives to slash-and-burn cultivation and reclamation of degraded lands. In Latin America, ICRAF will work as part of the CIAT-CATIE-IICA (International Centre of Tropical Agriculture, Centro Agronómico Tropical de Investigación y Enseñanza, Inter-American Institute for Cooperation in Agriculture) consortium on natural-resource management. Research will be conducted in a similar collaborative mode in Southeast Asia.

To achieve these objectives, ICRAF's five research and four dissemination programmes have recently been reformulated as part of the strategic plan. ICRAF's research programmes are as follows:

- Environmental characterization and analysis, including evaluation of land resources and socio-economic conditions
- Multipurpose-tree improvement and management, including the development of a Multipurpose-Tree Germplasm Resource Centre, concentrating primarily on leguminous shrubs, little-exploited fruit trees and fast-growing woody species particularly suitable for agroforestry
- Component interactions, addressing issues of competition for light, water and nutrients between trees, crops and livestock
- Systems improvement, emphasizing improved systems to recuperate degraded lands, reverse land depletion and provide an alternative to slash-and-burn
- Policy, adoption and impact analysis, assessing problems and constraints, evaluating the impact of improved agroforestry technologies and providing feedback for technology design.

ICRAF's dissemination programmes are:

- Training, enhancing the capacity of national institutions to carry out agroforestry research and development
- Education, strengthening agroforestry curricula in universities and technical schools
- Information and documentation, identifying, analysing and disseminating information related to agroforestry
- Communications, disseminating the results of agroforestry research and development programmes and information about ICRAF.

This is the first annual report reflecting the reformulation of ICRAF's structure and programmes.

The transition from council to centre that took place in 1991 is a natural consequence of ICRAF's institutional development. However, it has required some rethinking and a lot of hard work. The extraordinary effort involved has been fully supported by ICRAF staff and our small but dynamic management team.

ICRAF has been fortunate to attract an excellent complement of nearly 300 staff members from more than 30 countries. In 1991, we introduced a special award to recognize outstanding contributions of staff members from all levels of the institution. There were 10 recipients the first year.

Transitions are never easy, but the changes at ICRAF have been greatly facilitated by the Board of Trustees. I would also like to express our gratitude to the donors and national research partners who have supported our growth and who make all our work possible. Finally, I would like to express my personal appreciation to my predecessor, Björn Lundgren, whose long dedication and continuing support made 1991 a year of considerable accomplishment. ICRAF's numerous achievements during the year are reflected in the report that follows.

Pedro A. Sanchez
Director General

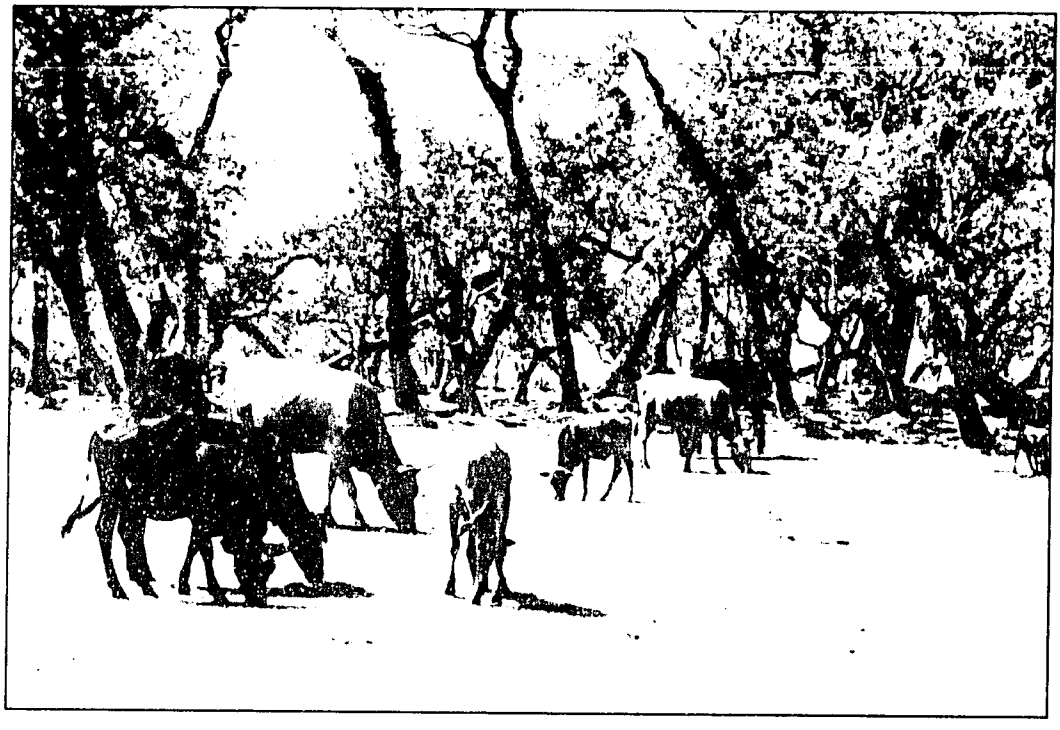


Photo: A. Njenga

In Southern Africa, such as this area around Makoholi, Zimbabwe, farmers are interested in agroforestry to help maintain soil fertility and to provide livestock fodder during the long dry season.

During the course of 1991, ICRAF realigned its research programmes to focus on three agro-ecological zones—the subhumid, humid and semi-arid tropics. In Africa, long-standing collaborative research is in progress in all three zones. Current activities and new programmes in Latin America and Asia will focus on the humid zone.

Most of ICRAF's field research in Africa is conducted in collaboration with national research institutions under the AFRENAs. These networks have been established in four regions: the highlands of Eastern and Central Africa and the uplands of Southern Africa in the subhumid zone, the forested lowlands of West Africa in the humid zone, and the Sahelian lowlands of West Africa in the semi-arid zone.

In 1991, collaborative research was in progress at 19 sites in the subhumid zone—in Kenya, Uganda, Rwanda and Burundi in the Eastern and Central African highlands and in Malawi, Tanzania, Zambia and Zimbabwe on the southern African plateau. In the humid zone, work was in progress at five sites in Cameroon and Nigeria, and in the semi-arid zone at 11 sites in Burkina Faso, Mali, Niger and Senegal. In addition to these collaborative activities, ICRAF conducted experiments at the Machakos Research Station and multipurpose-tree improvement research at the Maseno Agroforestry Research Centre, both in Kenya.

This broad network of coordinated experiments ensures that comparable data will be collected on agroforestry components and technologies over a wide range of altitudes, soils and climatic conditions.

Subhumid plateau of Southern Africa

The Southern Africa AFRENA programme was launched in 1986 with funding from the International Development Research Centre of Can-

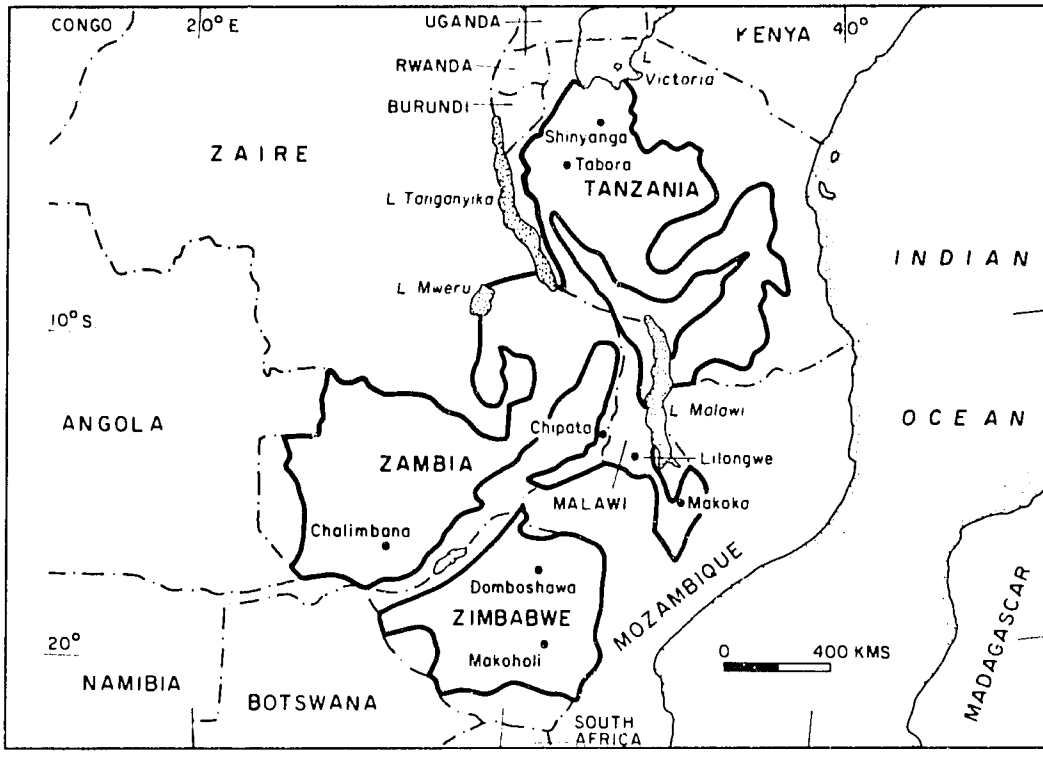


Figure 1. Collaborative research programme in the subhumid upland plateau of Southern Africa: location of research sites.

ada (IDRC) and the Canadian International Development Agency (CIDA). Other donors now include the Rockefeller Foundation, the Swedish Agency for Research Cooperation with Developing Countries (SAREC), and the Norwegian Agency for International Development (NORAD). The Government of the Netherlands provides research associates, and the host governments in each participating country allocate substantial resources in terms of staff, land and research facilities.

The programme focuses on the upland plateau ecological zone, a region that covers approximately 1.4 million sq km in Angola, Malawi, Mozambique, Tanzania, Zaire, Zambia and Zimbabwe (Figure 1). Altitudes range from 600 to 1600 m.

The main land-use system in this region is small-scale farming. Crop production relies on one growing season, from December to April, with a long dry season from May to November (Table 1). Diagnosis and design (D&D) studies in Malawi, Tanzania, Zambia and Zimbabwe revealed two major land-use problems that affect farmers across the region—declining soil fertility and dry-season shortages of livestock fodder. Research was designed to develop agroforestry interventions that address these problems in the zone as a whole. This work is now in progress at Makoka in Malawi, at Tumbi in Tanzania, at Chalimbana in Zambia, and at Makoholi and Domboshawa in Zimbabwe.

In addition, participating countries have developed national agroforestry research projects designed primarily to address the problems of a particular land-use system. ICRAF is participating in a national project initiated in 1987 at Chipata in Zambia, supported by SAREC and IDRC.

A second national project was initiated in 1990 in Malawi, emphasizing on-farm research, with funding provided by the Rockefeller Foun-

Photo: A. Njenga

In the highlands of Rwanda, agroforestry can play an important role in helping to control soil erosion on steeply sloping fields.

dation. This work is closely associated with an IDRC-funded agroforestry research project implemented by the National Agroforestry Commodity Team. A third national project started in 1991 in Tanzania, based at Shinyanga, with support from NORAD.

ICRAF helps coordinate all these activities together with the Southern African Centre for Cooperation in Agricultural Research and Training (SACCAR), which acts on behalf of the Southern Africa Development Coordination Conference (SADCC). Complementarity of research efforts is ensured primarily through regular zonal workshops and meetings of national agroforestry steering committees.

Malawi

Collaborative research in Malawi began in 1988 at the Makoka Agricultural Research Station near Zomba. Within the zonal programme, Makoka has the major responsibility for identifying, acquiring and evaluating multipurpose-tree germplasm. The objective is to select multipurpose trees that hold promise for alleviating problems of soil fertility and shortages of fodder and fuelwood in the region.

The on-farm research project is based at the Chitedze Research Station near Lilongwe. In two areas around Lilongwe, farmers are testing hedgerow intercropping, living fences, fodder banks and mixed intercropping, in some cases with fruit trees.

Tanzania

The zonal research project in Tanzania is based at Tabora in the west-central part of the country at the Ministry of Agriculture and Livestock Development's Tumbi Research Institute. Funding is provided by CIDA. Maize and tobacco are the main crops in the area and livestock production is also important. Major problems include low soil fertility, shortages of fuelwood for tobacco curing and household use, and inadequate grazing during the dry season.

The zonal mandate for agroforestry research at Tumbi focuses primarily on fast-growing multipurpose trees for fodder production. Tree fodder is assessed as a supplementary animal feed, and trees are also evaluated for their potential contribution to soil-fertility maintenance and fuelwood production.

The national agroforestry research project at Shinyanga addresses problems of soil fertility and crop and livestock production in the Sukuma agro-pastoral system near Lake Victoria. In this area, cotton is the major cash crop. Food crops include millet, sorghum, cassava and maize, while rice cultivation is increasing on low-lying, heavy-textured soils. Cattle production is important and, with increasing cultivation and livestock numbers, dry-season fodder shortages are acute. The region also faces severe deforestation, leading to shortages of fuelwood and other tree products as well as soil erosion and land degradation.

Table 1. Collaborative research programme in the subhumid upland plateau of Southern Africa: description of research sites.

Research Site	Altitude (m)	Minimum/Maximum Temperatures (°C)	Average Annual Rainfall (mm)	Soil Types (FAO, 1988)
Makoka, Malawi	1030	15.0°/26.0°	1045	ferric lixisols
On-farm sites near Lilongwe, Malawi	1180	13.0°/27.2°	600	lixisols
Shinyanga, Tanzania	1200	16.7°/28.9°	800	acrisols/pellic vertisols
Tabora, Tanzania	1200	16.3°/28.0°	880	ferric acrisols
Chalimbana, Zambia	1144	14.0°/28.0°	800	plinthic lixisols
Chipata, Zambia	1020	13.8°/32.5°	1000	ferric lixisols
Makoholi, Zimbabwe	1205	16.0°/28.0°	650	ferralic arenosols
Domboshawa, Zimbabwe	1475	18.0°/29.0°	895	haplic lixisols

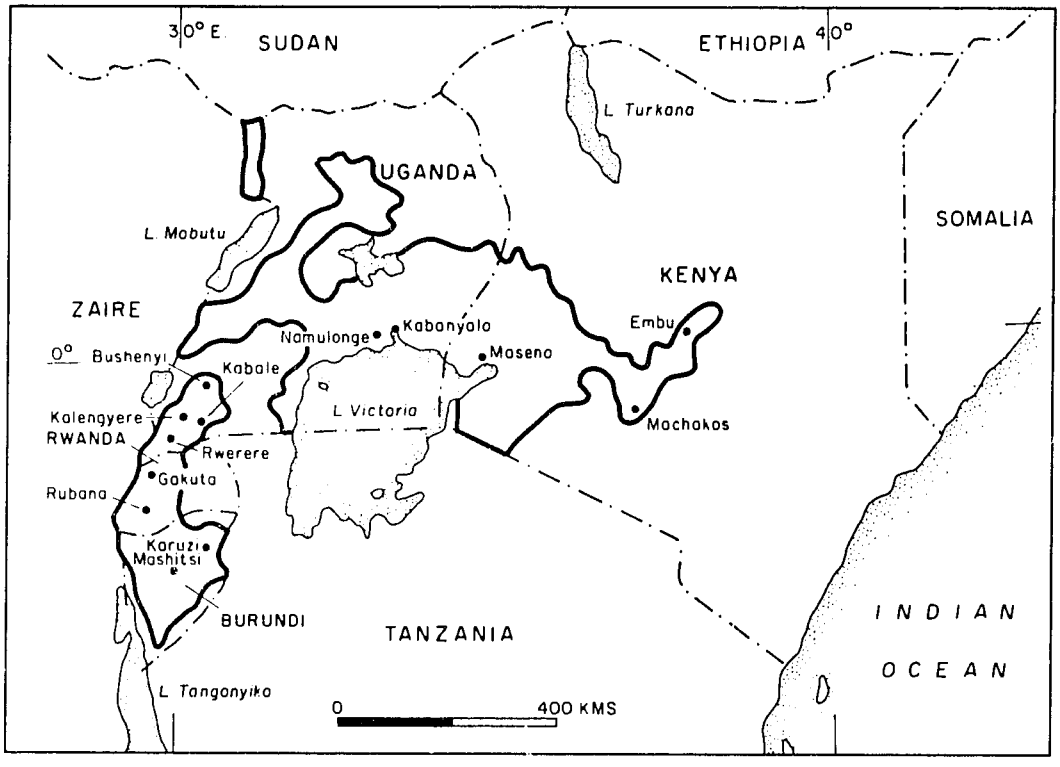


Figure 2. Collaborative research programme in the subhumid highlands of Eastern and Central Africa: location of research sites.

Beginning in 1986, the Tanzania Government initiated development projects such as Hifadhi Ardhi Shinyanga (HASHI) and the Shinyanga Soil Conservation and Afforestation Programme (SHISCAP) with an emphasis on natural-resource conservation and agroforestry. ICRAF's collaborative project is the agroforestry research component of SHISCAP. The goal is to develop agroforestry technologies that will help conserve the natural resources of the region and meet farmers' needs for improved crop production and better supplies of fodder, fuel and wood for construction.

Project activities include surveys, experiments and training. Field trials initiated in the second half of 1991 include the evaluation of mixed-intercropping and improved-fallow systems as well as hedgerow intercropping combining multipurpose trees with food crops or fodder legumes.

Zambia

A zonal agroforestry research project was established in 1987 at Chalimbana Agricultural Research Station in Zambia, concentrating on the contribution of agroforestry to soil fertility. Experiments in progress include multipurpose-tree screening trials and agroforestry technology trials focusing on hedgerow intercropping and improved fallows.

The national agroforestry research project is based at Msekera Regional Research Station at Chipata in Zambia's Eastern Province. Here, ICRAF collaborates with the Agriculture and Forestry Departments. Objectives are to screen multipurpose trees capable of improving soil fertility and providing supplementary dry-season fodder and fuelwood and to design and test agroforestry technologies, such as improved fallows and hedgerow intercropping, that are suitable for local land-use systems.

Zimbabwe

Agroforestry research in Zimbabwe is designed to develop and test technologies that will provide livestock fodder and fencing and help maintain soil fertility on farms in the communal areas. Another objective is to develop the scientific and institutional capacity of national agroforestry programmes. These are conducted by the Forestry Commission, the University of Zimbabwe, the Agricultural Technical and Extension Services (AGRITEX) and the Department of Research and Specialist Services.

A D&D study in 1987 and follow-up survey in 1989 led to the design of an agroforestry research project as well as expansion of agroforestry education and training activities. Direction is provided by the Committee for Agroforestry, Soil and Water Conservation (CASAWAC), under the Zimbabwe Scientific Council, with representation from all relevant government departments. Funding is provided by CIDA.

Project planning was completed and the first trials were established at the end of 1990 at two sites—the Makoholi Agricultural Research Station and the Domboshawa AGRITEX Demonstration Station. Domboshawa is located near Harare in the highland area best suited for intensive crop and livestock production. Makoholi is located to the southwest in a dryer region with farming systems based primarily on livestock plus limited drought-resistant crops.

At both sites, experimentation includes multipurpose-tree screening and trials to assess the potential of trees for fodder and mulch production, both in block plantings and intercropped with maize. In addition to other selection criteria, tree species chosen for introduction in Zimbabwe must be capable of withstanding occasional frost.

Subhumid highlands of Eastern and Central Africa

The subhumid and humid highlands of Eastern and Central Africa include parts of Burundi, Ethiopia, Kenya, Rwanda, Uganda and Zaire (Figure 2). The AFRENA programme in this region was launched in late 1986 with support from the United States Agency for International Development (USAID).

Research focuses on the subhumid highlands, at altitudes ranging from 1000 to 2500 m.

Table 2. Research programmes in the subhumid highlands of Eastern and Central Africa: description of research sites.

Research Site	Altitude (m)	Minimum/Maximum Temperatures (°C)	Average Annual Rainfall (mm)	Soil Types (FAO, 1988)
Karuzi, Burundi	1600	13.5°/25.8°	1140	ferralsols
Mashitsi, Burundi	1620	10.4°/28.4°	1185	ferralsols
Embu, Kenya	1490	14.1°/25.0°	1230	humic nitisols
Kakuyuni, Kenya	1500	11.8°/28.8°	700	lixisols
Machakos, Kenya	1600	11.8°/28.8°	760	haplic lixisols
Maseno, Kenya	1500	14.6°/30.7°	1780	lixisols/acrisols/ ferralsols
Gakuta, Rwanda	2350	8.8°/21.5°	1500	cambisols
Rwerere, Rwanda	2300	10.9°/20.7°	1160	ferralsols
Rubona, Rwanda	1650	13.0°/25.4°	1170	acrisols
Kabanyolo (Kampala), Uganda	1250	15.7°/27.9°	1440	ferralsol
Namulonge (Kampala), Uganda	1250	10.2°/29.5°	1295	ferralsols
Bushenyi, Uganda	1610	13.3°/25.6°	1200	ferralsols
Kabale, Uganda	2000	10.9°/23.5°	1040	ferralsols
Kalengyere, Uganda	2460	8.1°/20.9°	1550	andosols

Annual rainfall averages 1000 to 2000 mm and is distributed between two growing seasons, from March to May and from October to December. Zonal research projects are in progress at three sites in Kenya, at three sites in Rwanda, at two sites in Burundi and at five sites in Uganda (Table 2).

The subhumid highlands in the four participating countries cover an area of 207,000 sq km with a population of 25.8 million. Population density is high, farm sizes are small and land-use systems are among the most intense in Africa. Agricultural practices have not always kept pace with increasing pressure on the land, often resulting in a decline in the natural-resource base. D&D studies have shown that the potential for agroforestry is high, both to help reverse environmental degradation and to increase the productivity of local land-use systems.

As in the programme for Southern Africa, a key consideration in the design of the research programme has been complementarity among activities in each country. Agroforestry technologies with potential for the zone as a whole are being tested at multiple sites under varying environmental conditions. Research in Kenya, Rwanda and Burundi also includes general screening trials of multipurpose-tree species and provenances with potential value for the region. In addition to experimentation on station, farmer surveys and on-farm trials were initiated in 1990, focusing on the land-use systems surrounding the research sites.

Kenya

Experimentation on component interactions in agroforestry systems is based primarily at ICRAF's Research Station at Machakos, Kenya. Strategic research at Machakos is an essential prerequisite for interpreting results from field trials, such as those in progress under the AFRENA programmes, and for designing improved agroforestry technologies.

Machakos is at the dry edge of the subhumid zone. Like the neighbouring farms, most of ICRAF's Research Station consists of sloping land with variable soils. These are positive features since one aim of work at Machakos is to provide advice on experimental issues to collaborating scientists, many of whom encounter similar problems.

The Kenya Government provided the 40-ha site for the station in 1981. Beginning in 1990, ICRAF has also developed a modest facility for soil and plant analysis. Soil samples can now be analysed for pH, texture, bulk density, phosphorus, potassium and organic carbon. Substantial expansion of this facility is planned for 1992.

Also at Machakos, the Kenya Forestry Research Institute (KEFRI), the National Dryland Farming Systems Research Station and the Machakos Integrated Development Project (MIDP) conduct a Dryland Agroforestry Research Project, with ICRAF acting in an advisory capacity and funds provided by IDRC, the Rockefeller Foundation and the Centre technique forestier tropical (CTFT).

The project's on-station component focuses on hedgerow intercropping and the effects of mulching on soil fertility and crop yields. The on-farm component is based in the Kakuyuni catchment area. Here, farms range from 3 to 17 ha, and the most common crops are maize, beans, pigeonpea and cowpea. Farmers use oxen for ploughing and keep other livestock.

In Western Kenya, ICRAF conducts research under the AFRENA programme at the Maseno Agroforestry Research Centre. In addition, ICRAF's strategic research programme on multipurpose-tree improvement and management is based primarily at Maseno. All work at this site is conducted in collaboration with KEFRI and the Kenya Agricultural Research Institute (KARI).

Population density in the region averages around 230 inhabitants per sq km, ranging to more than 1000 in some areas. Farms vary from less than 0.5 to more than 10 ha of arable land.

Multipurpose-tree research at Maseno includes species-screening trials, farmer surveys, selection and breeding research on high-priority species, breeding biology and vegetative propagation studies, and work on tree-root symbionts. Research under the AFRENA programme includes multipurpose-tree screening trials and on-station and on-farm experimentation to develop and evaluate agroforestry technologies for soil-fertility maintenance and fodder production. The on-farm component is funded by the Rockefeller Foundation, the Swedish International Development Authority (SIDA) and the Government of the Netherlands.

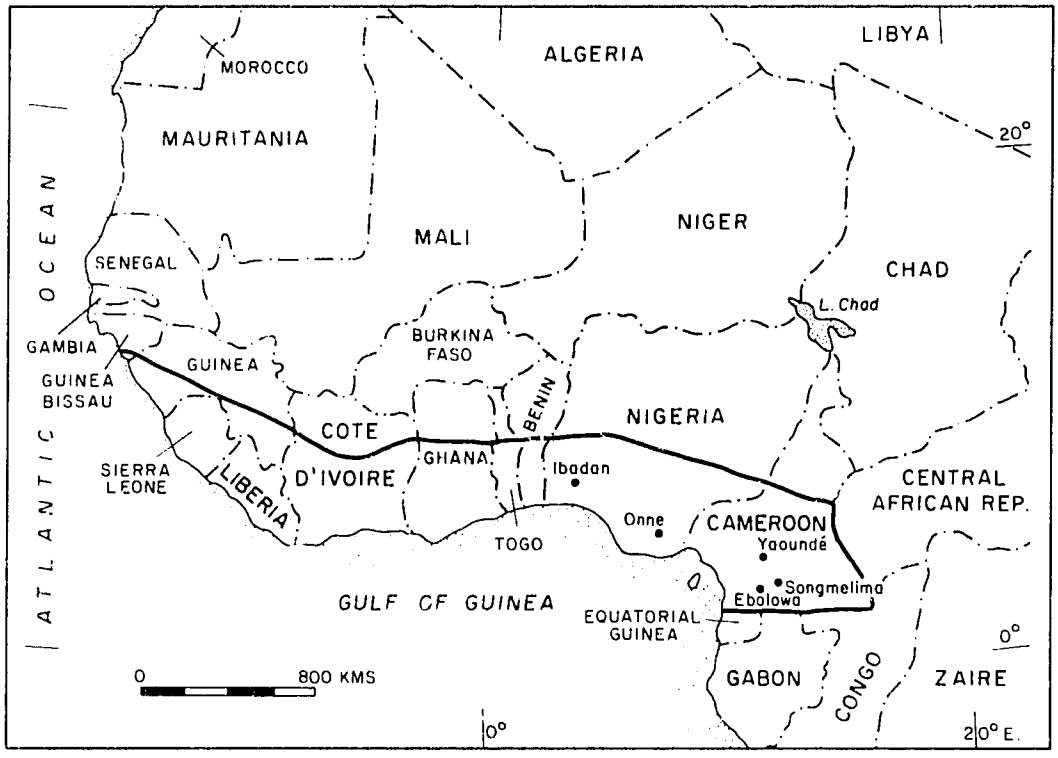


Figure 3. Collaborative research programme in the humid lowlands of West Africa: location of research sites.

In 1991, ICRAF launched an agroforestry research project based at the KARI Regional Research Centre in Embu, another densely populated region of Kenya. Here, on-station and on-farm research include multipurpose-tree screening, hedgerow-intercropping trials, multipurpose trees for fodder and fuelwood, and monitoring and evaluation of agroforestry in local land-use systems. Support is provided by SIDA and the Kenya Government.

Rwanda

ICRAF is working with the Institut des sciences agronomiques du Rwanda (ISAR) at three sites. Research at Rwerere in the Crête-Zaïre-Nil region includes multipurpose-tree screening, fodder-production and hedgerow-intercropping trials, and studies to improve tree establishment and management in the high-altitude zone. On-farm studies in 1991 included diagnostic surveys and exploratory trials testing promising agroforestry species and technologies.

With acid soils and an altitude of 2350 m, environmental conditions at Gakuta are harsh and few multipurpose-tree species are available locally. For this reason, research at this location puts considerable emphasis on general screening trials to identify multipurpose trees that perform well under these conditions.

In 1991, experiments were also initiated at the ISAR Research Station at Rubona. Work here focuses on improving coffee production by raising multipurpose trees in coffee fields to provide green manure and mulch.

Burundi

In Burundi, ICRAF is conducting a collaborative research project with the Institut des sciences agronomiques du Burundi (ISABU) at two sites—Mashitsi and Karuzi Research Stations. At Mashitsi, some experiments are also conducted in collaboration with the Institut de recherche agronomique et zootechnique (IRAZ).

General multipurpose-tree screening trials are in progress at both sites, and scientists at Mashitsi are also conducting species-screening trials for hedgerow intercropping, a fodder-production trial, and a study on multipurpose trees intercropped with banana. In 1991, work on farms included diagnostic studies and technology testing for fodder production.

Uganda

Collaborative research is in progress at five sites in Uganda, chosen to represent a range of altitudes within the zone. Experiments started in 1988 at the Makerere University Agricultural Research Institute at Kabanyolo near Kampala, and in 1989 at the Kachwekano District Farm Institute in Kabale District. In 1990, this work extended to the Namulonge Agricultural Research Station near Kampala, the Kalengyere Highland Agricultural Research Station in Kabale District, and the Bushenyi District Farm Institute in western Uganda.

Within the AFRENA programme for Eastern and Central Africa, work in Uganda focuses on selecting and screening multipurpose trees for upperstorey planting and developing appropriate arrangements and management practices to produce poles, timber, fuelwood, fodder, mulch and fruit. Work at Kabanyolo also includes tree screening for interplanting with banana.

In addition to these zonal responsibilities, the project includes research focusing on the Kigezi food-crop system in Kabale District. Technologies under evaluation here include hedgerow intercropping on the contours of steeply sloping land, shrub and grass strips on terrace risers and bunds, upperstorey trees with shrub and grass strips on contours and boundaries, and fruit trees in croplands. On-farm research, initiated in 1990, involves multipurpose-tree testing in cooperation with local groups of women farmers.

Humid lowlands of West Africa

The humid lowlands of West Africa—at an altitude of less than 1000 m—extend from Guinea Bissau in the west, through parts of Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, Benin and Nigeria, to Cameroon in the east. Annual rainfall averages more than 1500 mm at most sites, distributed between two growing seasons (Figure 3). The vegetation is tropical rain forest.

Within the region, ICRAF has been engaged in a collaborative agroforestry project since 1986 at three sites in Cameroon (Table 3). Funding is provided by IDRC. A second project was initiated in Nigeria in 1990, based at the International Institute of Tropical Agriculture (IITA). ICRAF also participates with IITA and the International Livestock Centre for Africa (ILCA) in the Alley Farming Network for Tropical Africa (AFNETA), with a coordinating unit at IITA in Nigeria.

Cameroon

ICRAF conducts collaborative research with the Government of Cameroon's Institut de la recherche agronomique (IRA). The focus is on the cocoa/food-crop production system in the southern plateau region of the country. The first phase of the project concentrates on the food-crop component. The second phase, which began in 1989, includes research on the role of agroforestry in cocoa production.

Table 3. Collaborative research programme in the humid lowlands of West Africa: description of research sites.

Research Site	Altitude (m)	Minimum/Maximum Temperatures (°C)	Average Annual Rainfall (mm)	Soil Types (FAO, 1988)
Yaoundé, Cameroon	700	19.2°/28.6°	1600	ferric acrisols
Ebolowa, Cameroon	710	19.2°/28.6°	1650	ferric acrisols
Sangmelima, Cameroon	720	19.0°/28.5°	1680	ferric acrisols
Ibadan, Nigeria	230	11.1°/38.9°	1280	ferric lixisols
Onne, Nigeria	20	13.9°/36.1°	2400	thionic fluvisols

Photo: E.Torquebiau

ICRAF's collaborative research programmes are based on extensive field surveys and interviews with farmers, such as here in Niger in the semi-arid zone of West Africa.

In these humid lowlands, small-scale farmers generally grow food separately from cocoa according to a complex system of shifting cultivation. They begin the crop-production cycle by clearing small plots from natural forest or fallow land. The cleared vegetation is usually burnt. Then as many as seven or more different food crops are planted. These include short-term crops such as maize, groundnut and yam and longer-duration crops such as plantain, cassava and sugarcane.

Short-term crops are harvested at the end of one season, while other crops are left in the fields for one, two or even three years. During this period, farmers return to their plots to harvest but do not practise any other form of management. By the time the last crops are removed, the plots have been completely overtaken by weeds and invading species, particularly *Eupatorium odoratum* and napier grass (*Pennisetum purpureum*). They remain under this natural fallow until the next cropping cycle begins.

As in many other regions of the tropics, increasing population pressure is accompanied by a reduction in the fallow period. Specific problems include: fragile and infertile soils; high labour requirements for land clearing, land preparation and weeding; crop destruction by free-ranging livestock; and limited resources to purchase chemical fertilizers or other inputs.

ICRAF is investigating agroforestry technologies that could potentially help solve these problems. Collaborative on-station and on-farm research is conducted primarily at Yaoundé in Central Province. In 1990, a new station was opened at Ebolowa in Southern Province. Experiments in progress in 1991 included multipurpose-tree screening and management trials for improved fallows, hedgerow intercropping, and hedgerow intercropping with livestock.

Trials also began in 1991 at the IITA Humid Forest Research Station at Mbalmayo. Work here is conducted under ICRAF's collaborative multipurpose-tree research project, which is based in Nigeria.

Nigeria

In October 1990, ICRAF launched a collaborative project with IITA and Oregon State University (USA) to identify and improve multipurpose trees for agroforestry development in the humid tropics of West Africa. Research is based at IITA headquarters in Ibadan, Nigeria, and at Onne in southern Nigeria. The project is supported by USAID.

Work focuses on the evaluation of a broad range of indigenous and exotic tree species with a potential role in agroforestry systems. The project places special emphasis on indigenous trees with potential to produce fruit, food or fodder and on the adaptation of trees and shrubs to the infertile, acid soils of the region.

Semi-arid lowlands of West Africa

The collaborative research programme in the SALWA region was launched in January 1989 with the establishment of national steering committees and task forces in the four participating countries—Burkina Faso, Mali, Niger and Senegal (Figure 4). In addition to national ministries and research institutes, regional and international organizations participating in the programme include the Institut du Sahel (INSAH), the Consultative Advisory Committee on Semi-Arid Food Grain Research and Development of the Organization of African Unity (OAU/-SAFGRAD), the Sahelian Centre of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and ICRAF. Funding is provided by the International Fund for Agricultural Development (IFAD) and CIDA.

Agroforestry research programmes have been designed for one priority land-use system in each of the four participating countries. These are:

- Burkina Faso: Agrosilvopastoral system of the northern sudanian zone
- Mali: 'Parkland' system of croplands with scattered trees
- Niger: Niger River valley system
- Senegal: groundnut basin system.

Table 4 lists the field sites where experiments have been initiated. Annual rainfall at these sites is low, ranging from only 315 to 850 mm. There is one growing season, from June or July to September.

Rainfed agriculture with mixed cropping is the dominant land-use pattern in all four of these

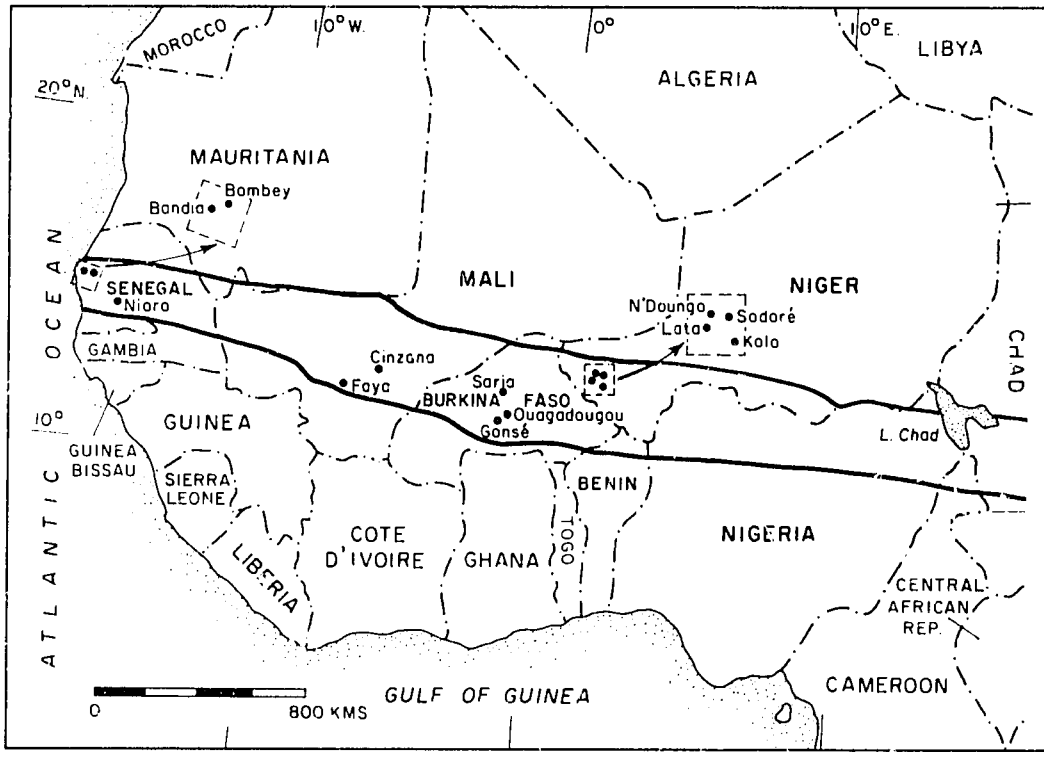


Figure 4. Collaborative research programme in the semi-arid lowlands of West Africa: location and description of research sites.

systems. Millet and sorghum are the staple food crops, and livestock production also plays an important role. In addition, farmers in Niger grow rice under irrigation near the Niger River.

D&D studies have identified several problems experienced by farmers in the region. The most serious are shortages of fuelwood and dry-season fodder, soil erosion caused by wind and water, poor soil fertility, and damage to crops by free-ranging livestock.

Agroforestry technologies that could help address these problems include windbreaks, trees on erosion-control structures, trees on field and farm boundaries, trees in croplands and rangelands, and fodder banks.

The following trials were initiated in 1991. They include a total of 15 multipurpose-tree species:

- In Burkina Faso, mixed intercropping with trees for soil-fertility improvement and increased crop production; screening and management trials for hedges on contour lines to control soil erosion
- In Mali, management of *Gliricidia sepium*, *Leucaena leucocephala*, *Pterocarpus erinaceus* and *Pterocarpus lucens* for intensive fodder production; establishment trials of living fences of *Ziziphus mauritiana* and *Balanites aegypiiaca*; species screening for use as mulch; studies of the 'parkland' system
- In Niger, multipurpose-tree species screening for windbreaks in irrigation schemes; management of *Prosopis juliflora* living fences
- In Senegal, establishment of living fences of single or multiple species; establishment of windbreaks of single or multiple species and assessment of their impact on soil characteristics and crop yields; species screening for hedgerow intercropping; study of the 'parkland' system.

A special research project was also initiated in the region in 1991 to improve selected mul-

Research Site	Altitude (m)	Minimum/Maximum Temperatures (°C)	Average Annual Rainfall (mm)	Soil Types (FAO, 1988)
Gonsé, Burkina Faso	315	22.0°/35.0°	750	lixisols
Saria. Burkina Faso	300	22.0°/35.0°	820	lixisols
Faya, Mali	340	24.8°/33.6°	850	lixisols
Cinzana, Mali	280	18.5°/41.6°	725	lixisols
Kolo, Niger	200	20.6°/35.1°	480	lixisols
Lata, Niger	190	22.6°/37.0°	315	lixisols
N'Dounga, Niger	210	22.7°/36.9°	460	lixisols
Sadoré, Niger	240	22.1°/45.8°	560	lixisols
Bambey, Senegal	20	22.0°/36.0°	500	planosols
Bandia, Senegal	50	20.0°/29.0°	375	lixisols
Nioro, Senegal	20	22.0°/37.0°	750	lixisols

Table 4. Collaborative research programme in the semi-arid lowlands of West Africa: description of research sites.

tipurpose trees. An ICRAF scientist has been assigned to this project based at ICRISAT's Sahelian Centre in Niger.

Table 5 lists the major agroforestry technologies under study in 1991 at different research sites across Africa. Tables 6a and 6b list the multipurpose-tree species under assessment within these technologies. General screening trials include a much larger number of species.

Table 5. Agroforestry technologies under study in 1991 at research sites in 16 countries of Africa.

Technology	Subhumid Zone	Humid Zone	Semi-Arid Zone
Hedgerow intercropping	Burundi, Kenya, Malawi, Rwanda, Zambia	Cameroon	Burkina Faso, Mali, Senegal
Improved fallows	Kenya, Malawi, Zambia	Cameroon	
Woodlots	Zambia		
Fodderlots	Burundi, Kenya, Zambia		Mali
Trees with fodder grass on erosion-control structures	Burundi, Kenya, Rwanda		Burkina Faso
Boundary planting	Kenya, Uganda		
Upperstorey trees in banana plots	Burundi, Uganda		
Trees planted in relay with food crops	Malawi		
Living fences	Malawi	Nigeria	Mali, Niger, Senegal
Rotational hedgerow intercropping	Tanzania	Cameroon	
Hedgerow intercropping with livestock	Kenya, Tanzania	Cameroon	Kenya
Home gardens	Kenya, Tanzania	Nigeria	
Mixed intercropping			Burkina Faso
Windbreaks			Niger, Senegal
Biomass transfer for soil fertility	Malawi, Zambia		

Species (Family)	Southern Africa	Eastern and Central Africa	Humid Lowlands of West Africa
Acacia auriculiformis (Leguminosae)			Hedgerow intercropping
Acacia nilotica (Leguminosae)	Mixed intercropping		
Acacia polyacantha (Leguminosae)	Mixed intercropping Improved fallows		Hedgerow intercropping
Acrocarpus fraxinifolius (Leguminosae)		Trees in banana plots	
Albizia chinensis (Leguminosae)		Trees in banana plots	
Albizia coriaria (Leguminosae)		Trees in banana plots	
Albizia lebbeck (Leguminosae)	Mixed intercropping		
Alnus acuminata (Betulaceae)		Trees in upperstorey	
Alnus melanoxylon (Betulaceae)		Trees in upperstorey	
Alnus nepalensis (Betulaceae)		Trees in upperstorey	
Artocarpus heterophyllus (Moraceae)		Trees in banana plots	
Azadirachta indica (Meliaceae)	Mixed intercropping		
Cajanus cajan (Leguminosae)			Hedgerow intercropping Improved fallow
Calliandra calothyrsus (Leguminosae)	Hedgerow intercropping	Hedgerow intercropping Fodder production on contour bunds Trees in banana plots Mulch in coffee plots Mulch production Propagation methods	
Carica papaya (Caricaceae)		Mixed planting on contour bunds	
Cassia siamea (Leguminosae)	Hedgerow intercropping	Hedgerow intercropping Trees in upperstorey	Hedgerow intercropping
Cassia spectabilis (Leguminosae)		Hedgerow intercropping Trees in upperstorey	
Casuarina cunninghamiana (Casuarinaceae)		Trees in upperstorey	
Casuarina equisetifolia (Casuarinaceae)		Trees in upperstorey	
Casuarina glauca (Casuarinaceae)		Trees in upperstorey	
Casuarina junghuhniana (Casuarinaceae)		Trees in upperstorey	
Cedrela odorata (Meliaceae)		Trees in banana plots	
Cedrela serrata (Meliaceae)		Trees in banana plots	
Cordia abyssinica (Boraginaceae)		Trees in upperstorey	
Crotalaria anagyroides (Leguminosae)			Improved fallow
Cupressus lusitanica (Cupressaceae)		Trees in upperstorey	
Cupressus sempervirens (Cupressaceae)		Trees in upperstorey	
Desmodium discolor (Leguminosae)			Improved fallow

Table 6a. Multipurpose-tree species tested in agroforestry technology trials at 35 sites in 1991.

Species (Family)	Southern Africa	Eastern and Central Africa	Humid Lowlands of West Africa
Desmodium distortum (Leguminosae)		Mulch in coffee plots	Improved fallow
Erythrina abyssinica (Leguminosae)		Trees in upperstorey	
Erythrina caffra (Leguminosae)		Hedgerow intercropping	
Erythrina poeppigiana (Leguminosae)		Trees in banana plots	
Eucalyptus grandis (Myrtaceae)		Trees in upperstorey	
Faidherbia albida (Leguminosae)	Wood/fodder lots		
Flemingia congesta (Leguminosae)	Hedgerow intercropping	Mulch in coffee plots	
Flemingia macrophylla (Leguminosae)		Mulch in coffee plots	
Ficus natalensis (Moraceae)		Trees in banana plots	
Gliricidia sepium (Leguminosae)	Hedgerow intercropping Biomass transfer	Hedgerow intercropping Mulch in coffee plots	Hedgerow intercropping
Grevillea robusta (Proteaceae)		Trees in upperstorey Trees in banana plots	
Jacaranda mimosifolia (Bignoniaceae)		Trees in upperstorey	
Leucaena diversifolia (Leguminosae)		Hedgerow intercropping Fodder production on contour bunds Trees in banana plots Mulch in coffee plots Mulch production Propagation methods	
Leucaena leucocephala (Leguminosae)	Hedgerow intercropping Improved fallows Biomass transfer	Hedgerow intercropping Fodder production on contour bunds Mulch production	Hedgerow intercropping Wood/fodder lots
Leucaena paniculata (Leguminosae)		Fodder production	
Maesopsis eminii (Rhamnaceae)		Trees in upperstorey	
Markhamia lutea (Bignoniaceae)		Trees in upperstorey Trees in banana plots	
Melia azedarach (Meliaceae)		Trees in upperstorey	
Paraserianthes falcataria (Leguminosae)			Hedgerow intercropping
Polyscias fulva (Araliaceae)		Trees in upperstorey	
Psidium guajava (Myrtaceae)	Mixed intercropping		
Pterocarpus milbraedii (Leguminosae)			Living fences Home gardens
Sesbania sesban (Leguminosae)	Hedgerow intercropping Improved fallows Biomass transfer Relay planting	Hedgerow intercropping Fodder production on contour bunds Mulch production Propagation methods	
Sesbania macrantha (Leguminosae)	Hedgerow intercropping		
Tephrosia vogelii (Leguminosae)		Mulch in coffee plots	

Table 6b. Multipurpose-tree species tested in agroforestry technology trials at 35 sites in 1991.

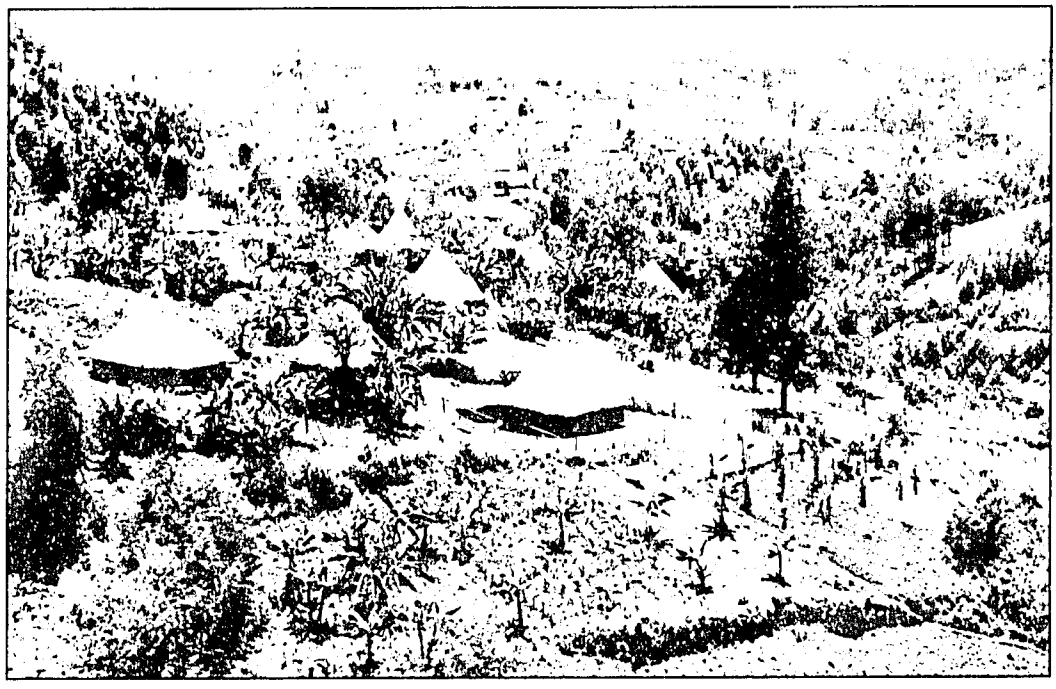


Photo: A Njenga

Trees fulfil many functions in densely populated areas of the Kenya highlands. Agroforestry research is designed to help farmers use trees even better.

During 1991, there was a major emphasis on reviewing the objectives and activities of ICRAF's Programme One. Previously called 'Land-Use Systems Analysis', the principal activities of this programme included conducting D&D exercises in the field, preparing reviews on priority topics, and developing and updating agroforestry databases and models. This annual report for 1991 highlights some of the results of these activities.

In line with the development of ICRAF's strategy and its increasing emphasis on research, the focus of Programme One was reformulated during the year. This redefinition stems from a recognition that the adoption and performance of improved agroforestry systems is influenced by a wide range of biophysical and socio-economic factors.

Programme One now focuses on the identification and analysis of these factors. This task is critical because it provides a logical framework for predicting the effects of agroforestry in environmental and socio-economic terms. Through the delineation of homogeneous land-use systems, work in Programme One also helps to improve the identification of research targets and potential beneficiaries. Such information is useful not only to ICRAF and to collaborating researchers, but also to national decision makers and land-use planners.

In keeping with this new emphasis, the name of the programme has been changed to 'Environmental Characterization and Analysis'. Three major research areas are envisaged in coming years:

- Evaluation of land resources, with a focus on defining the most appropriate targets for agroforestry research
- Predictive assessment of the socio-economic impact of agroforestry systems
- Predictive assessment of the environmental consequences of agroforestry initiatives, with emphasis on carbon fluxes and the conservation of biological diversity.

Characterization of land-use systems

Based on studies in several countries, ICRAF scientists have developed the 'diagnosis and design'—or D&D—methodology to describe and analyse existing land-use systems, to identify production constraints and causal factors, and to design appropriate agroforestry technologies to help alleviate these constraints. Methodological tools are now available for the initial planning of agroforestry research and development projects and also for the self-corrective 'rediagnosis and redesign' that continue throughout project implementation. This iterative process functions as the heart of a project's internal monitoring, evaluation and planning system.

Agroforestry research normally begins with a macro D&D exercise covering an entire ecological zone within a country. This consists of a rapid appraisal, based primarily on secondary information complemented by a few selected surveys in the field.

A central aspect of the macro D&D is the delineation of land-use systems within the chosen ecological zone, leading to the selection of target systems for more detailed analysis—the micro D&D. The main output of the D&D process is likely to be a research plan, aimed at developing agroforestry technologies that will address key needs and opportunities within the designated land-use system. Through research on station and on farmers' fields, agroforestry technologies are tested, redesigned and retested. At the same time, researchers go back to the target land-use system—through an iterative D&D process—to define and evaluate land-user problems and potentials with greater precision.

This continuous process of going back to the land users provides an essential input into research design and implementation. Information from continuous D&D surveys also plays a role in the analysis of experiments: results are assessed in terms of the land users' resources, management capabilities, anticipated costs and benefits, and risk. In 1991, ICRAF scientists and colleagues from national institutions conducted micro D&Ds and more detailed follow-up surveys in Bangladesh, Ghana, Kenya, Uganda and Rwanda.

Rice and food-crop production in the Barind Tract of Bangladesh

In 1991, ICRAF and the Bangladesh Agricultural Research Council (BARC) participated in the second of two micro D&D surveys in Bangladesh. Work focused on Godagari in the Barind Tract region of North Bengal. Here, annual rainfall averages 1400 mm, but it all falls during the six-month growing season, leaving the area extremely dry the rest of the year. Most of the farmland belongs to absentee landlords, with small farms cultivated by tenants. Any agroforestry technology introduced in this area must satisfy the needs of both groups.

Fields are terraced and houses are surrounded by home gardens. The farmers grow rainfed and some irrigated rice, plus off-season crops, such as chickpea, where residual soil moisture is adequate. Most tenant households also keep a few cattle. Field crops are shared equally between tenants and landlords, but the tenants usually keep all the produce from their home gardens.

In interviews with the D&D team, tenant farmers listed food and cash as their most important needs. Fodder for cattle was also insufficient. The farmers did not identify fuelwood as a major problem, probably because they rely almost entirely on cow dung for fuel. Indeed, some farmers considered dung the most important product from their animals. Major constraints were lack of water during the dry season and poor soil fertility. Other issues were poor development of home gardens and cottage industries and limited employment opportunities.

To increase opportunities for dry-season farming, the D&D team recommended the construction of irrigation ponds. To improve soil fertility, the team suggested dry-season tree fallows, using fast-growing nitrogen-fixing species such as *Sesbania aculeata* or *Cajanus cajan*. Farmers were already maintaining scattered *Acacia nilotica* trees in their fields and the team recommended the expansion of this practice. Finally, the researchers suggested that farmers plant hedges along boundaries, around ponds and around home compounds to provide fuelwood, animal fodder and mulch.

Hedgerow intercropping was proposed for non-irrigated terraces, using *Leucaena leucocephala* or *Cajanus cajan* with dry-season

crops of mungbean or sorghum. Woodlots were recommended for government-owned wastelands, and living fences to control cattle. The team also suggested improvements in the traditional home gardens.

Two agroforestry-based cottage industries were recommended—silk and lac production. Farmers with mulberry trees could sell the leaves to silk producers or could reap higher profits by raising their own silk cocoons. Lac could be harvested from several tree species—*Ziziphus jujuba*, *Acacia catechu*, *Acacia nilotica* or *Albizia lebbeck*—when infested with the appropriate scale insects.

Both the tenant farmers and the land owners were enthusiastic about the suggestions proposed by the D&D team and agreed to share the profits from agroforestry equally. Because some of these proposals involve major innovations, further research is needed in several areas. This will be conducted through the National Coordinated Farming Systems Research Programme at a nearby field site of the Bangladesh Agricultural Research Institute (BARI).

Oil palm, cocoa and food-crop production in the humid lowlands of Ghana

ICRAF's collaborative research project in Ghana began in 1989 with a macro D&D survey in the country's southern humid zone. The survey team identified six land-use systems and proposed appropriate agroforestry interventions for each. Two technologies hold the most promise for the region as a whole:

- Cover crops under oil palm, coconut and citrus trees to provide fodder and help maintain soil fertility and control weeds
- Boundary plantings to provide fodder, fuelwood and poles.

Other promising technologies include fodderlots and woodlots, mixed intercropping, improved fallows and living fences.

A micro D&D study was completed in 1991, focusing on the two most important land-use systems. In both, farmers grow oil palm, cocoa and food crops, but in one they emphasize oil palm and in the other the emphasis is on cocoa. A multidisciplinary team explored the practices and attitudes of a sample of 41 farmers. Table 7 presents some of their findings.

When farmers establish an oil-palm plantation, they cultivate food crops for two to three years under the young trees. Later on, weeds invade the plots and soil fertility declines. In some cases, erosion is also a problem. By contrast, on the large-scale Twifo oil-palm plantation in central Ghana, *Pueraria* sp. planted as a leguminous cover crop helps maintain soil fertility and produces 10 t/ha of fresh biomass with low maintenance costs. The study team proposed introducing a similar system on small farms, but with the addition of controlled grazing by sheep and goats. All the farmers interviewed were enthusiastic about the system and agreed to provide land for on-farm trials.

Farmers keep home gardens and raise a few sheep and goats, but neither activity is particularly well developed. The study team suggested several improvements, including living fences, boundary plantings, mixed intercropping with fruit trees, and better livestock management. Research will focus on competition, complementarity and the nutritive and economic value of different components in home gardens.

Hedgerow intercropping might be beneficial in food plots, particularly on sloping land where contour hedgerows could help control erosion. However, considerable research would be required to ascertain the biophysical and economic viability of this technology.

Results from these surveys will be used together with reviews of scientific information to formulate an agroforestry research programme for participating institutions in Ghana.

Wood, fodder and soil-fertility problems in western Kenya

Early D&D surveys in western Kenya indicated serious land-use problems on small farms devoted to maize, beans and other food crops. These included soil depletion and shortages of wood and fodder supplies. In 1991, a team based at the Maseno Agroforestry Research Centre conducted follow-up surveys to provide a more detailed analysis of some of the key constraints.

One informal survey analysed wood shortages, production opportunities, and farmers' species preferences for wood production. Work focused on areas of Yala Division at altitudes ranging from 1300 to 1500 m and annual rainfall averaging more than 1600 mm. Forty-three

Photo: A. Njenga

Fuelwood is scarce throughout Africa's subhumid zone. To cook food for their families, women farmers in Malawi are forced to lop high branches from trees along the roadside.

farmer groups participated in discussions and interviews. Women, who made up 57% of the farmers, were the main respondents on fuelwood issues, while men tended to answer questions about uses of wood for construction.

Farms in this high-potential area are small, ranging from 0.5 to 1.5 ha, and farmers rely almost entirely on their own trees for wood supplies. There is little communal land and most cropland is under almost continuous cultivation. A typical household requires about 8.5 kg of dry fuelwood every day. Women normally spend two hours each afternoon collecting fuelwood. Available sources are mostly of poor quality, often twigs from hedgerows of *Lantana camara* or *Euphorbia tirucalli*. Crop residues are also increasingly used as fuel instead of being returned to the land or fed to livestock.

Farmers prefer fuelwood species that dry quickly and that give a long-lasting fire without producing smoke. Species such as *Markhamia lutea*, *Albizia coriaria* and *Combretum molle* are popular, but seldom available.

For a typical household, the construction of essential buildings requires about 60 large-diameter (13 cm) and 60 small-diameter (8 cm) poles—equivalent to 30 five-year-old trees plus 60 three-year-old trees. The buildings need to be reconstructed after about 20 years, and farmers usually buy poles from neighbours when they are required. Thus, on average, farmers would need to harvest about five trees per year

Table 7. Practices and attitudes of farmers in the humid lowlands of Ghana related to the adoption of agroforestry: results of a survey conducted in 1991.

	Oil Palm/Food Crops/ Cocoa (n = 20)	Cocoa/Food Crops/ Oil Palm (n = 21)
Major uses of trees		
Shade/windbreak	100%	90%
Building materials	95%	95%
Ornamental value	85%	67%
Livestock fodder	70%	62%
Stakes for yam plants	65%	48%
Erosion control	65%	38%
Willingness to adopt agroforestry technologies		
Cover crops under trees	100%	100%
Woodlots	70%	52%
Mixed intercropping	70%	52%
Boundary plantings	65%	57%
Fodder production	55%	48%
Soil-improvement methods currently in use		
Fallowing	60%	71%
Mulching	40%	19%
Manuring	20%	5%
Cover cropping	15%	0%
Well-maintained plots	10%	10%
Constraints to agroforestry adoption		
Lack of planting material	45%	19%
Financial constraints	15%	14%
Labour bottlenecks	10%	19%
No problems anticipated	45%	43%

Photo: A. Njenga

Farmers in Zambia sell fuelwood harvested illegally from natural forests. Agroforestry can help these farmers earn cash without destroying the natural-resource base.

to meet their and their neighbours' construction needs. Farmers stated a preference for species that grow quickly and provide poles that are durable, straight, strong and termite resistant. Favourite pole species are *Markhamia lutea*, eucalyptus and *Bridelia micrantha*. Cypress and *Grevillea robusta* are preferred for timber.

There are good markets for fuelwood, poles and timber. However, increased production is limited to species that do not compete strongly with crops because there is no space to plant trees except within or bordering cropland. Farmers and extensionists also cited the high cost and poor availability of tree seeds and seedlings as well as limited information on tree-planting methods. Formal surveys are now in progress to confirm these findings.

Another 1991 survey in the same area concentrated on fodder production. There is a market for milk, manure and traction, but livestock productivity tends to be low, with unimproved cattle kept mainly as a source of capital. Extensionists are working to introduce stall-feeding systems with improved dairy cattle. However, purchased concentrates are expensive and farm-produced fodder is limited and of poor quality, particularly during the dry season.

On-station results at Maseno have indicated positive interactions between leguminous fodder trees, such as *Leucaena leucocephala* and *Calliandra calothyrsus*, and the fodder grass *Pennisetum purpureum* when trees and grass are grown together on soil-conservation bunds. In 1991, ICRAF joined the Kenya Ministry of Livestock Development to test these combinations on about 40 farms, either on bunds or in fodder banks in cropland. Many farmers asked to take part in the trial, suggesting a high level of interest in improved fodder production.

A third survey conducted in 1991 focused on the current soil-fertility status of farmers' fields in high-rainfall areas of Kisumu, Siaya and Vihiga Districts. An earlier literature review had identified soil acidity, low nutrient reserves, low available phosphorus, and limited rooting depth as constraints on agroforestry development in the region.

The 1991 survey was based on 24 topsoil samples (at depths of 0–15 cm), 12 subsoil samples (15–50 cm), and 6 deeper samples (90–

100 cm) taken from maize fields on 32 farms. The farms were selected to represent the major soil types of the Eastern and Central African highlands—acrisols, ferralsols and nitisols. The samples were analysed by KARI at their Muguga laboratory.

Stone or laterite layers likely to restrict tree root growth were found in the subsoil—at depths less than 50 cm—on 10 out of the 32 farms. Three additional farms had restrictions at less than one metre. Most of the topsoils and subsoils were strongly acidic, with pH values (in water) between 4.0 and 5.4.

More than half of the farms had very low levels of available phosphorus (Olsen P<4 mg/kg) in the topsoil. On 26 farms, available phosphorus in the subsoil and deeper layers was also very low. These results confirm that phosphorus inputs are likely to be essential for sustainable agroforestry. Reserves of other nutrients are still being analysed.

Agroforestry systems inventory

ICRAF's agroforestry systems inventory project, conducted over five years from 1982 to 1987, produced a database of information on indigenous agroforestry systems in Latin America, Africa and Asia. In 1991, ICRAF entered into collaboration with the School of Agricultural and Forest Sciences of the University of Wales at Bangor (UK) to develop, extend and maintain this database. Work in 1991 entailed:

- Restructuring the data with a consistent focus on agroforestry practices within a systems framework
- Designing a new structure for a multiple-file relational database using dBASE IV
- Developing a menu-driven user interface to allow inexperienced users to conduct powerful searches
- Setting up a file structure to facilitate the incorporation of new data.

Future activities will include the systematic collection, processing and entry of information on agroforestry practices observed all over the world. Issues of compatibility with component databases, such as ICRAF's *Multipurpose Tree and Shrub Database*, and with other international databases will also be addressed.

Agroforestry and fruit crops

Agroforestry development activities have tended to focus on the use of trees and shrubs to enhance soil fertility and to provide fuelwood, fodder, timber and poles. The potential of fruit trees for agroforestry has seldom been fully considered, and information is fragmentary.

Yet D&D exercises and other field surveys have indicated that fruit trees tend to have high priority among farmers. In 1991, ICRAF commissioned a review of agroforestry and fruit crops, aimed at formulating a strategy to fit fruit crops into agroforestry research and development and identifying priority research issues. A senior visiting fellow conducted a one-year research project that included an extensive literature review plus field surveys in Eastern and Central Africa. The project was funded by the German Agency for Technical Cooperation (GTZ).

Table 8. Some fruit species with multiple uses in traditional agroforestry systems.

Agroforestry System and Country	Species	Uses
Home gardens, Bangladesh	*Artocarpus heterophyllus*	Fruit, timber, fodder
Cashew/coconut plantations, Kenya	*Anacardium occidentale*	Fruit, fuelwood
Terraced food crops, Sudan	*Cordia abyssinica*	Fruit, fodder, wood for construction
Maninjau forest gardens, Indonesia	*Durio zibethinus*	Fruit, timber
Cocoa/coffee plantations, Ecuador	*Anacardium excelsum, Vitex* spp.	Fruit, shade
Coffee plantations, Venezuela	*Inga* spp., *Syzygium americana*	Fruit, living fences, shade
Coffee/banana plantations, Burundi	*Persea americana*	Fruit, food, fuelwood

Land-use System	Species
Cocoa/foodcrops system, humid lowlands of West Africa	*Artocarpus altilis, Dialium guineense, Irvingia gabonensis, Tetracarpidium conophorum*
Coffee/banana system, subhumid highlands of Eastern and Central Africa	*Artocarpus heterophyllus, Boinbacopsis glabra, Cyphomandra betacea, Durio zibethinus, Inga edulis, Persea americana*
Annual foodcrops system, subhumid to semi-arid highlands of Eastern and Central Africa	*Annona cherimola, Cordia abyssinica, Grewia asiatica, Mangifera indica, Ziziphus spina-christi*
Annual foodcrops system of the semi-arid lowlands of West Africa	*Annona senegalensis, Borassus aethiopum, Mangifera indica, Parkia biglobosa, Sclerocarya birrea, Ziziphus mauritiana, Butyrospermum paradoxum* ssp. *parkii*
Cocoa and annual foodcrops system of the humid lowlands of Latin America	*Achras sapota, Bactris gasipaes, Citrus paradisi, Crataegus mexicana, Guazuma ulmifolia, Inga edulis, Paraqueiba sericea, Prunus capuli, Syzygium malaccense*
Agroforests and plantation systems of Southeast Asia	*Areca catechu, Artocarpus integer, Averrhoa bilimbi, Baccaurea reticulata, Durio zibethinus, Lansium domesticum, Mangifera foetida, Pandarus tectorius, Samanea saman, Syzygium malaccense*

Table 9. Suggested fruit species for research and extension in different ecological zones.

Fruit crops are defined as trees, shrubs and perennial herbs that are exploited primarily for their edible fruits. Farmers in Africa, Asia and Central and South America include fruit crops in home gardens and on crop and pastureland (Table 8). The literature from different parts of the world describes 14 species in home gardens, 17 species in communal gardens, and 16 species on cropland or pastures.

Some examples of fruit crops in agroforestry systems are given in Table 9. Where markets are accessible, farmers tend to grow fruits mainly to generate cash income. In more remote areas, the primary role of fruits is to enhance family food supplies.

In field surveys, farmers mentioned several fruit-production problems. These are listed with suggestions for research and extension:

1. Shortage of good planting material—fruit species, selected according to farmer preferences, should be included in tree nurseries
2. Low proficiency in fruit-crop husbandry—researchers should develop prototype combinations of fruit species with food crops and other multipurpose trees; extension agencies and non-governmental organizations should conduct training courses on the production and management of fruit crops in agroforestry systems
3. Small farm size, accentuating problems of competition with food crops—fruit species should be selected with small or sparse canopies; they should be planted in appropriate farm niches such as boundaries, valley bottoms or contour bunds; suitable pruning systems need to be developed

Photo: S.B. Westley

Livestock-feeding trials assess the palatability and nutritional value of fodder from multipurpose trees.

4. Marketing problems, including transport and pricing—farmer cooperatives should be developed to market fruit crops; researchers and extensionists should develop and promote appropriate techniques for fruit processing and preservation
5. Pests and diseases—integrated pest-management strategies are needed.

Agroforestry and pastoralism

A series of reviews on agroforestry in arid and semi-arid lands was largely completed in 1991, with support from NORAD. Work focused primarily on experience in the pastoral areas of Eastern Africa, but considered issues relevant to other pastoral regions. Topics included:

- Evaluation of participatory extension and research in a pastoral system. A case study from Turkana, Kenya, describes an extensive, participatory extension programme.
- Tenure rights to trees among the Turkana pastoralists. The Turkana system of usufruct rights to trees provides interesting lessons for agroforestry research and development. The implications for land policy and law are also considered.
- Agroforestry in the interface between pastoralism and agriculture. A review of the current and potential role of agroforestry in regions shared by pastoralists and agriculturalists identifies important research and policy issues to ensure, in particular, that the introduction of agroforestry does not further marginalize pastoralists.
- Local knowledge, natural-resource management and participatory extension in pastoral areas. A review for field practitioners uses experience among the Turkana in Kenya to demonstrate practical approaches to natural-resource management and participatory extension in pastoral areas.

Photo: A. Njenga

ICRAF and collaborating scientists initiated multipurpose-tree screening trials at Makoholi, Zimbabwe, in December 1990.

Multipurpose trees are an integral component of agroforestry systems. Most grow quickly, and many—such as *Leucaena leucocephala* and *Sesbania sesban*—are legumes that fix atmospheric nitrogen, thus improving the soil. Others produce fruit or timber and grow well in combination with annual crops.

Besides providing a wide range of services and products, several multipurpose trees are adapted to difficult environmental conditions, such as drought or saline or strongly acidic soils. Others cope with difficult management conditions, such as frequent lopping to provide branches for fodder and fuelwood.

Most of these multipurpose-tree species exist primarily as wild or unselected populations with a great deal of natural variability. There are considerable opportunities for improving such populations through selection and breeding.

Because agroforestry fits into diverse land-use systems, catering for the needs of different types of land user, tree-improvement programmes for agroforestry must look at a much wider range of species than forestry programmes. There are currently some 1100 species listed in ICRAF's *Multipurpose Tree and Shrub Database*. An agroforestry programme must also take into account a wide range of goals for tree improvement. These may include food, fodder and mulch production, adaptability to difficult sites, compatibility with crops and livestock, and suitability for intensive management.

Given the paucity of current information on multipurpose trees and the prospects for genetic improvement, the potential benefits of research in this area are enormous. The goal of ICRAF's Multipurpose-Tree Improvement and Management Programme is to identify and improve

Photo: A. Njenga

Bridelia micrantha *is a popular agroforestry species in the home gardens of northern Tanzania. Here a farmer lops branches for fodder.*

species and provenances that can enhance the productivity, diversity and sustainability of target land-use systems. This is done by:

- Surveying farmer knowledge, preferences, utilization and constraints related to multipurpose trees
- Screening species for adaptation to particular sites and agroforestry technologies
- Evaluating provenances of high-priority species
- Collecting, evaluating and conserving germplasm
- Assessing genetic variation in natural and cultivated populations
- Studying breeding biology
- Selecting and breeding superior ideotypes
- Developing improved tree-management systems
- Assembling information on multipurpose trees for global dissemination.

Multipurpose-tree surveys

ICRAF and collaborating scientists have conducted multipurpose-tree surveys in six countries—Cameroon, Kenya, Malawi, Nigeria, Tanzania and Zambia. The objectives are to learn how farmers use and manage multipurpose trees, which species they know and value, and what opportunities exist for improving the productivity and sustainability of local land-use systems through agroforestry. This information is used to help refine research agendas.

In 1991, surveys were completed in five states of southeastern Nigeria, in Kenya's Embu District, in western Tanzania, and in the area around Kigezi in southwestern Uganda. Some of these will be described in more detail. Future plans include:

- Surveys in the subhumid tropics of Eastern and Southern Africa on the use of trees for soil improvement plus fodder, fuelwood and fruit production
- Surveys in the West African humid tropics on trees for soil improvement and food production
- Surveys in the semi-arid tropics of West Africa on traditional uses of multipurpose trees for soil improvement and fodder production.

Multipurpose trees in Tanzania's subhumid zone

A survey was completed in 1991 in the Tabora region of Tanzania to learn how farmers use and manage multipurpose trees, particularly in relation to their cropping and livestock enterprises. One aim was to identify trees that are popular with farmers as a basis for selecting species to test in agroforestry technologies.

Researchers conducted four group interviews and 21 individual interviews with farmers in each of four districts. Land holdings ranged from 2 to 15 ha, often divided into two or three separate plots. Most land was under continuous cropping.

Wood is used for household fuel, construction and tobacco curing. Although supplies from natural forests are becoming scarce, very few farmers plant trees in their fields because of possible competition with crops and because tree roots hinder ploughing by draught animals. Very few have established treelots due to labour constraints, lack of seedlings and training, and the slow growth of local species.

Most farmers leave a few trees when they clear their fields, particularly those that are associated with fertile soils or provide useful products. Preferred species include *Albizia harveyi*, *Brachystegia boehmii*, *Brachystegia spiciformis*, *Margaritaria discoidea* and *Pericopsis angolensis* as well as fruit trees.

Another major concern is fodder for livestock during the dry season. Farmers use tree fodder as available and expressed an interest in planting quick-maturing fodder trees on fallow land, in home compounds, in fodder banks or around farm boundaries. The tree species most widely used for fodder are *Azanza garckeana*, *Dalbergia melanoxylon*, *Dichrostachys cinerea*, *Friesodielsia obovata*, *Lonchocarpus bussei*, *Margaritaria discoidea*, *Phyllanthus engleri*, *Tamarindus indica*, *Vitex mombassae* and several species of *Acacia*.

Farmers expressed keen interest in fruit trees. Indigenous fruits, harvested from natural stands, provide an important dietary component, particularly for children. The most common are *Azanza garckeana*, *Canthium burtii*, *Flacourtina indica*, *Friesodielsia obovata*, *Grewia bicolor*, *Rothmannia englerana*, *Vitex iringensis*, *Vitex mombassae* and *Ximenia*

caffra. Production of indigenous species was constrained by a lack of planting material and information on management.

Exotic fruit trees have greater market potential. All the farmers interviewed had planted some exotic species, most often in their home compounds. About half were interested in planting both indigenous and exotic fruit trees, while the other half would plant only exotic species. In addition, every household had at least one tree kept for medicinal purposes.

This survey suggested several priority areas for agroforestry research. These include:

- Propagation, management and marketing of indigenous fruit trees
- Introduction of multipurpose trees for soil fertility, particularly in improved fallows
- Woodlots and boundary planting for fodder and wood production
- Identification of suitable species for living fences.

Multipurpose trees intercropped with banana in Uganda and Rwanda

Banana and tree associations are found in many land-use systems of Eastern and Central Africa, particularly in Uganda, Rwanda and Burundi where bananas are a staple food. In Uganda, ICRAF and national scientists conducted a micro D&D survey in 1991, focusing on trees in banana plots within the intensive banana/coffee production system.

This land-use system covers 13,000 sq km on the northern shore of Lake Victoria. Population density is high and farms are small, averaging less than 1 ha of cultivated land. Soils are deep and highly leached ferralsols, with little or no reserve of weatherable minerals. Rainfall is bimodal, averaging 1000 to 1500 mm a year.

The main food crop is banana and the main cash crop is coffee. Other crops include maize, beans, cassava, sweet potato, groundnut and vegetables. Farmers keep a few pigs, goats, sheep and dairy cattle. There are good marketing opportunities for fruit, but any intensification of production on existing plots must take into account problems of soil fertility, moisture conservation and weed control.

Several tree species are found scattered in banana plots, including *Ficus natalensis*, *Markhamia lutea*, *Cassia spectabilis*, *Albizia chinensis* and exotic fruit trees such as jackfruit (*Artocarpus heterophyllus*), avocado, papaya and mango. Species considered competitive with banana, such as *Markhamia lutea* and *Cassia spectabilis*, are more likely to be found growing around the edges of plots. Farmers reported that *Ficus natalensis* and *Albizia chinensis* are easy to propagate and have a positive effect on banana plants. They have recently increased the number of both these species on their farms.

Propagation methods include planting stem cuttings and transplanting wildlings. Tree management is largely limited to branch pruning to reduce shade, collecting dead branchwood for fuel, and some cutting for poles. Many fruit trees are infested with pests and diseases.

Based on these findings, several research areas were proposed. These include studies on below-ground interactions between banana and multipurpose trees, screening of new species with potential for green manure and mulch production, and improved management trials for fruit and pole production.

A second survey in 1991 covered the intensive banana/coffee farming system of Rwanda's central plateau. Here, farms are located on hillsides at altitudes ranging from 1500 to 2100 m. Acrisols in association with younger soils are of medium fertility and bimodal rainfall averages 1000 to 1400 mm a year.

On landholdings averaging only 1.1 ha, small coffee plots are cultivated in pure stands. Other crops tend to be grown in mixtures, including banana, beans, sweet potato, cassava, sorghum, maize, potato, groundnut, cocoyam, cowpea and yam. Some farmers keep a few livestock, particularly goats and dairy cattle. These are largely stall fed, using grass grown in contour strips on the farms. The major source of cash income is the sale of banana beer.

Soil erosion and poor soil fertility are major problems. With severe pressure on land, farmers also report poor supplies of fuelwood and livestock fodder.

Farmers plant or maintain trees in small woodlots, along roads and paths, around houses and scattered in fields. These provide wood for construction and fuel, fruit, stakes for bean

plants and sometimes fodder for livestock. Opportunities for tree planting are limited by the small size of holdings.

The study focused on trees interplanted in banana plots as a promising niche for increasing productivity. The objective was to evaluate existing practices and suggest possibilities for improvement, including further research requirements.

Banana plots are situated on hillsides or plateaux generally near homes. Cultivation is continuous, with fertility problems addressed by mulching and, to a lesser extent, application of manure.

Trees most often planted in banana plots include avocado, guava, *Cyphomandra betacea*, *Annona cherimola* (indigenous fruit trees), citrus species, papaya, mango, *Grevillea robusta*, eucalypts, cypress and shrubs such as *Ricinus communis* and *Dracaena afromontana*. Planting material is produced on the farm or obtained from neighbours or communal nurseries. Management practices include thinning, pruning and removing dead branches.

The farmers mentioned several trees with positive effects on banana including two indigenous species, *Senecio manii* and *Erythrina abyssinica*. Beneficial trees, such as papaya, tend to be interplanted with banana, while species with negative effects, such as eucalyptus and avocado, tend to be planted around the edges of the plots.

The study team concluded that border plantings around banana plots could usefully be intensified, with tall timber species, such as *Grevillea robusta*, interplanted with shorter species, such as *Sesbania sesban* or *Leucaena diversifolia*, for fuelwood and stakes. Several fruit trees could be interplanted with banana, but less competitive varieties of avocado should be identified. To help control soil erosion, contour strips could be planted with mixtures of trees, shrubs and fodder grass.

Species evaluation

General species screening trials represent the first step in multipurpose-tree improvement research. Since 1986, species evaluation trials have been conducted at all of ICRAF's field sites (Table 10). These trials are still in progress, generating additional information every year. This report will highlight some of the most important results from 1991.

Research Site	Total Number of Species
Karuzi, Burundi	13
Mashitsi, Burundi	25
Yaoundé, Cameroon	10
Sangmelima, Cameroon	10
Machakos, Kenya	3
Maseno, Kenya	42
Makoka, Malawi	37
Ibadan, Nigeria	12
Onne, Nigeria	30
Rwerere, Rwanda	45
Gakuta, Rwanda	63
Tabora, Tanzania	10
Chalimbana, Zambia	16

Table 10. Multipurpose-tree species screening trials in progress during 1991.

New species-screening activities were initiated during the year in two agro-ecological zones of West Africa. In the humid tropics, scientists are screening a broad range of species for adaptation to acidic soils with phosphorus deficiency and aluminium toxicity. Trials include indigenous food-producing species such as *Treculia africana*, *Dialium guineense* and *Pterocarpus milbraedii* as well as potentially useful exotic species such as *Calliandra calothyrsus* and *Leucaena* spp. In 1991, trials began at Ibadan and Onne, Nigeria, in addition to previously established studies at Yaoundé and Sangmelima in Cameroon.

In West Africa's semi-arid tropics, multipurpose-tree screening concentrates on fodder species that tolerate low and erratic rainfall. These include species such as *Faidherbia albida*, *Prosopis africana* and *Combretum aculeatum*. Trials are being established at sites in Burkina Faso, Mali, Niger and Senegal.

Species screening for West Africa's humid zone

ICRAF's collaborative research programme in Cameroon began with two multipurpose-tree screening trials, starting at Yaoundé in 1987

and at Sangmelima in 1988. The goal was to identify species well adapted to local conditions and suitable for the three agroforestry technologies identified as priorities: hedgerow intercropping, improved fallows and rotational hedgerow intercropping with livestock.

The trial at Yaoundé included 10 exotic species, planted both in pure stands and intercropped with maize. Seven exotic species were tested at Sangmelima, along with three species indigenous to the area. These were planted in pure stands and intercropped with groundnut. Interplanting with maize tended to inhibit tree establishment and early growth, while interplanting with groundnut had no significant effect on tree performance.

The trees were monitored for survival, growth in height and stem diameter, biomass production, response to cutting, and effect on soil fertility. Based on these measurements, *Calliandra calothyrsus* appeared particularly promising. *Leucaena leucocephala* and *Gliricidia sepium* generally performed well, but were more difficult to establish on acidic soils. *Cassia siamea* also performed well, but local farmers are not likely to adapt this species because they consider it a weed.

Paraserianthes falcataria consistently showed the best growth in terms of height, stem diameter and biomass yield, but resprouted poorly after cutting. *Acacia mangium* and *Acacia auriculiformis* gave similar results. These species might be useful for agroforestry systems that do not require regular pruning.

The local species included in the study were *Chlorophora excelsa*, *Duboscia macrocarpa* and *Dialium guineense*. All performed poorly in terms of early growth and biomass production. The two sesbania species showed good early growth but died within two years. In the humid zone of West Africa, these species might be useful for short-term improved fallows.

One of the major objectives of introducing agroforestry in this region is to improve soil fertility. The potential contribution of trees has often been emphasized, but seldom documented. These experiments examined effects on soil fertility by analysing the nutrient content of above-ground biomass and leaf litter. Among the 10 species planted at Yaoundé, calliandra and leucaena had the highest leaf nitrogen content, both from litter and from harvested biomass, with sesbania, gliricidia and the acacias following closely. Long-term changes in soil organic matter, organic carbon, total nitrogen, phosphorus and calcium are also being analysed.

The intensive phase of this experiment finished in 1991 with a detailed report, but scientists will continue to monitor soil and tree parameters on an annual basis. The site will also be used for training and demonstrations.

Table 11. Survival and growth of the best accessions of 11 multipurpose-tree species 26 months after planting at Makoka, Malawi.

Species	Survival at 15 Months (%)	Height at 26 Months (m)	Root Collar Diameter at 26 Months (cm)
Acrocarpus fraxinifolius	100	7.1	15.4
Calliandra calothyrsus	96	5.5	10.2
Cassia siamea	100	4.7	11.3
Gliricidia sepium	100	4.6	9.4
Gmelina arborea	100	4.4	14.3
Flemingia congesta	96	4.0	7.8
Albizia falcataria	100	4.0	7.2
Albizia schimperiana	88	3.9	7.0
Schizolobium excelsum	92	3.8	9.1
Cassia spectabilis	100	3.4	9.6
Maesopsis eminii	92	3.0	6.9

Species	Foliage	Biomass (t/ha dry wt) Wood	Total
Acrocarpus fraxinifolius	6.2	27.3	33.5
Calliandra calothyrsus	8.4	31.6	40.0
Cassia siamea	9.9	19.7	29.6
Gliricidia sepium	7.6	15.0	22.6
Flemingia congesta	3.7	14.6	18.3
Albizia falcataria	8.0	15.6	23.6
Albizia schimperiana	2.5	5.4	7.9
Schizolobium excelsum	4.9	9.3	14.2
Cassia spectabilis	7.8	16.6	24.4
Maesopsis eminii	2.3	6.1	8.4

Table 12. Biomass production of the best accessions of 10 multipurpose-tree species 26 months after planting out at Makoka, Malawi.

Screening trials for the subhumid zone of Southern Africa

ICRAF's major multipurpose-tree screening trial in the subhumid *miombo* ecological zone of Southern Africa was initiated in December 1988 at Makoka, Malawi. A number of different agroforestry technologies have been identified as appropriate for the region, each with different requirements from the tree component. For this reason, a wide range of multipurpose trees has been tested—49 accessions of 37 species.

Survival was assessed in early 1990, and height, root-collar diameter, branching characteristics, coppicing ability, biomass production and nutrient content have been evaluated on a continuous basis. In general, the species and provenances that showed excellent survival also demonstrated the best growth (Table 11) and biomass production (Table 12).

Of these, *Acrocarpus fraxinifolius* developed a single stem with very few branches and coppiced readily, making it a good candidate for short rotations. *Calliandra calothyrsus*, *Gliricidia sepium*, *Gmelina arborea*, *Cassia spectabilis* and *Flemingia congesta* developed multiple stems, copious branching and wide crowns. Growth of *Cassia siamea* was affected in dry seasons by the fungus *Erysiphe acacia*, but the trees recovered well during the rains.

Most of the species that grew well also coppiced well and produced high foliage and woody biomass—ranging from 8 to 14 t/ha. In particular, *Calliandra calothyrsus* appeared well suited to hedgerow intercropping for fodder, mulch and fuelwood production. *Acrocarpus fraxinifolius*, *Cassia siamea* and *Gliricidia sepium* also appeared promising. Tree growth will be monitored for several more years.

Nutrient concentrations were highest in the foliage. In *Calliandra calothyrsus*, foliage constituted only 21% of the total above-ground biomass, but accounted for 70% of total nitrogen accumulation. These proportions indicate that wood could be harvested with only limited loss of nutrients from the system. However, continuous removal of leafy biomass, for instance for animal fodder, could result in significant nutrient depletion with effects on long-term productivity.

Of 17 Australian acacias evaluated, only *Acacia auriculiformis* and *Acacia aulacocarpa* showed good survival and growth. The four prosopis species tested—*Prosopis chilensis*, *Prosopis cineraria*, *Prosopis juliflora* and *Prosopis tamarugo*—all failed, while accessions of *Faidherbia albida* performed at intermediate levels. *Vangueria infausta*, a popular indigenous fruit tree, reached maturity and produced fruits in less than two years.

The Australian acacias are thought to have considerable potential for introduction in appropriate regions of Africa, although this was not confirmed by results at Makoka. Further studies of these trees should include several

provenances of each species, inoculated with appropriate root symbionts to stimulate nitrogen fixation and nutrient utilization.

Researchers at Chalimbana, Zambia, established a screening trail in 1987 with 16 multipurpose-tree species. One year after planting, all showed excellent survival except *Sesbania grandiflora*.

Eight species showed rapid growth up to 28 months after planting. These were *Sesbania sesban*, *Sesbania macrantha*, *Eucalyptus camaldulensis*, *Eucalyptus grandis*, *Leucaena leucocephala*, *Cassia siamea*, *Flemingia congesta* and *Acacia polyacantha*. They ranged from 3.5 to 6.8 m in height, 8.0 to 14.3 cm in basal diameter, and 19.0 to 57.7 t/ha in aboveground biomass (dry wt).

One year after planting, the *Sesbania macrantha* started dying out, while the *Sesbania sesban* began dying 1.5 years later. These fast-growing but short-lived species are good candidates for improved fallows and treelots for fodder or green manure. *Leucaena leucocephala*, *Cassia siamea* and *Flemingia congesta* have potential for improved fallows and also for hedgerow intercropping, while *Acacia polyacantha* shows promise for mixed intercropping.

The following species showed slow initial growth: *Faidherbia albida*, *Acacia ataxacantha*, *Afzelia quanzensis*, *Sterculia africanum*, *Albizia adianthifolia*, *Casuarina cunninghamiana* and *Ventilago viminalis*.

In the area around Tabora, Tanzania, fuelwood shortages are increasingly critical, both for tobacco curing and for home consumption. To help solve this problem, ICRAF and collaborating scientists initiated a trial in January 1990 to evaluate six Australian acacia species for biomass production and coppicing ability. Germplasm was provided by the Commonwealth Scientific and Industrial Research Organization (CSIRO).

Trees were planted in pure stands and samples were cut at ground level and 50 cm above ground 26 months after planting. Coppice regrowth was measured two months later. *Acacia crassicarpa* and *Acacia auriculiformis* produced the most woody and leafy biomass from the initial harvest, while *Acacia tumida* produced the most sprouts after cutting (Table 13). All species responded poorly when cut at ground level, but coppiced well when cut at 50 cm above ground. These results suggest that well selected Australian acacias have good potential for wood production in the Tabora region.

In Zimbabwe, ICRAF and national partners are screening eight multipurpose-tree species at Domboshawa and Makoholi. Seedlings were planted out in December 1990 with no fertilizer or rhizobium inoculant. Rainfall in 1991 was below average at both sites. Generally, performance was better at Makoholi, although rainfall was lower and soils less fertile than at Domboshawa (Table 14). This site was pre-

Table 13. Biomass production of six Australian acacias 26 months after planting out and 2-month coppice regrowth, Tabora, Tanzania.

	Biomass Production (t/ha dry wt)		Coppice Regrowth (number of sprouts)	
	Wood	Leaves/Twigs	Cut at Ground	Cut at 50 cm
Acacia crassicarpa	117.2	27.2	0	5
Acacia auriculiformis	89.2	3.4	4	8
Acacia leptocarpa	63.1	1.7	0	6
Acacia aulacocarpa	6.9	3.0	0	4
Acacia tumida	5.6	1.9	13	46
Acacia holosericea	4.7	0.4	0	13

Species and Provenance	— Height — (cm)		— Biomass — (t/ha dry wt)	
	Domboshawa	Makoholi	Domboshala	Makoholi
Sesbania macrantha	223	270	25.47	7.66
Sesbania sesban	207	410	18.82	15.19
Flemingia congesta	122	66	0.59	2.30
Acacia angustissima	121	129	12.33	4.82
Calliandra calothyrsus (19671)	66	—	0.75	—
Calliandra calothyrsus (19678)	—	128	—	4.04
Calliandra calothyrsus (19679)	61	72	0.39	3.15
Gliricidia sepium	28	53	0.41	2.30
Leucaena leucocephala (19681)	26	95	0.00	5.36
Leucaena leucocephala (19682)	24	91	0.00	2.82
Leucaena leucocephala (19683)	23	82	0.70	2.47
Leucaena leucocephala (19684)	22	94	0.00	4.09
Leucaena leucocephala (19685)	31	112	0.33	7.03
Gleditsia triacanthos	10	20	0.00	0.79

Table 14. Height and biomass yield of eight multipurpose-tree species 12 months after establishment at Domboshawa and Makoholi, Zimbabwe.

viously under *miombo* woodland, while the Domboshawa site was predominantly a *Hypparhenia* grassland with very few trees. Thus, the differences in tree growth may be explained by the presence or absence of appropriate rhizobia in the soil.

Species screening for the subhumid highlands of Eastern Africa

During 1991, a comparison of the performance of 10 multipurpose-tree species at four sites in Eastern and Central Africa indicated that much of the observed difference in height growth could be attributed to differences in temperature, as affected by altitude, and in rainfall. For example, differences in height growth for *Acrocarpus fraxinifolius* were explained largely by rainfall at all four sites.

There were also some interesting exceptions. For *Markhamia lutea* ex Kakamega (Kenya), differences in height growth at Maseno (Kenya), Rwerere (Rwanda) and Karuzi (Burundi) were explained by differences in temperature, but this was not the case at Mashitsi (Burundi) (Figure 5).

The effects of adverse biophysical conditions on tree growth were clearly demonstrated at Gakuta, Rwanda, at an altitude of 2350 m and with extremely acidic soils (pH 3.2 to 4.4). Here, most tree species grew less than 1 m in 12 months. Results for the most promising species are given in Table 15.

Evaluating provenances of high-priority species

As general screening trials identify appropriate species for agroforestry technologies in different ecological zones, greater emphasis will be placed on multilocational trials to evaluate the performance of well-documented provenances of the most promising species.

In 1991, provenance evaluation in the subhumid zone included trials of *Gliricidia sepium* at Chipata (Zambia) and at Machakos (Kenya). Gliricidia is a leguminous tree distributed naturally in the Western Hemisphere—from southern Mexico through Central America to northern South America. It is now also cultivated in Eastern and Southern Africa, Southeast Asia and Australia. It appears well adapted to a wide range of soil and climatic conditions. It is easy to propagate, coppices well and pro-

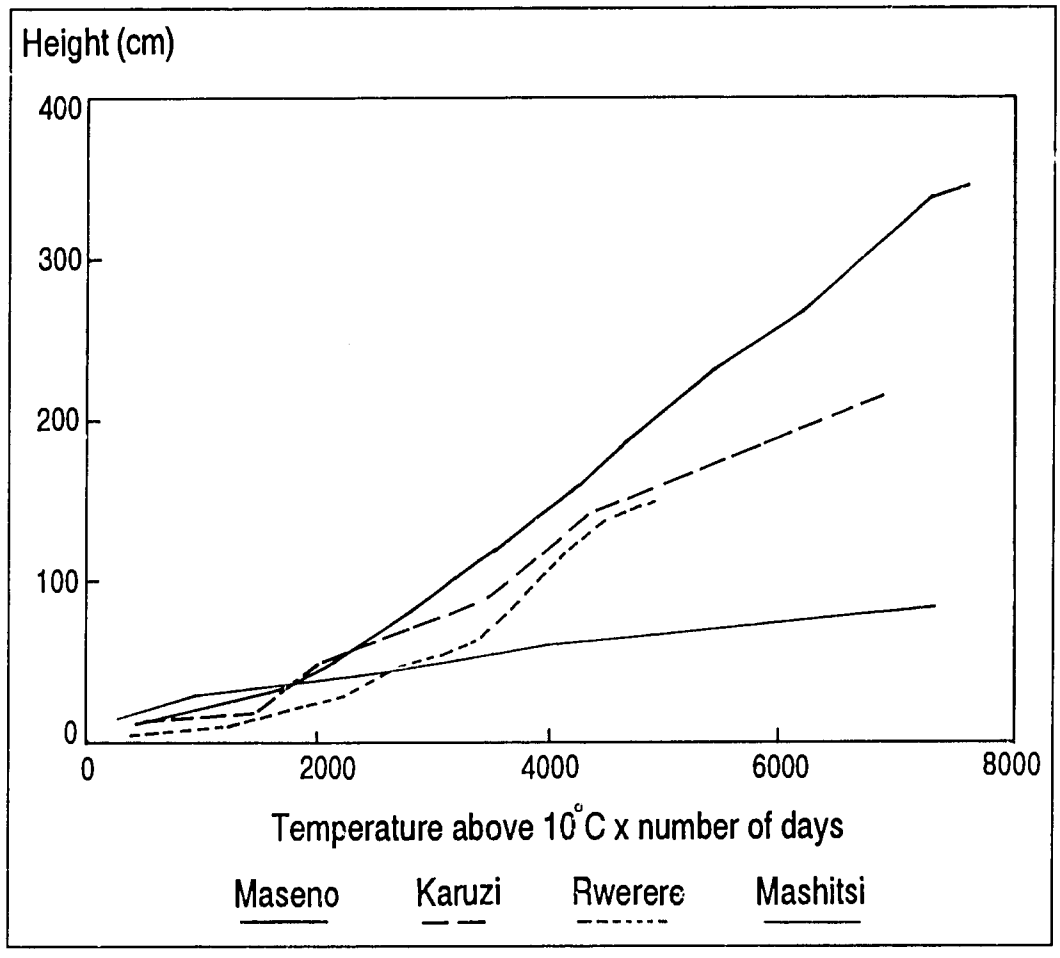


Figure 5. Height growth of Markhamia lutea *as affected by temperature at four sites in Eastern Africa.*

duces abundant leafy biomass, providing fodder and green manure as well as fuelwood and poles.

The Oxford Forestry Institute (UK) provided germplasm of 15 gliricidia provenances, representing collections from extreme ecological conditions in Central America that might be promising for the drier areas of Eastern and Southern Africa. These have been evaluated for growth, fodder production and resistance to pests and diseases.

At Makoka, scientists have evaluated accessions of *Leucaena leucocephala* and *Sesbania sesban*. Sesbania accessions were also evaluated at Tabora.

The Oxford Forestry Institute has also conducted range-wide exploration, collection and documentation of leucaena germplasm. The goal is to facilitate cross-site evaluations of species and provenances. In 1991, ICRAF established trials at four sites in Southern Africa that include 24 of these accessions. The sites are Chalimbana, Chipata, Lilongwe (Malawi) and Makoholi.

Also in 1991, screening trials at Tabora, Machakos, Domboshawa and Makoholi focused on genotypes of pigeonpea (*Cajanus cajan*). This legume is widely grown in semi-arid areas of India, Eastern Africa and the Caribbean. It provides farmers with food,

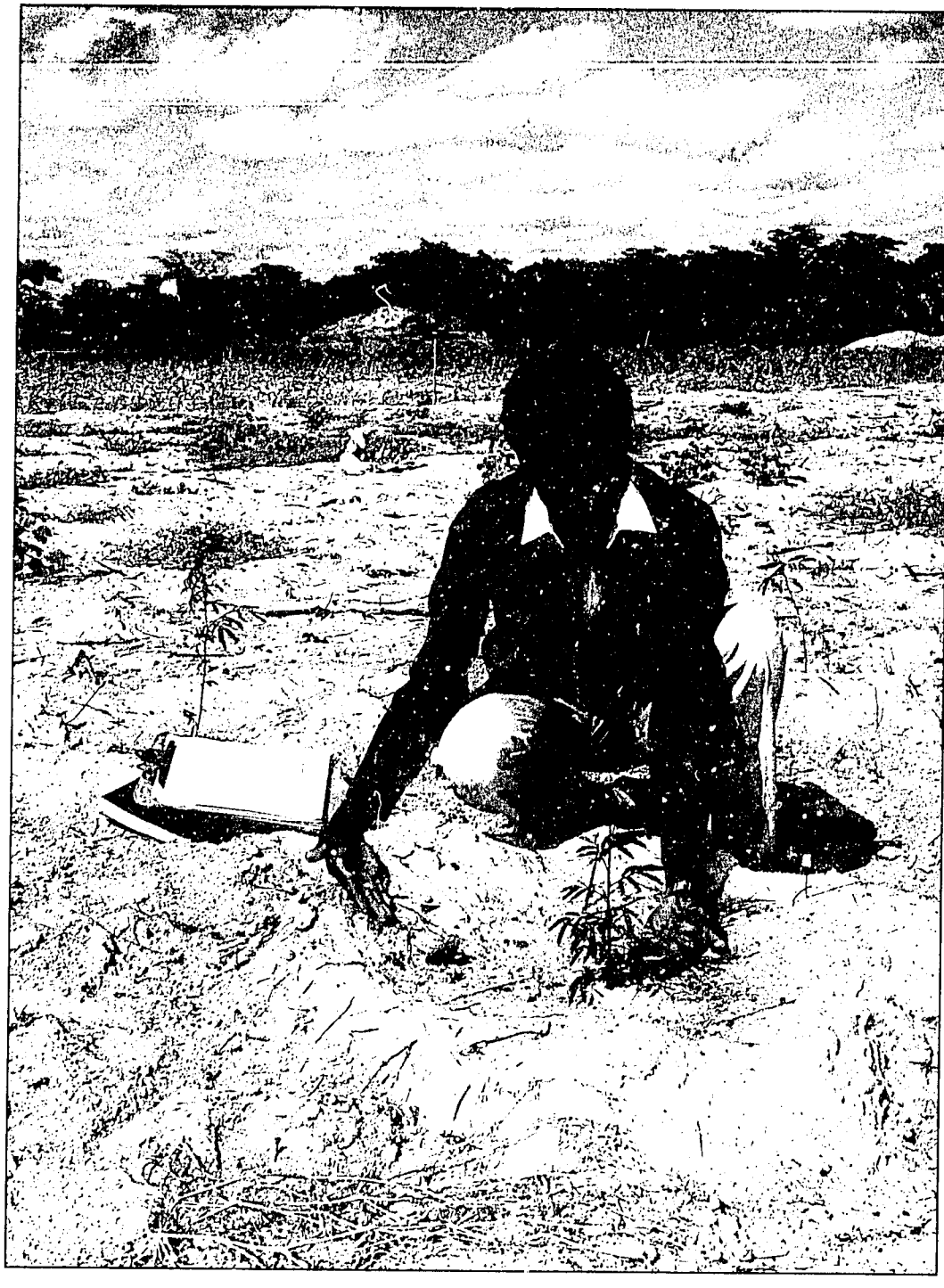


Photo: A. Njenga

Multipurpose-tree seedlings planted in screening trials at Makoholi, Zimbabwe, benefit from microcatchments to make full use of scarce rainfall.

fuelwood, fodder and fencing material. Although intrinsically a perennial, it is often grown as an annual because of its susceptibility to pests and diseases.

In the humid tropics of West Africa, provenances of *Gliricidia sepium* are being evaluated for soil improvement, food and fodder production, and tolerance of acid soils. In West Africa's semi-arid tropics, *Faidherbia albida* provenances will be evaluated for rapid growth, drought tolerance and fodder production.

Screening provenances of *Gliricidia sepium*

The 15 provenances of *Gliricidia sepium* supplied by the Oxford Forestry Institute have been assessed at Chipata in a trial that started in 1987. Germination was better than 80% for all provenances and survival has generally been high. Aphids, mealybugs and ants have been observed, but do not appear to cause significant damage. No termite infestation was observed.

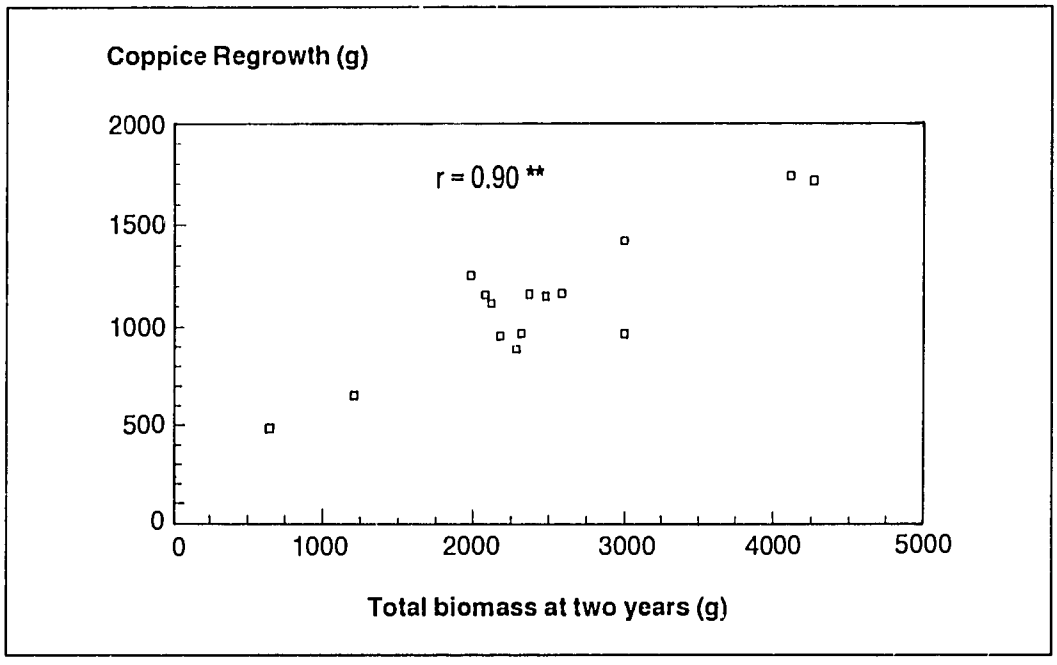
In the first three months, there was already wide variation in growth. Provenances that produced the most leaves also grew fastest, as indicated by height and root-collar diameter.

In 1990, after two years of growth, four provenances were taller, had larger basal areas and had produced more above-ground biomass than the others. In 1991, the same four pro-

	Height (m)	Root-Collar Diameter (mm)
Mimosa scabrella	3.14	54
Chamaecytisus proliferus	2.50	49
Sesbania aculeata	1.84	18
Sesbania macrantha	1.58	15
Sesbania microphylla	1.39	13
Acacia melanoxylon	1.33	18
Sesbania sesban	1.32	—
Acacia koa	1.32	20

Table 15. The eight fastest-growing tree species tested at Gakuta, Rwanda: height and root-collar diameter at 12 months.

Figure 6. Relationship between total biomass production two years after planting and subsequent coppice regrowth for 15 provenances of Gliricidia sepium *at Machakos, Kenya.*



venances were still leading in total biomass production and one-year coppice regrowth, but there was a distinction in growth patterns: three were superior in height, while the other was superior in basal area, indicating extensive branching.

Among the top provenances, the precise ranking in terms of productivity shifted from one year to the next. This suggests that selection based on a few years' data may be misleading. Provenances that produced the highest total above-ground biomass did not necessarily produce the highest one-year coppice growth, indicating that different selections might be appropriate for different management regimes.

The nitrogen, phosphorus and potassium content of mature leaves varied widely, as measured in the third year of growth. Nitrogen content was generally high, averaging 3.4% and ranging from 2.9% to 4.0%.

There was also wide variation in growth and biomass production among individual trees of the same provenance. This would be expected from a small sample of germplasm collected from wild trees. The trees shed their leaves and flowered during the dry season and there was some dieback every year, but this was replaced by new shoots at the onset of the rains.

The next phase of this study will include quality assessments for feed, mulch and fuelwood. Progeny evaluation is also in progress, focusing on the most promising provenance, Retalhuleu from Guatemala. Sixty families of this provenance are being grown out in a seed orchard as planting material for further studies.

In general, *Gliricidia sepium* performed well in terms of survival, growth, biomass production, coppicing ability, pest resistance and nutrient quality. These results suggest that selected breeding material from this species holds promise for agroforestry systems in the *miombo* ecological zone of Southern Africa.

ICRAF is evaluating the same 15 gliricidia provenances in Kenya at the Machakos Research Station. Seedlings were planted in April 1989 in pure stands at a spacing of 1.5 x 1.5 m and allowed to grow normally to assess their suitability for woodlots. During the early growing period, measurements included height,

Table 16. Biomass yield of 15 provenances of Gliricidia sepium *two years after planting and from three subsequent prunings at Machakos, Kenya.*

Provenance	Biomass Two Years After Planting (kg/tree)			Coppice Regrowth from Three Prunings (kg/tree leafy biomass)
	Stem	Leaf	Total	
Volcan Suchitan	3.58	0.69	4.28	1.70
Retalhuleu	3.61	0.52	4.13	1.73
Belen Rivas	2.52	0.49	3.01	1.24
Palya Azul	2.62	0.38	3.00	0.95
San Mateo	2.13	0.46	2.59	1.16
Pontezuela Bolivar	1.99	0.50	2.49	1.14
Monterrico	1.98	0.39	2.37	1.15
Gualan	1.80	0.52	2.32	1.41
Los Puebla	2.04	0.26	2.29	0.87
Local	1.74	0.45	2.19	0.94
La Garita	1.62	0.50	2.12	1.10
Mariara	1.77	0.32	2.09	1.14
Palya Tamarindo	1.52	0.47	1.99	1.24
Palmasola	0.95	0.26	1.21	0.64
Pedasi	0.51	0.14	0.65	0.47
SED	0.457	0.114	0.532	0.180

Leucaena leucocephala Seed Source	Survival (%)	Biomass Production (t/ha dry wt) Foliage	Pods	Wood	Total
Namiyanga, Machinga, Malawi	99	7.9	10.6	20.9	39.4
Isiolo, Kenya	97	4.5	9.6	25.1	39.2
Kawinga, Malawi	98	3.8	11.2	17.8	32.8
Kasama, Zambia	98	7.8	9.7	12.9	30.4

Table 17. Biomass from one-year coppice regrowth of four promising Leucaena leucocephala *seed sources 30 months after planting at Makoka, Malawi.*

number and diameter of branches, and stem diameter at 30 cm above ground. Leaf-retention, flowering and fruiting characteristics were recorded, plus susceptibility to aphid attack.

In March 1991, two years after planting, all the trees were cut back to 50 cm above ground and total biomass was measured. The stumps were evaluated for coppicing ability after three subsequent prunings—in June, October and December 1991. Information on coppicing will be useful in selecting provenances for fodder banks and hedgerow intercropping.

Differences between provenances were greater for total biomass production after two years than for coppice regrowth, but there was a positive correlation between the two parameters (Figure 6). This correlation has useful implications for the selection of provenances for specific agroforestry technologies. For one thing, it is easier to assess total biomass than to monitor leafy biomass production from repeated cuttings. Provenances selected on the basis of total biomass production for technologies such as woodlots or stake production are also likely to be suitable for technologies requiring high production of leafy coppice regrowth.

Two of the gliricidia provenances—Retalhuleu and Volcan Suchitan—stood out as the most promising in terms of both total biomass and coppice regrowth (Table 16). In addition to these, Palya Azul and Belen Rivas appeared promising for wood or stake production. For leafy biomass, Palya Tamarindo, Gualan and Belen Rivas gave good results. The trial is continuing, including an assessment of long-term productivity under competition from crops.

Screening accessions of *Leucaena leucocephala* and *Sesbania sesban*

Leucaena leucocephala has been planted widely throughout the tropics for more than two decades, but many introductions have been based on only one or two self-pollinated progenies. This narrow genetic base has resulted in problems such as poor growth on acid soils and lack of tolerance to cold and drought. In the *miombo* zone of Southern Africa, many unclassified seed sources have been introduced, but the extent of their variation has not been documented.

ICRAF and collaborating scientists at Makoka initiated a trial in January 1989 to investigate the performance of 17 seed sources of *Leucaena leucocephala*, as well as 4 provenances of *Sesbania sesban*, and 1 provenance each of *Sesbania macrantha*, *Sesbania bispinosa*, *Sesbania formosa* and *Calliandra calothyrsus*. Assessment focused on growth, coppicing ability, and quantity and quality of biomass production.

The leucaenas generally grew well, although less quickly than the sesbanias, and production characteristics tended to be rather uniform. They were cut back in April 1989, April 1990 and June 1991. Four seed sources were clearly superior in terms of regrowth after the third cutting, producing 30 to 40 t/ha (dry wt) of total biomass (Table 17). Six accessions produced less than 20 t/ha of total biomass, and the others produced from 20 to 30 t/ha. In all cases, pod production was heavy, representing more than 30% of total biomass. This could be limited by increasing the frequency of cutting.

For the sesbanias, initial growth was excellent but few provenances coppiced well after

cutting. *Sesbania macrantha* and *Sesbania bispinosa* died out after the second cutting. After the third cutting, only 27% to 38% of the *Sesbania sesban* grew back, but the trees that did grew vigorously. *Sesbania sesban* ex Jamhuri (Kenya) produced a total biomass of 25.1 t/ha (dry wt), while *Sesbania sesban* ex Kakamega produced 18.1 t/ha and *Sesbania sesban* ex Magoye (Zambia) produced 17.3 t/ha. Regrowth after cutting tended to be delayed, suggesting that trees cut to provide green manure at the beginning of the growing season might not be competitive until later, when interplanted maize is well established.

Although Africa is the centre of diversity for *Sesbania sesban*, reports on fodder production by this species are largely from other continents. A trial was initiated at Tabora in December 1990 to evaluate 23 accessions of *Sesbania sesban* var. *nubica* for fodder, mulch and fuelwood production. This work is part of a multilocational study coordinated by ILCA at several sites in Africa.

Samples of each accession were harvested 23 weeks after planting for assessment of biomass yield. Seed and pod yields were measured for the remaining plants after 33 weeks of growth.

The accessions differed significantly in terms of fodder, wood and seed production. Fodder yields ranged from 0.1 to 2.4 t/ha and wood yields from 0.1 to 1.7 t/ha. Large, highly branching trees tended to produce both more fodder and more wood. Based on these results, further trials will be limited to the most promising accessions.

Screening pigeonpea cultivars under agroforestry systems

A trial was initiated at the Machakos Research Station in November 1989 to evaluate 10 pigeonpea genotypes for biomass production, coppicing ability, grain yields, soil-fertility improvement and effects on adjacent crops. Germplasm was provided by the Kenya National Dryland Farming Research Centre (NDFRC) and by ICRISAT.

Table 18. Biomass yields (t/ha) of grain plus stalks from 10 Cajanus cajan *(pigeonpea) cultivars under hedgerow intercropping and strip cropping at Machakos, Kenya.*

Cultivar	November 1989–July 1990 Intercropping	November 1989–July 1990 Strip Cropping	October 1990–July 1991 Intercropping	October 1990–July 1991 Strip Cropping
KPP 605	4.3	2.1	3.0	3.6
ICP 13277	4.3	2.1	5.8	4.4
ICP 11012	4.4	2.8	10.6	5.6
ICP 88040	1.8	0.7	1.5	1.9
ICP 13304	3.6	2.3	4.8	6.1
ICP 0933	3.9	2.6	5.4	2.4
KPP 81/3/3	3.7	2.1	7.7	1.6
ICP 11289	4.4	1.5	1.3	1.2
ICP 6443	5.0	2.3	0.3	0.3
KPP 590	3.0	2.0	4.2	6.1
Average	3.8	2.1	4.5	3.3
SED system	0.20		0.47	
SED genotype	0.39		1.38	
SED between systems within the same genotype	0.56		1.91	
SED between genotypes within the same system	0.55		1.95	

Cultivar	November 1989–July 1990 Intercropping	Strip Cropping	October 1990–July 1991 Intercropping	Strip Cropping
KPP 605	2.7	3.9	2.5	2.9
ICP 13277	2.8	3.8	2.2	3.4
ICP 11012	2.4	4.1	1.4	3.1
ICPL 88040	3.0	3.6	3.2	2.5
ICP 13304	3.1	3.7	2.2	3.0
ICP 6933	2.6	3.8	1.9	3.3
KPP 81/3/3	3.1	4.0	2.6	2.6
ICP 11289	3.0	4.3	2.4	3.2
ICP 6443	3.4	3.6	3.5	3.6
KPP 590	3.2	4.1	3.0	3.4
Sole maize	4.2		3.7	
SED system	0.7		0.25	
SED genotype	0.3		0.37	
SED between systems within the same genotype	0.8		0.49	
SED between genotypes within the same system	0.4		0.52	

Table 19. Maize grain yields (t/ha) in combination with 10 Cajanus cajan *(pigeonpea) cultivars under hedgerow intercropping and strip cropping at Machakos, Kenya. Yields for each year represent totals from two growing seasons.*

Researchers compared two planting arrangements with control plots of maize planted in pure stands. These were intercropping, with one row of pigeonpea followed by two rows of maize, and strip cropping, with four rows of pigeonpea followed by eight rows of maize. Both agroforestry systems had one-third fewer maize plants than the plots with maize only. Both had the same overall pigeonpea and maize populations, but the degree of interaction between the two species was higher for hedgerow intercropping than for strip cropping.

Pigeonpea grain was harvested in the first year only. Yields varied considerably across genotypes, ranging from 0.09 to 1.23 t/ha. The Kenyan genotypes (KPP 605, KPP 81/3/3 and KPP 590) tended to yield the most grain, but not the highest overall biomass. Pigeonpea grain yields were significantly higher under intercropping than under strip cropping, presumably because plants under intercropping had access to space in the alleys between maize cropping cycles.

The pigeonpea became infested with *Fusarium* wilt and plants started dying in the dry season after the first grain harvest. For several of the genotypes, more than half the plants had died by the end of the second year and surviving plants were severely infested with scale insects, pod fly and pod borer. For this reason, grain could not be harvested a second time.

Mortality levels were not associated with either of the planting systems. Two years after planting, three genotypes from ICRISAT (ICP 13277, ICP 11012 and ICP 13304) and one from Kenya (KPP 590) showed better than 50% survival and produced more than 5 t/ha of biomass (Table 18). The two lines that produced the most biomass in the first year (ICP 11289 and ICP 6443) suffered high mortality rates.

During the first year, two crops were produced from the sole-maize plots and from the plots under strip cropping, but only one crop was produced under intercropping due to moisture competition from the pigeonpea. Annual maize yields under intercropping with different pigeonpea genotypes ranged from 56% to 80% of sole maize yields, while yields from strip cropping ranged from 85% to 100% of yields from sole maize (Table 19).

At the beginning of the second year, the pigeonpea was cut back to a height of 1 m and maize was sown in both seasons. In the first season, maize yields were similar for all planting arrangements and all pigeonpea genotypes. The one exception was hedgerow intercropping with one ICRISAT genotype, ICP 11912, with crop yields only 62% of those from sole maize.

In the second season, pigeonpea suppressed crop yields in both arrangements, with the most severe competition under intercropping. Maize yields under intercropping were 12% to 52% of yields under sole maize (Table 19). Under strip cropping, maize yields ranged from 40% to 84% of sole maize yields. Combining the yields of two seasons, intercropping in the second year gave 51% to 94% of sole maize yields, while strip cropping gave 68% to 98%. Crop yields were generally higher where the associated pigeonpea had suffered high mortality.

These results suggest that none of the pigeonpea genotypes tested at Machakos is suitable for hedgerow intercropping. Pruning might help improve maize yields but would very likely aggravate pigeonpea mortality. In view of the short life-span of most genotypes, this species would probably be more suitable for short-term improved fallows. It is not appropriate for any agroforestry technology that requires long-term survival under a system of regular pruning.

Farmers might prefer pigeonpea for improved fallows rather than other fast-growing multipurpose trees such as *Sesbania sesban* because of the grain produced, which has economic value. Grain production would have to be weighed against lower yields of other products such as fuelwood and fodder. However, the usefulness of pigeonpea, even for short-term fallows, will depend on the identification of genotypes that can withstand insects and diseases and survive for two to three years.

ICRISAT has recently expanded its pigeonpea programme in Eastern Africa. ICRAF's testing programme at Maseno has been suspended in favour of collaboration with ICRISAT to identify promising perennial types with high biomass production. Once such types are identified, ICRAF researchers will test them in agroforestry systems in comparison with other multipurpose trees.

In 1989 and 1990, scientists at Tabora assessed biomass production and management strategies for 22 pigeonpea genotypes, including 11 biennial fodder types and 11 perennial tree types. This work has led to the selection of nine particularly promising genotypes for grain and fodder yields. These were planted in pure stands in 1991 and evaluated at maturity for production of grain, green fodder and edible seed pods.

The highest grain yield was 3.3 t/ha and the lowest 0.41 t/ha, while green fodder yields ranged from 1.1 to 0.4 t/ha. Green fodder from seven of the genotypes had sufficient amounts of protein, calcium, magnesium, potassium and phosphorus in the correct balance for livestock feed. Two showed calcium/phosphorus imbalances and would require dilution or supplemental phosphorus if used to feed livestock.

ICRAF's collaborative research programme in Zimbabwe is evaluating the productivity of 20 pigeonpea genotypes at Domboshawa and Makoholi. Seed for 19 genotypes was provided by the research programme at Tabora, and one local genotype was tested as a control. All were planted in blocks without fertilizer in December 1990, and grain was harvested and the plants cut back to 50 cm one year later.

Growth performance during the first year was generally better at Domboshawa where soils are more fertile and rainfall was higher. There were no serious pest or disease problems at either site. Grain yields were low at Makoholi due to flower abortion and poor grain filling caused by moisture stress.

At each site, the same three genotypes appeared to offer a good combination of grain, leafy biomass and wood yield. However, these were not the same ones that proved most productive at Tabora. Future experimentation will focus on managing these genotypes under agroforestry systems.

Assessing genetic variation

Information on genetic variation is a prerequisite for selection and breeding programmes. In assessing genetic variation, a small number of high-priority species will be emphasized in

Photo: D. Boland

By excluding pollinators, scientists at the Maseno Agroforestry Research Centre in Kenya learn whether Calliandra calothyrsus *and other species are capable of inbreeding.*

Species	Height (m)	Breast-Height Diameter (cm)	Crown Diameter (m)
Trees established in 1979 (12 years old)			
Gmelina arborea	17.1	26.2	6.7
Pterocarpus soyauxii	12.8	17.1	3.5
Pterocarpus santalinoides	8.7	14.2	5.5
Cassia siamea	12.2	17.5	7.6
Cordia alliodora	21.3	23.0	6.5
Treculia africana	12.6	16.4	4.0
Leucaena leucocephala	14.9	17.0	2.8
Trees established in 1982 (9 years old)			
Delonix regia	12.7	15.7	7.2
Peltophorum pterocarpum	11.2	14.4	5.3
Gliricidia sepium	8.8	11.1	5.9

Table 20. Growth of the most promising multipurpose-tree species at the IITA arboretum (average of 10 trees in centre of 28-tree plots).

each of the three ecological zones that provide a focus for ICRAF's research programme.

Preliminary studies were conducted in 1991 on variation in growth rates and morphological characteristics of *Sesbania sesban* from two different sites in western Kenya. Seedlings from Kisii grew about 1.5 times faster than seedlings from Kakamega and also showed significant morphological differences. These findings call for further taxonomic study.

In the semi-arid lowlands of West Africa, ICRAF has initiated a collaborative project with the Office de la recherche scientifique et technique d'outre-mer (ORSTOM) to study genetic variation in natural populations of *Faidherbia albida* through the use of isoenzyme analysis.

Tree germplasm supply and exchange

ICRAF plans to develop a Multipurpose Tree Germplasm Resource Centre at headquarters in Nairobi, Kenya. The reference will be global. Planning activities began in 1991, including consultation with the Danish International Development Agency (DANIDA) Forest Seed Centre and with other national, regional and international centres.

Meanwhile, ICRAF scientists are already acquiring, collecting and exchanging multipurpose-tree germplasm for their research. Activities in 1991 included:

- Acquisition of 23 accessions of *Sesbania sesban* var. *nubica* from ILCA for fodder evaluation at Tabora
- Collection of 336 accessions of 120 species indigenous to Nigeria. This collection has been stored at the IITA genebank and is being evaluated at field sites in the humid zone of West Africa (Table 20)
- Acquisition of 22 varieties/cultivars of *Cajanus cajan* from ICRISAT for evaluation at Domboshawa and Tabora
- Acquisition of 94 accessions of *Grevillea robusta* from the Australian Tree Seed Centre for seed-orchard establishment and field evaluation at Kakamega, Kenya.

Selecting superior trees for the subhumid zone

Results from D&D exercises, farmer surveys, and species and provenance trials in Eastern and Central Africa have led to the selection of five species for initial breeding research. These are *Sesbania sesban*, *Calliandra calothyrsus*, *Leucaena diversifolia*, *Grevillea robusta* and *Markhamia lutea*. Work is based at the Maseno Agroforestry Research Centre in western

Kenya, but the objective is to support tree-breeding activities in Kenya, Uganda, Rwanda, Burundi, and possibly Zaire and Ethiopia.

Base breeding populations were established in 1990 from germplasm of ideal ideotypes ('plus trees') in Kenya. Using open-pollinated seed from these plus trees, scientists have established progeny-evaluation trials for four species at five sites in Kenya (Table 21).

Results from these trials will provide a basis for assessing the breeding value of selected ideotypes, for reselecting material for advanced breeding trials, and for estimating the genetic parameters of some characters. There are plans to extend germplasm collection and progeny evaluation to Uganda, Rwanda and Burundi.

Vegetative propagation of indigenous trees in the humid zone

Vegetative propagation is particularly important for tree species whose seed is not readily available. Vegetatively propagated clonal stocks are also required for studies on genetic variation and subsequent selection and improvement. Scientists working in ICRAF's collaborative project with IITA and Oregon State University (USA) in Nigeria have developed effective propagation methods for *Tetrapleura tetraptera*, *Treculia africana*, *Acioa barterj*, *Indigofera microphylla*, *Alchornea cordifolia* and *Pterocarpus milbraedii*. Bulked clones of *Indigofera microphylla* and *Calliandra portoricensis* have been produced for evaluation and eventual selection of superior material for improved fallows.

Simple prototype nurseries have been constructed at Onne and Ibadan and a training manual is being prepared to help other institutions wishing to construct low-cost nurseries for the tropics. A similar nursery will be constructed at Mbalmayo, Cameroon, in 1992. By the end of 1991, the nursery at Ibadan had produced 16,000 seedlings and the nursery at Onne had produced 28,000. These have been used for multipurpose-tree screening trials and arboretum establishment, with excess stock supplied to collaborating national scientists.

At Ibadan, 20 tree species are being screened under continuous growth and hedgerow intercropping. At Onne, 30 species are being screened on acidic soils. Establishment has been good. Growth will be monitored in 1992 to evaluate species adaptability at these sites.

Breeding biology studies

Research on breeding biology is a key component of any multipurpose-tree improvement programme. The resulting information provides a guide for the timing of germplasm-collection and controlled-pollination work and also a basis for the design and management of seed orchards.

Controlled pollination for progeny testing in the subhumid zone

Studies on priority species for the Eastern and Central Africa highlands include tree breeding cycles, the potential for self- and cross-pollination and the identification of pollinators. Field observations during germplasm collection have been supplemented by more detailed studies on tagged trees. Work focuses on aspects of breeding biology that play an important role in controlled pollination, including the timing of anthesis and stigma receptivity, pollen viability, percent outcrossing and pollinating agents.

Table 21. Number of entries in progeny-evaluation trials in progress at five sites in Kenya.

Species	Maseno	Kisii	Malava	Kakamega	Meru
Sesbania sesban	30	30	31	–	–
Grevillea robusta	–	86	–	84	72
Markhamia lutea	–	–	46	42	46
Calliandra calothyrsus	12	–	16	–	–

Programme staff have recorded data on tree development sequences in order to construct flowering and fruiting calendars as guidelines for pollen and seed collection. Based on the findings obtained in 1991, routine controlled-pollination work is in progress at Maseno. Starting with *Sesbania sesban*, *Markhamia lutea* and *Grevillea robusta*, researchers are developing and testing techniques for flower emasculation (to avoid self-pollination), pollen collection and storage, hand pollination, and *in vitro* germination.

In 1991, project staff carried out 30 single-pair matings between individual markhamia 'plus trees' and 40 single-pair matings representing wide crosses of sesbania germplasm provided by ILCA. Progeny evaluated for pod and seed development and early nursery performance has shown wide variation.

Breeding biology studies in the humid zone

Surveys in southern Nigeria led to the identification of several multipurpose-tree species of particular value to farmers in the region. Scientists are now investigating the breeding biology of four of these species to obtain information on germination, fertility estimation and pollen storage and management. These are *Millettia thonningii*, *Acioa barteri*, *Tetrapleura tetraptera* and *Lonchocarpus sericeus*, all found to be outbreeders.

Improved management of multipurpose trees

Few multipurpose-tree species have been subject to extensive management research. Studies on practices such as spacing, pruning, thinning, vegetative propagation, seed pretreatment and root-symbiont inoculation are likely to yeild substantial improvements in tree performance.

Propagation of *Sesbania sesban* in the subhumid highlands

Sesbania sesban has been identified as a particularly important multipurpose tree for the highlands of Rwanda. Out of 24 species screened at Rwerere, *Sesbania sesban* showed the best growth in height and root-collar diameter. The species is also particularly popular with farmers: more than half the farmers surveyed in the region mentioned using *Sesbania sesban* as living stakes for bean production.

Expanded use of this popular species has been limited by the expense and labour requirements associated with standard propagation techniques, requiring planting in seedbeds, growing out seedlings in polythene bags and transporting them from nurseries to the hillsides where the farmers have their fields. Scientists at Rwerere conducted two experiments, beginning in 1989, to test the feasibility of simpler and cheaper propagation methods.

Seeds were planted in seedbeds, and the young plants were removed three months later at a height of 50 to 60 cm. They were planted out as bare-rooted seedlings without polythene bags.

Various treatments were tested to improve their survival and early growth—removing the leaves, removing the terminal buds, and cutting off all top growth 10 cm above the root collar. Some seedlings were planted as soon as they were dug up and others were held in the shade and planted eight hours later, simulating the delay that occurs when farmers transport seedlings to their fields from distant nurseries.

Results from these experiments indicate that *Sesbania sesban* planted as bare-rooted seedlings grows and survives nearly as well as seedlings grown in polythene bags. As this species seeds prolifically and germinates readily, these results suggest that farmers can propagate the trees successfully by planting seed in beds near their houses, digging up seedlings when they are 50 to 60 cm tall and planting them directly in their fields.

Direct-seeding studies are also in progress. These include *Leucaena leucocephala* and *Calliandra calothyrsus* as well as sesbania.

Establishment of indigenous fruit trees

A multipurpose-tree survey conducted in 1989 indicated that farmers in Malawi value several indigenous fruit trees as a family food supplement and, in some cases, as a source of cash income. Many of these fruit trees are found only in natural stands and are thus declining as more land is brought under cultivation. Some have particularly high nutritional value.

Farmers were interested in planting local fruit trees on boundaries or around their homes, but they lacked information on how to propagate them. Thus, ICRAF's collaborative research programme at Makoka included an experiment in 1990 to identify simple and effective germination techniques for 18 species.

In 1991, a visiting scientist tested the propagation of 13 species from stem cuttings. *Vitex doniana* rooted well from intact cuttings soaked in water. *Syzygium cordatum*, *Uapaca kirkiana* and *Syzygium owariensis* showed satisfactory rooting, while the other species rooted poorly.

Seedlings from the 1990 germination study were planted out and assessed for growth, flowering and fruiting at the end of 1991, nearly two years after germination. *Ziziphus mauritiana*, *Ziziphus abyssinica*, *Ficus vallis-choudae*, *Azanza garckeana* and *Vangueria infausta* all flowered and bore fruit within this period.

Both ziziphus species showed good growth and heavy branching with thorns. This suggests their potential usefulness as living fences in addition to fruit and fodder production. Other species that grew well were *Bridelia cathartica*, *Bridelia micrantha*, *Parkia filicoidea*, *Sclerocarya caffra*, *Uapaca kirkiana*, *Syzygium cordatum*, *Tamarindus indica* and *Terminalia catappa*.

Information dissemination

Many important multipurpose trees are not well documented in the scientific literature. An important task is to compile whatever information is available for wider dissemination. Information on multipurpose trees must also be accompanied by guidelines on where and how to order seed for research. In 1991, ICRAF made major contributions in both these areas.

Multipurpose tree and shrub database

In 1983, ICRAF began compiling an inventory of multipurpose trees and shrubs in the tropics and subtropics. This work has resulted in the development of a computerized database with information on a wide range of agroforestry species. The project has been financed by the German Ministry of Economic Cooperation (BMZ) through GTZ.

The main development phase was completed in 1991 with the release of version 2.1 of ICRAF's *Multipurpose Tree and Shrub Database*, containing 2400 descriptions of 1093 woody species. About half of the information in the database was obtained from questionnaires completed by researchers and development workers in the field. The other half was gathered from the scientific literature.

To facilitate searches, standardized descriptors have been developed for each species. Starting with particular species, the user can obtain summaries or full data sheets with a range of practical information on appropriate sites, growth requirements, and products and services. Working in reverse, it is possible to specify site conditions and production requirements and generate a list of candidate species from the database.

Potential users include researchers, development workers, planners, teachers and extensionists. One of the main applications is to help field workers choose species for agroforestry projects and experiments. Selection is based on computerized matching of the biophysical requirements and desired uses of multipurpose trees with site characteristics and project objectives.

Released in October 1991, the database has been distributed to more than 100 users. Work will continue in 1992, with BMZ funding, to keep this important information tool up to date and to expand the scope of its coverage.

Multipurpose tree and shrub seed directory

The second edition of ICRAF's seed directory, *Multipurpose Trees and Shrubs: Sources of Seed and Inoculants*, was published in 1991. The directory gives seed information for more than 900 woody species, including names and addresses of 113 seed suppliers and information on seed purchase and delivery procedures.

Practical information is also provided on the functions and benefits of root symbionts, with the names and addresses of 28 suppliers. General information on a selection of species, including climatic requirements and uses, is provided from the *Multipurpose Tree and Shrub Database*.

Photo: C.K. Ong

Maize yields decline at ICRAF's Machakos Research Station the closer the crop row to unpruned Leucaena leucocephala. *Detailed studies are in progress to elucidate the mechanisms involved.*

Well-designed agroforestry systems are based on tree, crop and livestock components that are carefully selected and managed to minimize competition and enhance productivity on a sustainable basis. These land-use systems are, in fact, extremely complicated and present major scientific challenges.

The selection and management of agroforestry components requires a basic understanding of how a system functions as a whole. ICRAF is working to improve this basic understanding through strategic research on the fundamental biophysical processes involved in agroforestry.

Studies are designed to address key problems identified through agroforestry surveys, research and development activities. These problems may stem from inadequate knowledge of how agroforestry works or from inadequate methods and tools for conducting research or analysing results. ICRAF's research programme on component interactions brings together the high concentration of technical expertise and research facilities necessary to tackle some of these fundamental problems. Work focuses on six major issues:

- Utilization of growth resources, including problems of resource sharing and competition
- Nutrient cycling in agroforestry systems
- Management of organic residues
- Control of soil erosion
- Integrated pest management
- Component interactions with livestock.

A small project also addresses methods for assessing variability on farmers' fields.

Work in this programme is conducted primarily at ICRAF's Research Station in Machakos, Kenya (Table 22). Future studies

- Evaluation of prototype hedgerow-intercropping systems
- Comparison of hedgerow intercropping and green manuring
- Hedge-alley-hedge-alley (HAHA) experimental design
- Tree/crop competition for above- and below-ground resources
- Comparison of annual versus perennial legumes for soil improvement
- Complementarity in resource use on sloping land
- Response of crops to light
- Resource capture by species with different rooting depths
- Effects on trees and associated crops of inoculating *Acacia tortilis* with mycorrhizae and rhizobium
- Soil-conservation studies
- Mulching for crop growth and erosion control

Table 22. Component-interaction experiments in progress in 1991 at ICRAF's Machakos Research Station.

will be extended to carefully selected sites in Africa, Asia and Latin America. Activities are described here that were concluded in 1991 or that yielded particularly interesting results during the year.

Utilization of growth resources

When trees and crops are planted together, there is inevitable competition for growth resources. The productivity of each component depends on its ability to capture light, water and nutrients and its response to changes in the microclimate. To understand the interactions among components at a given site, it is crucial to identify which resources limit productivity and to understand the mechanisms of competition for these resources.

Above-ground interactions between trees and crops include the interception of light and rain and modifications of windspeed, temperature and humidity. Below-ground interactions include competition for water and soil nutrients. A better understanding of these processes should make it possible to design agroforestry systems that maximize the positive interactions and minimize the negative ones.

Tree/crop competition for above- and below-ground resources

An experiment was established at the Machakos Research Station in November 1989 to assess the importance of above- and below-ground competition between single hedgerows of *Leucaena leucocephala* and adjacent maize. At Machakos, water tends to be the main resource limiting the growth of both trees and crops.

Work in progress during 1991 involved managing *Leucaena leucocephala* in single hedgerows by regular pruning or allowing the trees to grow freely as an upperstorey. Under both management systems, researchers removed all prunings from the experimental site to simulate the situation on farms where prunings are likely to be used as fodder.

In an effort to distinguish above- and below-ground competition, scientists buried a root barrier of galvanized iron sheets on some plots to a depth of 1 m between the trees and crops. All tree and crop rows were arranged on contours irrespective of orientation, since previous findings indicated that orientation has little effect on tree/crop interactions at Machakos.

Maize was planted on either side of the leucaena in parallel rows 75 cm apart. For successive maize crops, researchers measured yields row by row up to 10 rows out from the trees. During the first growing season of 1990, it was clear that the newly transplanted leucaena was not competing with the crop: there were no apparent differences between maize yields with trees and in sole stands.

By February 1991, after a growing season with good rain, the results of competition were obvious. On plots with upperstorey trees, maize yields were lowest from rows closest to the trees and increased linearly as distance from the trees

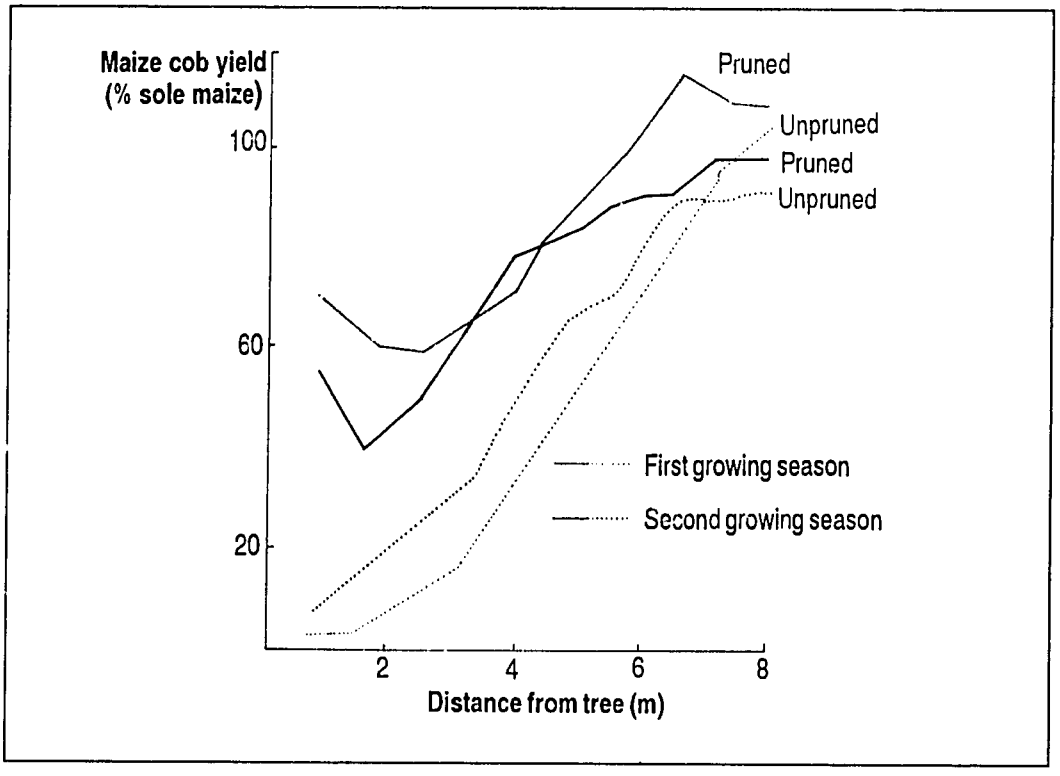


Figure 7. Effect of distance and pruning on competition between Leucaena leucocephala *and maize in two cropping seasons at Machakos, Kenya.*

increased (Figure 7). This pattern was visible within 5 m of the trees, but even beyond this distance yields were well below the average for sole maize. Overall yields from plots with upperstorey trees were 46% below sole maize yields.

Where the leucaena was pruned to a height of 50 cm, maize yields were also generally lower near the trees but reductions were less severe. Overall yields were 20% below yields from sole maize. Interestingly, the first maize row next to the hedgerows was 10% to 15% more productive than the next row out.

In the next growing season, rainfall was poor and there was a long dry spell following crop emergence. Sole maize yields averaged only 1.5 t/ha—about 40% of the average for the previous season. Again, the negative effects on individual maize rows extended 5 m out from the leucaena. Despite the difference in rainfall, overall reductions in crop yield were similar—46% to 55% on plots with upperstorey trees and 18% to 20% on plots with pruned hedgerows.

To elucidate above-ground interactions, scientists installed rain gauges and tube solarimeters between the trees and crops to measure rainfall redistribution and shading. To assess below-ground interactions, they installed neutron access tubes to a depth of 2 m between the trees and crops to measure soil-moisture profiles. They monitored tree transpiration rates using heat-balance equipment.

The upperstorey canopy had a major influence on rainfall redistribution for the three nearest crop rows. This influence was greatest during light rains—of less that 10 mm a day—when the nearest crop row received only 55% of the total rainfall. When rain was heavier than 30 mm a day, the nearest row received 75% of the total. In other words, every time it rained the trees deprived the adjacent crop rows of about 5 mm of rainfall. These results suggest that the

rain shadow created by upperstorey canopies of unpruned trees can cause substantial losses in crop yield, especially in areas with a high proportion of light rains.

Shading by upperstorey-tree canopies extended to 3.8 m distance from the trees, leading to a 25% reduction in solar radiation on adjacent crops. At Machakos, such a reduction is probably not sufficient to explain 46% to 55% losses in crop yield.

Both hedgerows and upperstorey trees showed similar transpiration rates during rainy and dry periods. Although the upperstorey trees had much larger canopies, the pruned hedgerows had a higher proportion of young, actively transpiring leaves. The similarity in transpiration rates suggests that differences in competition must relate to other factors. Information on soil-moisture profiles will be available in the next season to show where water is extracted in the soil profile.

In general, these results indicate that competition between leucaena and maize in the seasonally dry tropics can be substantial—whether or not the trees are pruned and even in seasons of relatively good rainfall. Competition for below-ground growth resources extend well beyond any effects associated with tree canopies.

Despite evidence of the importance of below-ground interactions, the root barriers had a negligible effect. In the first season, they led to crop yield increases of only 12% next to upperstorey trees and 7% next to hedgerows. Results in the second season were similar. Probably, the tree roots grew under the barriers and arched back towards the upper soil layers to compete with adjacent crops. Previous experience at Machakos with trees planted in 50-cm sunken pits showed a similar pattern. Future work will include more detailed root studies.

Studies on tree root systems and their graphical presentation

A thorough understanding of below-ground interactions in agroforestry systems requires information on how tree and crop roots exploit the soil when different species are combined. Information is required on changes in tree rooting habits with growth over time, with management inputs such as pruning, and with the addition of intercrops. All root research is difficult and time consuming, and root studies in agroforestry may be complicated by difficulties in distinguishing the fine roots of trees from those of crops.

Three methods are commonly available for investigating tree root systems—trenching, core sampling and probing with mini-rhizotrons. Studies at Machakos have been based on trenching because this approach provides the most complete picture of rooting patterns. Work has concentrated on the interface between blocks of trees and maize, hedgerows of different species, and unpruned trees surrounded by crops. Researchers obtained results in 1991 for three different hedgerow species, with particular emphasis on developing methods for the graphical display of root systems.

Observations were derived from trenches excavated at right angles across hedgerows of *Cassia siamea*, *Leucaena leucocephala* and *Gliricidia sepium*. The trees had been established for about 4.5 years. They were spaced at intervals of 50 cm within rows arranged 5 and 6 m apart. All hedgerows had been pruned regularly four times a year to a height of 60 cm. Maize was growing between the hedgerows at the time of observations.

Field workers excavated trenches by hand at widths of 80 to 100 cm, leaving vertical faces undisturbed down to the rocky outcrop 1.5 to 2.0 m below the soil surface. Any roots extending into the trench were cut back to the soil face, which was wetted with a fine jet of water immediately prior to data collection. This exposed fine roots and made them more visible.

Root profiles were depicted by marking the position of each root on clear polythene sheets spread across the trench faces. Three root grades were distinguished—fine roots of less than 0.5 mm in diameter, medium roots of 0.5 to 2.0 mm, and large roots of 2.0 to 5.0 mm. The marks were later counted using a wire grid divided into units of 5 x 5 cm.

Neither photographic records nor numerical data gave a comprehensive picture of underlying root patterns, so total counts from each grid unit were grouped into appropriate classes and depicted in two ways: by splining and by a scaled-density random-dot method.

With the splining method, the number of roots in each grid unit is displayed as a single value attributed to the centre of the unit. A cubic

Photo: A. Njenga

A field technician monitors the soil-moisture status between hedgerows and crops at the Chalimbana Agricultural Research Station in Zambia.

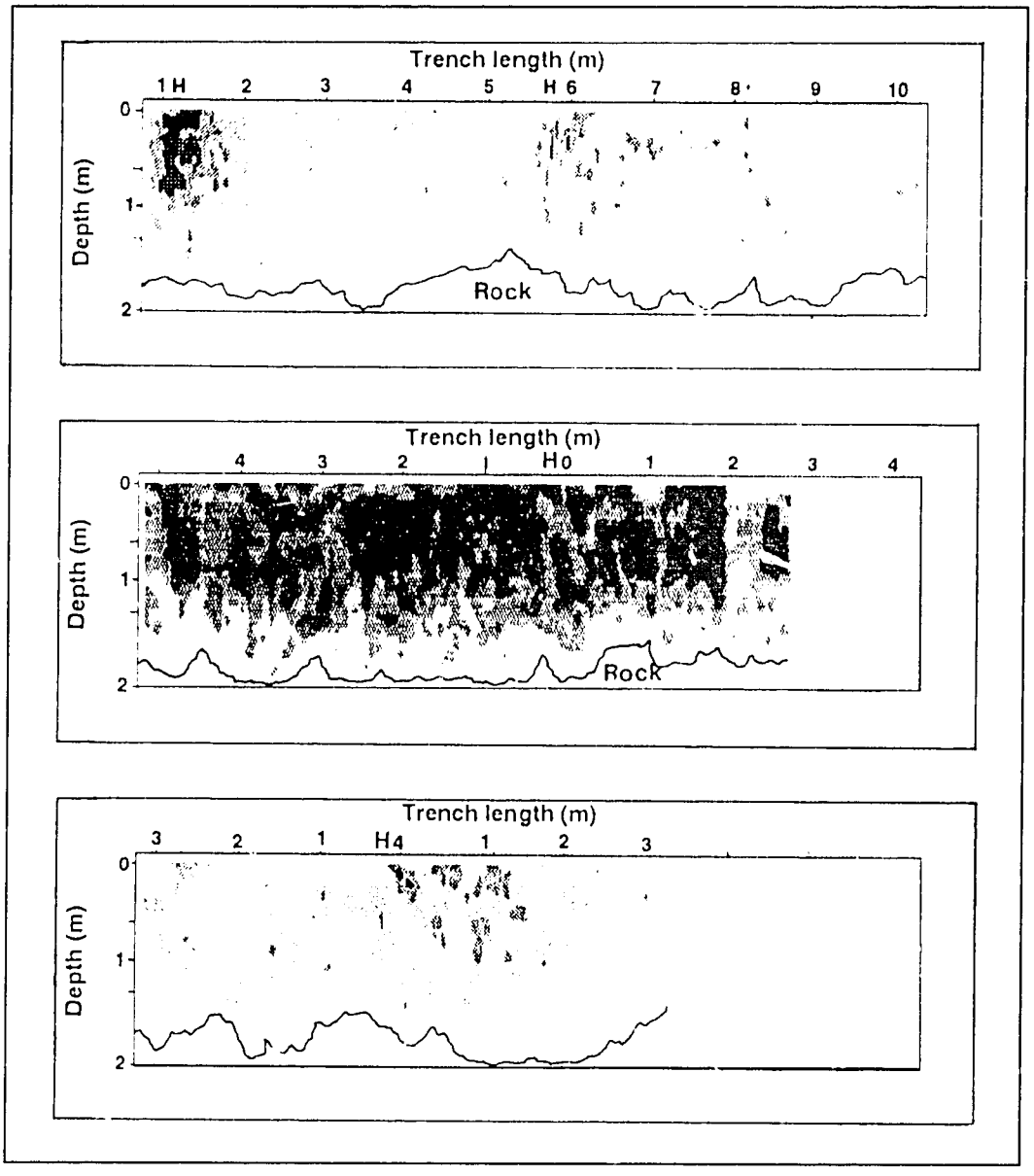


Figure 8. Computerized representation of fine roots of Cassia siamea, Leucaena leucocephala *and* Gliricidia sepium *hedgerows at Machakos, Kenya, displayed by a splining technique. Observations are from trenches cut perpendicular to the hedgerows. Values are means of both sides of the trench.*

spline function is then used to smooth these points and produce a contour diagram of root densities. Figure 8 shows the distribution of fine roots adjacent to cassia, leucaena and gliricidia hedgerows as depicted by this method.

With the random-dot method, all dots representing individual roots in each original grid unit are displayed in locations assigned at random within the unit. Figure 9 is a dot diagram of root distribution next to the cassia hedgerow.

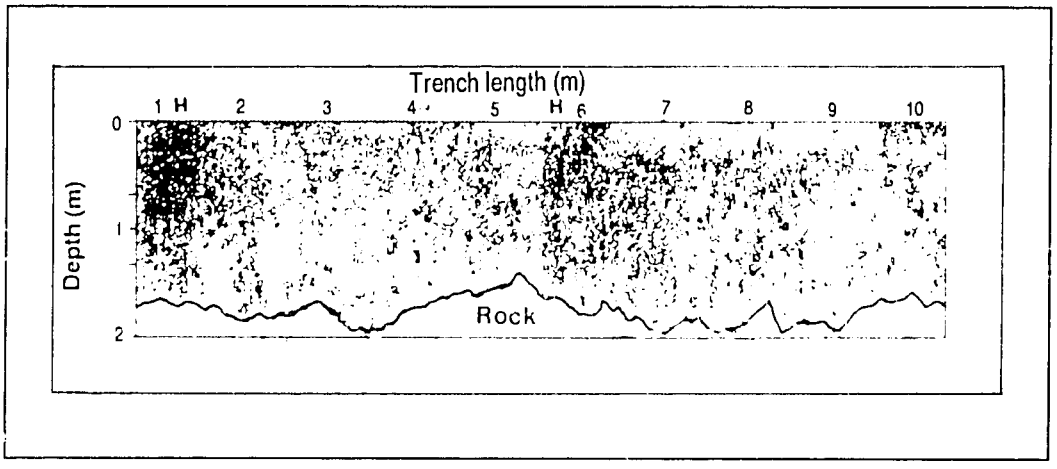


Figure 9. Computerized representation of the fine roots of a Cassia siamea *hedgerow at Machakos, Kenya, displayed by a scaled-density random-dot technique. Observations are from a trench cut perpendicular to the hedgerow. Values are means of both sides of the trench.*

The roots of all three species reached a maximum depth of about 1.5 m. Cassia and gliricidia both had moderate rooting densities, with fine roots generally clustered beneath and near the hedgerows. By contrast, the fine roots of leucaena were spread densely throughout the 8-m trenches. The leucaena also appeared to root more deeply than the other two species. These observations may help explain other results from Machakos indicating that *Leucaena leucocephala* is highly competitive at this site.

Several observations relate to the accuracy of the methodology. The 5 x 5-cm grid used in this study depicts root densities more precisely than would be possible using larger grids. The random-dot method generates accurate information with small grid units, especially at low root densities, because it depicts root numbers precisely. The splining method displays larger-scale rooting patterns more clearly, especially at high root densities.

Nutrient cycling

Throughout the tropics, farmers report declining soil fertility as one of their most serious problems. Agroforestry can help maintain soil fertility through several mechanisms—maintenance of soil organic matter, nitrogen fixation, erosion control and increased efficiency of nutrient cycling.

Nutrient cycling is the process by which plants retrieve nutrients from the soil through their roots and return them through the decomposition of residues. These include leaves and roots that are shed, prunings applied to the soil, and whole plants when they die.

Under natural forest, less than 10% of the nutrients recycled between soils and plants is lost from the system. By contrast, under continuous cropping, 40% or more of total nutrients may be lost. Agroforestry systems can potentially achieve a recycling ratio somewhere between these two values.

This potential arises primarily from the capacity of tree roots to take up soil nutrients that would otherwise be lost by leaching. Leguminous trees also have the ability to fix atmospheric nitrogen, making this important nutrient available to other plants.

In any specific situation, the capacity of an agroforestry system to enhance nutrient cycling depends both on environmental conditions and on management factors. Physical and chemical soil characteristics and soil fauna are important as well as climate. Management aspects include the selection of tree species with appropriate phenology, rooting patterns and litter quality, the temporal and spatial arrangement of the

trees, the selection and management of associated crops, fertilizer application, and nutrient removal through the harvest of trees and crops.

Scientists need to understand these complex processes in order to predict the impact of introducing agroforestry in a particular environment. ICRAF launched a comprehensive research programme in this area in 1991, beginning with a planning workshop. Studies already in progress included a comparison of soil-fertility maintenance by annual and perennial legumes.

Planning workshop on soil fertility and nutrient cycling

Collaborating scientists came to ICRAF headquarters in March 1991 to plan a comprehensive research programme on nutrient cycling in agroforestry systems. These included researchers and research directors from the University of Reading (UK), the Tropical Soil Biology and Fertility (TSBF) Programme, the International Fertilizer Development Centre (IFDC), the University of Nairobi and KARI. Representatives from donor organizations also participated in the meeting.

Key research questions were broken down into specific hypotheses and these were ranked in terms of priority. These hypotheses will provide the basis for a new research initiative on nutrient cycling, to be funded in part by the British Government's Overseas Development Administration (ODA). Researchers are now in the processing of selecting appropriate experimental sites for the programme, representing typical situations of land depletion. These will be in the area around Machakos and in western Kenya.

Comparison of annual and perennial legumes

Farmers throughout the world traditionally grow annual leguminous crops—such as beans, cowpea and pigeonpea—in rotation or under intercropping with cereals. These legumes produce edible grain and help improve soil fertility by fixing nitrogen. Before introducing agroforestry into traditional systems, it is important to ask whether leguminous trees can enhance the efficiency of nutrient cycling and make a better long-term contribution to soil fertility than annual legumes.

Scientists established an experiment at ICRAF's Machakos Research Station in 1989 to compare the soil-fertility effects of a short-season legume (cowpea), a full-season legume (pigeonpea) and a leguminous tree (*Gliricidia sepium*). These are raised in the following systems, using maize as a test crop to detect improvements in soil fertility:

- Maize in sequence with cowpea
- Maize in sequence with pigeonpea
- Maize intercropped with pigeonpea

Table 23. Maize yields (t/ha) in combination with annual and perennial legumes at Machakos, Kenya.

Cropping System	— Year One — Oct 89–Feb 90	Apr–Jul 90	— Year Two — Oct 90–Feb 91	Apr–Jul 91
Cowpea-maize rotation	—	2.40	3.01[a]	1.91
Pigeonpea-maize rotation	—	—	3.07	2.22
Pigeonpea/maize intercropping	3.17	—	3.38	—
Gliricidia/maize hedgerow intercropping	3.09	1.52	2.79	0.86
Maize + gliricidia mulch (block planting)	2.57	2.04	3.38	1.62
Continuous sole maize	3.02	2.17	2.96	1.47
SED	0.341	0.204	0.411	0.266
Rainfall (mm)	440	620	333	214

[a]Yield is from the repeated maize-cowpea sequence, which represents one season's effect of cowpea.

- Maize intercropped with gliricidia, with tree prunings applied to the crop as mulch
- Maize and gliricidia grown separately, with similar land areas allocated to trees and crop as under hedgerow intercropping and all tree prunings applied to the crop as mulch
- Continuous sole maize cropping as a control.

The two sequential systems have been repeated, starting with cowpea or pigeonpea, to allow comparison of maize yields across all systems in every season.

Preliminary results from four cropping seasons are given in Table 23. One season of cowpea in rotation did not influence maize yields, but two cowpea/maize rotations improved maize yields by 30% compared with continuous maize cropping. Similarly, the first maize crop immediately following pigeonpea did not benefit from a residual effect, but the second maize yield was improved by 50%. Yields from maize intercropped with pigeonpea were similar to yields from the control.

In the hedgerow-intercropping arrangement, young gliricidia trees did not compete with maize in the first season, but in subsequent seasons larger trees were very competitive with adjacent crops. This competition was more pronounced when the trees were not pruned and when rainfall was below normal.

Under the block-planting arrangement, maize plots lost 17% of their area to gliricidia. In the first two seasons, the application of tree mulch was not effective enough to outweigh this loss of planting area: total maize yields were slightly lower than those from control plots. In the third and fourth cropping seasons, however, maize yields were the same or better under block planting than controls, probably due to the beneficial effects of the mulch.

These preliminary results indicate the potential benefits of tree mulch but do not favour hedgerow intercropping at this site. The long-term evaluation of the different cropping systems will include assessments of nutrient budgets and soil-nutrient status.

Effect of *Frankia* on the growth and development of *Casuarina*

The casuarinas, native multipurpose trees of Australia, may have potential for producing fuelwood, charcoal and building poles in the subhumid zone of Southern Africa. In other regions, they grow well on poor soils because they can fix atmospheric nitrogen in symbiosis with the actinomycetes fungus *Frankia*.

ICRAF and collaborating scientists at Chipata, Zambia, began an experiment in 1990 to evaluate the survival and growth of *Casuarina equisetifolia*, *Casuarina cunninghamiana* and *Casuarina glauca* propagated from seed with or without inoculation with the *Frankia* symbiont. Six months after planting in the field, *Casuarina equisetifolia* showed the bene[illegible] [illegible] *Frankia* inoculation. The inoculated seedlings were twice the height of non-inoculated controls and were considerably larger in terms of root-collar diameter.

Mortality rates were generally high, due primarily to termite damage, but were lower for plants that had been inoculated. The other two species did not respond significantly to *Frankia* inoculation, but they were generally less susceptible to termite damage than *Casuarina equisetifolia*.

Control of soil erosion

Agroforestry offers a powerful tool for soil and water conservation. Trees may be added as a supplement to conventional soil-conservation structures—such as banks, ditches, grass strips or terraces—or they can help control erosion on their own, by checking runoff and soil loss. Two agroforestry systems in particular provide this important function: contour-aligned hedgerow intercropping, which can be practised over a wide range of environmental conditions, and multilayered tree gardens, whose potential lies largely in the humid tropics.

The design of an agroforestry system for soil conservation must take several environmental factors into consideration, such as slope, soil type, and rainfall amount and intensity. Design questions include the choice of species, planting arrangement, pruning regime, and management of residues. Strategic research on the soil-conservation function of agroforestry systems provides an information base to help design appropriate systems for specific sites.

ICRAF has been investigating and demonstrating the soil-conservation potential of

agroforestry at the Machakos Research Station since 1984. Experiments test the effectiveness of contour-aligned hedgerows of *Leucaena leucocephala* and *Cassia siamea* on land sloping at 14%. Other trials compare single and double hedgerows spaced at different intervals across the slope.

Erosion control by soil cover from tree prunings

There are basically two ways to use trees and shrubs to control erosion—by providing barriers or ground cover. With the first approach, contour-aligned hedgerows are used as semi-permeable barriers to increase water infiltration and retain soil particles. These provide an alternative to earth structures, which perform a similar function.

With the cover approach, pruned material or litter from trees is spread over the soil surface, checking both raindrop impact and runoff. Computer modelling and experimental data both show that the maintenance of a ground cover of plant litter can be highly effective in checking erosion. Even a 10% cover can reduce runoff by 75%, while a 40% cover can reduce runoff by 90% compared with the rate for bare soil.

ICRAF is testing erosion control at Machakos using hedgerow intercropping and the application of tree-litter mulch. The trials are designed to measure the movement of water, soil and plant nutrients and to determine rates of loss.

One experiment comparing the effectiveness of barriers with soil cover generated interesting results in 1991. The objectives were twofold: to establish the quantity of soil cover obtainable from tree prunings, either from hedgerows or from an external source, and to determine whether surface mulch from prunings could provide an effective soil cover throughout the erosive rainy period.

Four treatments were compared:

1. Cassia siamea hedgerows plus mulch: single hedgerows 4 m apart were composed of plants spaced at intervals of 25 cm and all prunings were applied as mulch on the cropped alleys.
2. Mulch only without hedgerows: the same amount of cassia mulch as in treatment 1, from an external source, was applied to sole crops.
3. *Leucaena leucocephala* hedgerows plus mulch: the same as treatment 1, but with a different hedgerow species.
4. Control: sole crops with no soil-conservation treatment.

The crops were cowpea in the first growing season each year and maize in the second. Cassia hedgerows were pruned twice a year, once before each growing season The leucaena grew more quickly and had to be pruned once or twice more during the growing seasons to prevent spreading across the alleys.

Fresh hedgerow prunings were weighed and sampled to determine dry weight before being applied as mulch. Soil cover was measured at randomly selected points every 10 days from before crop germination to harvest, using a 1.33 sq m quadrat divided into a grid with 100 intersection points. Measurement was based on counting how many intersection points fell on hedge, crop, weeds, mulch or stones. In the data presented here, the low values for weeds and stones are omitted.

Results are available for five cropping seasons from 1989 to 1991—three with cowpea and two with maize. Rainfall was average for one season, above average for two seasons, and below average for two seasons. Fresh biomass from cassia prunings averaged 1.21 kg/m of hedge annually, equivalent to 3.00 t/ha. Dry matter was approximately 35% of fresh weight. The leucaena hedgerows produced 1.70 kg/m of fresh biomass annually, equivalent to 4.39 t/ha.

Single hedgerows spaced at 4 m produced more than enough mulch to provide a 30% cover for the cropped alleys. A plot of trees in sole stand, spaced at 1 x 1 m, produced about 8.5 t/ha of mulch per year.

Figure 10 depicts the percentage of soil cover provided by different components of the system throughout the cropping season. Initially, the cover provided by the crop was low, but after 50 days it reached 50%. The tree mulch provided an initial cover of 50%, decreasing to 30% after 30 days and 10% after 40 days as the material decayed. Thus the growth of the crop and the decay of the mulch were complementary, so that throughout the growing season the total soil cover never fell below 50%. With cowpea, soil

cover increased again at the end of the growing season when the crop shed its leaves.

This pattern occurred in all the growing seasons, whether the crop was maize or cowpea. In almost every case, the crop established a cover of 50% to 60% about 50 days after germination. The lowest crop cover at this stage of growth, provided by cowpea during the poorest growing season, was 35%. This would be sufficient to control most erosion problems. Thus the key role of the trees was to maintain adequate cover during the first 50 days of the growing season, when crop cover was scant and when intense storms are likely to occur.

On all plots with cassia, mulch cover was never lower than 24%, and in 7 out of 10 seasons the lowest cover in any 10-day period was more than 30% (Table 24). On plots without mulch, cover was less than 10% for a period ranging from 20 to 30 days at the beginning of the growing season. Because leucaena mulch decayed so rapidly, the cover provided by this species was consistently less than the level provided by cassia.

The single hedgerows planted 4 m apart in this experiment occupied 10% of the cropped area. Trees planted in blocks required more land to produce the same amount of mulch, or slightly more than one-third of the entire area available to trees and crops. The hedgerows were probably more productive than the trees planted in blocks because they had access to moisture and nutrients in larger areas during the non-cropping period.

These findings indicate that the most effective approach for controlling erosion is to plant contour hedgerows and to apply mulch, but either hedgerows or mulch alone reduces erosion to acceptable levels. Runoff and soil-loss data are now being compiled for different treatments and years. Although a system of hedgerows with mulching is generally more efficient

Figure 10. Development of soil cover under hedgerow intercropping with maize or cowpea and Cassia siamea*: average of observations over five growing seasons at Machakos, Kenya.*

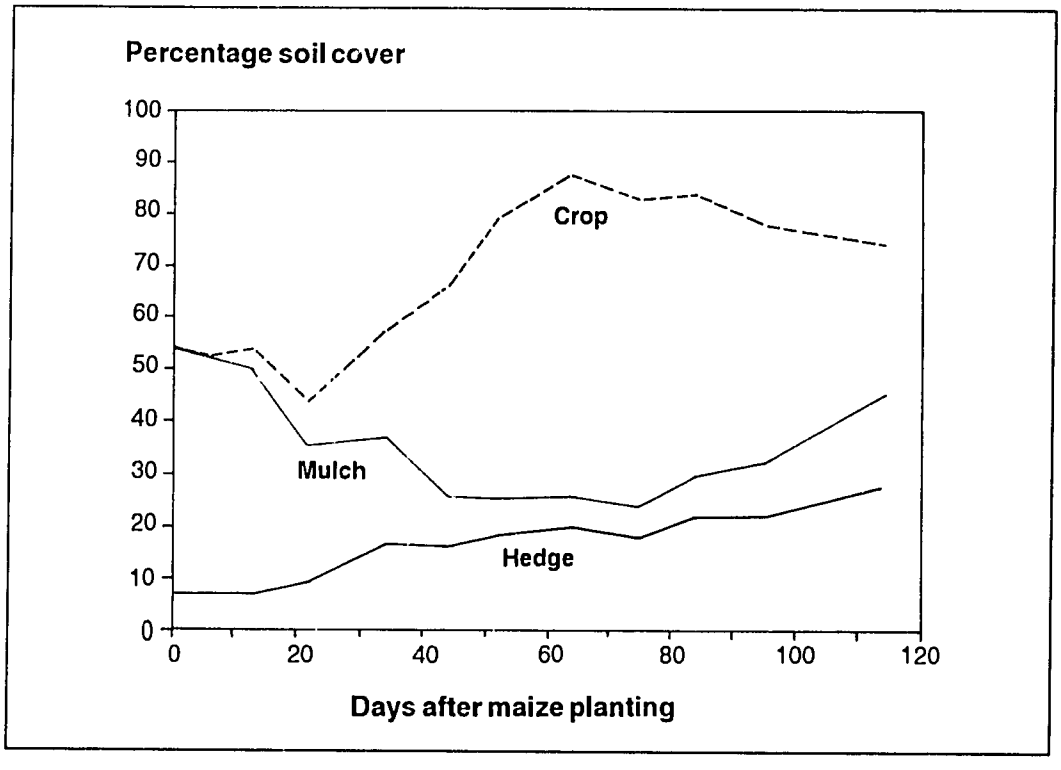


Photo: C.K. Ong

Heat-pulse probes on the trunk of a Faidherbia albida *at the Machakos Research Station measure the rate at which the tree takes up water.*

Technology	Crop	Year	— Lowest Soil Cover (%) — One 10-day Period	Two or More 10-day Periods
Cassia hedge + mulch	cowpea	1989	43	50
Cassia hedge + mulch	cowpea	1990	54	54
Cassia hedge + mulch	cowpea	1991	46	51
Cassia hedge + mulch	maize	1989	35	48
Cassia hedge + mulch	maize	1990	27	28
Cassia hedge + mulch	mean of five seasons		41	46
Leucaena hedge + mulch	mean of five seasons		31	34
Cassia mulch only	cowpea	1989	52	52
Cassia mulch only	cowpea	1990	38	38
Cassia mulch only	cowpea	1991	42	52
Cassia mulch only	maize	1989	24	38
Cassia mulch only	maize	1990	26	27
Cassia mulch only	mean of five seasons		36	41
Control, no conservation	mean of five seasons		2	3

Table 24. Lowest levels (%) of soil cover provided by mulch from tree prunings at Machakos, Kenya.

than planting trees in blocks, a farmer with a small area of poor land suitable for tree production can also achieve effective erosion control by applying mulch from a block planting.

Integrated pest management

The full biological potential of agroforestry systems may not be realized if the interactions of components result in increased pest problems. Trees and crops may both host the same pest, resulting in pest populations that increase to harmful levels.

By contrast, trees may act as a barrier or trap to inhibit the spread of pests or may serve as hosts to natural parasites.

In 1991, an entomologist came to ICRAF from India on a fellowship sponsored by GTZ The objectives of the fellowship were to:

- Review and synthesize available information on insect pests in agroforestry including problems associated with specific agroforestry systems
- Survey insect pest infestation at ICRAF's field research sites in Africa and, if possible, ascertain the importance of observed pests
- Suggest future research priorities related to insect pests in agroforestry.

ICRAF will publish a detailed report on this study as a Working Paper.

Surveys at five sites did not reveal any examples of component interactions that either favoured or inhibited the build up of pest populations. In general, the inclusion of diverse species in agroforestry systems may tend to reduce the incidence of crop pests.

Among the dozens of multipurpose trees now being screened at different sites, *Cajanus cajan* (pigeonpea), *Sesbania sesban*, *Erythrina abyssinica* and *Cassia siamea* most frequently harboured insect pests, while *Calliandra calothyrsus* showed insect damage at one site in Burundi (Table 25). No other species showed major pest damage.

Green aphids were commonly observed on gliricidia, pigeonpea and calliandra, while mealybugs and leaf hoppers were observed on

erythrina and *Albizia lebbeck*. Erythrina was heavily attacked by a lepidopteran stem borer, particularly trees planted in pure stands. Interestingly, a number of hymenopteran parasites were observed on the sucking insects infesting pigeonpea and cassia. Samples were sent for identification to the International Institute of Entomology in the UK.

Susceptibility of sesbania to *Meloidogyne javanica*

Tobacco is an important cash crop in the region around Tabora, Tanzania. Sesbania and tobacco are both susceptible to root-knot nematodes (*Meloidogyne* spp.) and infestation can become a serious problem if these two species follow each other frequently on the same land. In a nursery study conducted in 1990, both *Sesbania sesban* and *Sesbania macrantha* showed root damage after nematode infestation, although the *Sesbania macrantha* showed more resistance than the *Sesbania sesban*. In 1991, scientists at Tabora evaluated 10 accessions of *Sesbania sesban* and 1 accession of *Sesbania macrantha* for susceptibility to *Meloidogyne javanica*.

Individual plants were grown in separate pots of sterilized sandy loam, forest clay loam and sand. The accessions were evaluated in two separate tests: they were inoculated with second-stage juveniles of the nematodes or with nematode egg masses. Fifty days after inoculation, the plants were rated for susceptibility to

Table 25. Insect pests observed on multipurpose trees at field sites in Kenya, Burundi and Cameroon.

Tree Species	Insect	Nature of Damage
Cajanus cajan		
	Melanogromyza chalcosoma	Maggots bore into buds and damage seeds
	Helicoverpa armigera	Caterpillars bore into flowers, buds and pods
	Ptyelus grossus	Sucks sap from stems and branches
	Coccus longulum	Sucks sap from shoots
	Megalurothrips sp.	Infests flowers
	Aphrophora alni	Sucks sap from stems and branches
Sesbania sesban		
	Mesoplatys ochroptera	Defoliates
	Trochalus sp.	Defoliates
	Riptortus sp.	Sucks sap
Erythrina abyssinica		
	Libyapsis punctata	Devitalizes plants
	Aprostocetus sp.	Forms galls on leaves
Cassia siamea		
	Xyleutes capensis	Larvae bore stems
	Xyopsocus sp.	Bores holes in wood
	Spilococcus sp.	Infests leaves
	Coptotermes sp.	Damages roots and shoots
	Odontotermes noiaensis	Damages roots and shoots
Calliandra calothyrsus		
	Apion sp.	Feeds on foliage
	Monolepta pauperata	Feeds on foliage
	Myllocerus sp.	Feeds on foliage
	Diplognatha silicea	Sucks sap and injures bark
	Pachnoda aemula	Defoliates
	Antestiopsis cincticollis	Sucks sap from tender parts
	Atelocera sp.	Sucks sap from tender parts
	Megalurothrips sp.	Infests flowers
	Thrips sp.	Infests flowers

Species and Accession	Inoculation with Juveniles			Inoculation with Egg Masses		
	Root-Gall Index	Egg-Mass Index	R	Root-Gall Index	Egg-Mass Index	R
Sesbania sesban 028	4.3	3.8	0.8	2.0	2.0	0.4
Sesbania sesban 08 B	4.3	3.5	0.8	3.5	2.5	0.6
Sesbania sesban 014	2.8	2.3	0.5	1.5	2.0	0.4
Sesbania sesban 15	2.0	2.0	0.4	4.5	4.0	0.9
Sesbania sesban 027	2.0	1.8	0.4	4.0	4.0	0.9
Sesbania sesban 029	6.0	4.0	0.9	1.5	1.5	0.3
Sesbania sesban SR19	3.3	2.8	0.6	4.0	3.5	0.8
Sesbania sesban T110	2.3	1.8	0.4	5.0	4.0	0.9
Sesbania sesban NRB1	3.8	3.0	0.7	6.0	3.0	0.7
Sesbania sesban ex-Tumbi	3.3	2.8	0.6	3.0	3.5	0.8
Sesbania macrantha 017	1.5	1.0	0.2	3.0	2.5	0.6
Tomato (cv. Money Maker)	6.0	4.5	1.0	7.0	4.5	1.0
SED	0.61	0.55	—	1.02	0.52	—

R (reproductive rating) = Egg mass index of accession/Egg mass index of tomato.

Table 26. Effects of inoculating different sesbania accessions with the root-knot nematode Meloidogyne javanica.

the nematodes on the basis of root-gall and egg-mass indices. A reproductive index (R) was computed by dividing the average egg-mass index of each accession by the egg-mass index of susceptible tomato plants.

All accessions became infected, but there were significant differences in rates of infection as evidenced by root-gall and egg-mass indices (Table 26). In general, the root systems of infected plants were short, with fewer lateral or tertiary roots than those of non-infected plants.

These results indicate that *Sesbania* species can support the reproduction of *Meloidogyne javanica*, which restricts the range of crops that can be grown in association with sesbania in soils where nematode infestation is a problem. Nevertheless, the variability in susceptibility to the nematode suggests the potential of selecting appropriate germplasm for infested soils.

Component interactions with livestock

Domestic animals are an important component of most smallholder farming systems in the tropics. However, livestock fodder is often of poor quality and many farmers experience fodder shortages, particularly during the dry season. The incorporation of trees into the cropping system provides an opportunity to produce high-quality tree fodder throughout the year.

Table 27. Chemical composition (% dry matter) of tree fodder fed to goats at Tabora, Tanzania.

	Nitrogen	Phosphorus	Calcium	Magnesium	Potassium
Leucaena leucocephala	3.23	0.22	0.43	0.42	1.33
Cajanus cajan	3.25	0.30	0.41	0.25	1.20
Sesbania sesban	3.44	0.20	0.47	0.11	1.64

	Wet Season (Oct-Mar) Daily Intake (g/head)	Wet Season (Oct-Mar) Daily Weight Gain (g/head)	Dry Season (Apr-Jun) Daily Intake (g/head)	Dry Season (Apr-Jun) Daily Weight Gain (g/head)
Leucaena leucocephala	86	37	92	41
Cajanus cajan	91	43	113	40
Sesbania sesban	83	38	79	39
Controls (no supplement)	—	21	—	20
SED		3.6		1.8

Table 28. Daily intake and weight gain of kids grazing on natural pasture and supplemented with three fodder species, Tabora, Tanzania.

ICRAF is examining the potential of multipurpose trees to produce fodder when grown separately in fodder banks or interplanted with grasses or crops. Scientists are monitoring animal intake and responses to tree fodder. One objective is to identify anti-nutritional characters inherent in fodder from some trees.

Research on livestock in agroforestry systems is a modest activity at ICRAF. Studies are now in progress at three sites—Tabora, Chipata and Yaounde (Cameroon). This work will increase as research programmes expand in Burkina Faso, Mali, Niger and Senegal.

Supplementary fodder trials in the subhumid zone

Farmers in Tanzania keep more than 6 million goats, depending exclusively on natural pasture to fill their nutrient requirements. However, during most of the year, the region's grasslands are deficient in protein and minerals to meet the animals' maintenance and production requirements. One solution would be to help farmers grow high-quality tree fodder as a feed supplement for their livestock. ICRAF's collaborative zonal programme based at the Tumbi Research Institute is assessing the feed intake and growth rate of kids supplemented with fodder from three multipurpose-tree species—*Cajanus cajan*, *Leucaena leucocephala* and *Sesbania sesban*.

From October 1990 to June 1991, 40 kids were allowed to graze on natural pasture during the day and provided with all the tree fodder they could eat at night. A control group of 16 kids were also allowed to graze, but without any supplements. All animals were offered water *ad libitum* and were sprayed for external parasites and dewormed on a monthly basis.

Chemical analysis of fodder from the three species showed mean nutrient levels generally above the minimum recommended for ruminants (Table 27). The exception was *Sesbania sesban*. Fodder from this species had low magnesium levels and an unfavourable calcium/phosphorus balance.

Kids fed on each species showed higher liveweight gains than controls (Table 28). Supplement intake and associated weight gains were similar during both wet and dry seasons, indicating that the natural pastures did not provide an adequate feed source even at the most favourable time of year. The animals fed selectively on leafy biomass from all three species, refusing most of the stems.

A 12-week feeding trial at Chipata compared weight gains among penned goats fed maize husk supplemented with tree fodder or 1% urea. Fodder supplementation was with fresh leafy biomass of *Leucaena leucocephala* and *Calliandra calothyrsus*. Crude protein content was 28% for the leucaena, 33% for the calliandra and 4% for the maize husk (Table 29).

Supplementation with fodder lowered the intake of maize husk, but increased total dry-matter intake. It also resulted in significantly better digestibility. Goats supplemented with tree fodder gained more weight than those supplemented with urea. The average daily weight

gain was 4.9 g for maize husk plus urea, 28.7 g for maize husk plus leucaena, 18.5 g for maize husk plus calliandra and 22.6 g for maize husk plus calliandra and leucaena.

Guidelines for agroforestry experimentation

One aspect of ICRAF's strategic research programme on component interactions is concerned with the development of methods and tools for conducting agroforestry research and analysing results. Work in this area in 1991 focused on developing methods to handle the wide variability encountered when agroforestry research goes on farm.

Implications of spatial and temporal variability in agroforestry research

Knowledge of site variability is essential to design efficient field experiments. Guidelines based on long-standing experience or on the results of uniformity trials are not widely available for agroforestry or for on-farm experimentation. For this reason, ICRAF initiated a project in 1990 to help develop guidelines for on-farm experimentation in agroforestry.

The goals are to:

- Determine the spatial and temporal variation of crops and trees in farmer-managed systems
- Investigate the implications of this variation for on-farm agroforestry experimentation
- Identify factors that might indicate the scale of variability on farmers' fields for use in the design of on-farm field experiments.

The study was undertaken on 12 farms neighbouring ICRAF's Machakos Research Station. Here farmers grow maize and beans sequentially on fields averaging 0.29 ha. ICRAF researchers measured crop yields from small quadrats covering whole areas of the fields—initially 3.24 sq m and later increased to 12.96 sq m. They also analysed low-level aerial photographs taken twice in each growing season to capture growth variability.

Data from one farm have been analysed to determine the coefficients of variation for aggregation of quadrats into different plot sizes and shapes, as well as the variance structure of spatial data. In analysing coefficients of variation for plot sizes, blocks were kept as square as possible. Each contained four or five plots, which were either square or long and narrow. Long, narrow plots were orientated in two directions at 90° angles to each other.

The coefficients of variation for the long, narrow plots were about half of those for square plots (Figure 11). This trend was observed in two different seasons, even though the correlation between data sets for the two seasons was small. Coefficients of variation were similar for long, narrow plots at different orientations.

This analysis only gives results for particular blocks and plots. Modeling spatial variability by calculating semi-variance is a more useful approach because it supports plot design on fields of all shapes and also makes it possible to use data sets of unequal size and with missing values. These data were analysed by calculating the semi-variance, which describes the change in the variance of the difference between two data points as the distance between them increases.

Figure 12 shows variograms for maize yields on the same farm in three seasons. These variograms were similar for the three maize harvests. Although the correlations suggest that yields in the three seasons were spatially different, the variograms indicated that the structure of variation was similar.

Table 29. Chemical composition (% dry matter) of feed components fed to goats at Chipata, Zambia.

	Dry Matter	Crude Protein	Ash	Acid Detergent Fibre
Maize Husk	87	4	4	30
Leucaena leucocephala	28	25	11	23
Calliandra calothyrsus	33	24	8	46

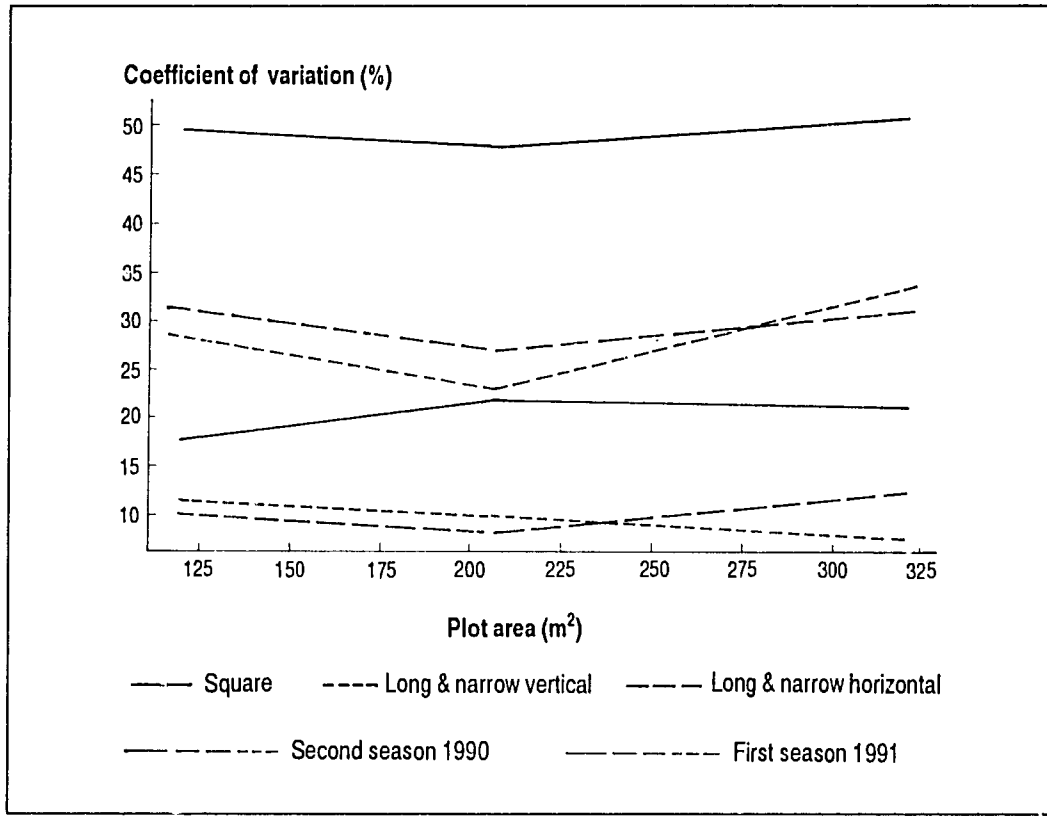


Figure 11. Coefficients of variation (%) of maize cob yield from two harvests on a farmer's field at Machakos, Kenya. Coefficients of variation were obtained for three plot sizes (117, 207 and 324 sq m) and three plot shapes (square, long and narrow vertical, and long and narrow horizontal).

Using the variograms, contour plots were produced for yields in the three seasons and residual variances were constructed for different plot and block sizes and shapes to judge the efficiency of different designs. The results revealed that long, thin plots provided better estimates of total yield on this field, as long as one dimension was less than the range, which was 5 quadrats.

For example, a plot of 7 quadrats square had a residual variance of 13, compared with a residual variation of 4 for a long, thin plot of the same area. Thus the long, thin plots were three times as efficient as the square plots.

Further analyses will include the costs associated with different designs to determine optimum plot size and shape. The data from the other farms will also be analysed. In October 1991, *Grevillea robusta* trees were planted on four of the farms at a spacing of 1 m. This will make it possible to compare the variance structure associated with maize and bean yields with variance associated with trees.

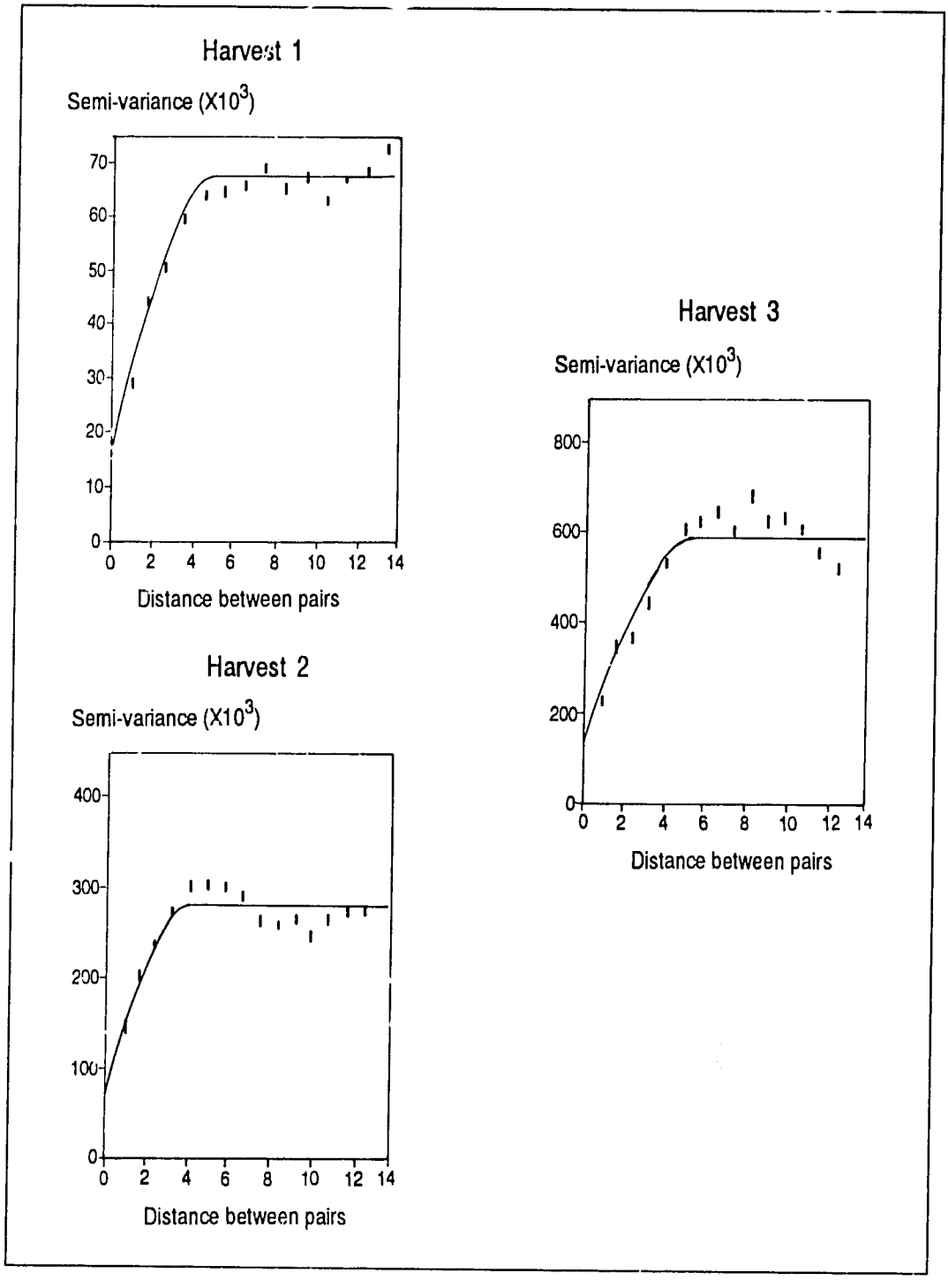


Figure 12. Variograms, depicting semi-variance against distance between pairs, for three maize harvests on a farmer's field at Machakos, Kenya, with models fitted to the data.

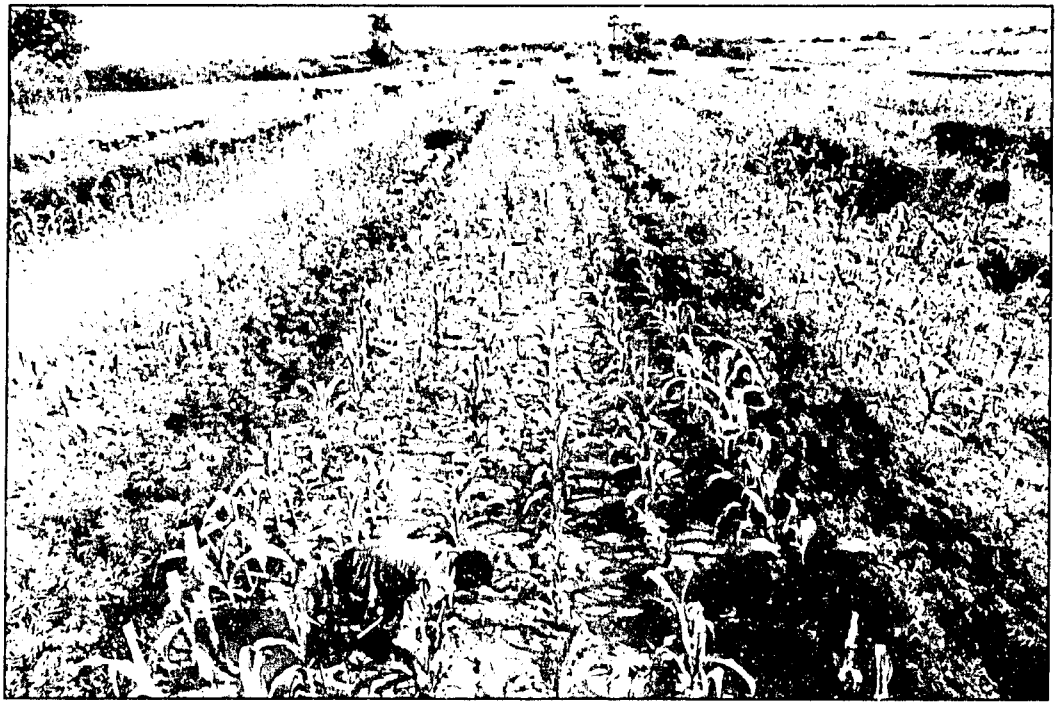


Photo: A. Njenga

Hedgerow-intercropping trial at the Chalimbana Agricultural Research Station in Zambia: several hedgerow species are being evaluated with maize interplanted in the alleys.

ICRAF's research programme on agroforestry systems focuses on traditional and innovative practices that have the potential to alleviate rural poverty while arresting the global threats of deforestation and land depletion. The selection of research areas is based on assessment of the problems and opportunities of land users in priority ecological zones. Current work addresses alternatives to slash-and-burn agriculture in the humid tropics and problems of land depletion in the subhumid and semi-arid tropics. This will be expanded to include studies on agroforestry for the reclamation of abandoned lands. Improved agroforestry systems are assessed in terms of biophysical, ecological and socio-economic impact and sustainability.

Multidisciplinary teams conduct long-term research at a range of sites across ICRAF's three priority agro-ecological zones—the humid, subhumid and semi-arid tropics. They are assessing agroforestry systems on station and on farm, including improved fallows, hedgerow intercropping, scattered trees in cropland, systems that provide tree by-products while helping to control soil erosion, fodder banks, and systems with upperstorey trees for wood production.

Improved fallows

In many parts of the humid and subhumid tropics, farmers traditionally fallow land to restore soil fertility. However, increasing pressure on land resources has resulted in shorter fallow periods and declining soil fertility.

Farmers may respond by clearing new land, often destroying natural forests. Alternatively, they may use expensive chemical fertilizers or accept lower levels of production. Managed fallows with leguminous trees and shrubs are another, promising, alternative. Well-selected

Photo: A. Njenga

A farmer near the Msekera Regional Research Station at Chipata, Zambia, is trying out an improved fallow of Sesbania sesban *on her farm.*

fallow species grow and make their contribution to soil fertility more quickly than natural vegetation. They may also provide valuable by-products such as poles and fuelwood.

Improved-fallow research in Africa's subhumid tropics focuses primarily on the indigenous nitrogen-fixing tree, *Sesbania sesban*. Management factors include fallow length, tree density and the timing of fallow establishment. In Southern Africa, studies include 'relay cropping' in which sesbania is interplanted with maize during the cropping season and allowed to grow on during the dry season after the maize is harvested.

Studies on improved fallows in the humid tropics include *Cajanus cajan* (pigeonpea), *Desmodium distortum* and *Crotalaria anagyroides*, among other species. Management factors include fallow length, timing and method of tree establishment, and treatment of fallow residues.

The effects of improved fallows are evaluated in terms of tree growth and biomass production, the productivity of crops, the impact on crop responses to fertilizer, and changes in soil-nutrient status. Table 30 shows the sites where improved-fallow systems were under evaluation in 1991. Results were obtained in the subhumid zone at Chipata (Zambia) and Makoka (Malawi) and in the humid zone at Yaoundé and Ebolowa (Cameroon).

Improved fallows for the subhumid tropics

ICRAF and collaborating scientists began an improved-fallow trial at Msekera Regional Research Station in eastern Zambia in December 1987. They grew *Sesbania sesban* at different densities for one, two or three years, felled the trees and planted maize with or without inorganic fertilizer.

The trial included two provenances of *Sesbania sesban* var. *nubica*—Kakamega from Kenya and Chipata from Zambia. This indigenous multipurpose tree was selected because of its adaptability to the climate and soil conditions of eastern Zambia, its fast growth and high biomass production, its ability to fix nitrogen, and its wide availability. Throughout the study, there were no important differences between the two sesbania provenances.

Tree seedlings were planted at three spacings—giving densities of 40,000, 20,400 and 10,000 trees/ha—on plots that had previously been under natural fallow. Three months after establishment, both provenances had grown up to 2 m in height with at least 40 branches. At six months, trees averaged 3.2 m tall with about 50 primary branches. Three years after establishment, height of the sesbanias averaged 5 m, root-collar diameter averaged 5.3 cm and stem diameter at breast height (130 cm above ground) averaged 3.0 cm.

Woody biomass production was similar at different spacings as stand mortality lessened the original differences in plant densities. Monthly litter fall ranged from 0.6 t/ha in June 1991, at the beginning of the dry season, to 0.01 t/ha at the end of the dry season in November, when the trees were almost leafless.

Weeds were effectively suppressed during the first year with complete canopy closure. However, as tree mortality increased in the second and third year, so did weed biomass.

Table 30. ICRAF's major improved-fallow trials in 1991.

Site	Year Initiated	Experimental Factors
Chipata, Zambia	1987	Fallow length, tree density, tree provenance
Yaoundé, Cameroon	1987	Tree species
Chalimbana, Zambia	1989	Fallow length
Yaoundé, Cameroon	1989	Tree species, fallow length
Ebolowa, Cameroon	1990	Fallow length, tree species
Yaoundé, Cameroon	1990	Residue management
Yaoundé, Cameroon	1990	Cropping systems
Makoka, Malawi	1991	Planting time, fertilizer level

Length of Fallow	Fertilizer Application (kg nitrogen/ha)	1987/88	— Cropping Season — 1988/89	1989/90	1990/91
None	0	grass	1.6	1.2	1.9
None	37	grass	3.9	3.2	2.9
None	74	grass	4.7	4.2	3.7
None	112	grass	6.1	4.9	4.3
One year	0	sesbania	2.3	3.8	4.4
One year	37	sesbania	3.8	4.6	5.4
One year	74	sesbania	5.4	5.1	6.4
One year	112	sesbania	6.7	6.0	6.7
Two years	0	sesbania	sesbania	5.0	5.6
Two years	37	sesbania	sesbania	6.3	6.8
Two years	74	sesbania	sesbania	6.3	6.8
Two years	112	sesbania	sesbania	7.2	7.9
Three years	0	sesbania	sesbania	sesbania	6.0
Three years	37	sesbania	sesbania	sesbania	7.0
Three years	74	sesbania	sesbania	sesbania	6.8
Three years	112	sesbania	sesbania	sesbania	7.4
SED					
Between fertilizer levels for same fallow period			0.17	0.27	0.38
Between fertilizer levels for different fallow periods			–	0.41	0.47
Between fallows and no-fallow treatment			0.52	0.83	1.18
Between successive years after one- and two-year fallows			0.28	0.39	

Table 31. Maize grain yields (t/ha dry wt) following Sesbania sesban *fallows of one, two and three years with different levels of fertilizer at Chipata, Zambia.*

When the trees were felled, the roots were left in the ground and all above-ground biomass was incorporated into the soil except the stems and primary branches, which farmers would normally use as fuelwood. As expected, production of woody biomass was low after a fallow of only one year, averaging about 10 t/ha dry wt. Production was highest after a three-year fallow at the densest spacing, averaging more than 20 t/ha.

Both wood and leaf production were low compared with results for sesbania elsewhere, most likely due to moisture stress at this site However, annual wood production was considerably higher than that of natural fallows in the region, estimated at 3 t/ha.

Subsequent maize crops were fertilized at rates of 0, 37, 74 or 112 kg N/ha. During the 1990/91 growing season, grain yields without fertilizer averaged 4.4, 5.6 and 6.0 t/ha (dry wt) from crops after one-, two- and three-year fallows (Table 31). During the same season, the average yield from control plots without fallows or fertilizer was 1.9 t/ha. Maize yields tended to be higher after fallows planted at higher densities, but differences between the two sesbania provenances were negligible.

Even with the addition of the full recommended rate of nitrogen fertilizer—at 112 kg/ha—maize grain yields on control plots declined steadily over three years of continuous cropping. Maize yields at this level of fertilization were substantially higher after a one-year fallow, and higher still after fallows of two or three years. At every level of fertilizer application, the positive effects of fallowing were still apparent in the second year of cropping after the fallow and even in the third. This long-term effect may be due to the slow decomposition of tree roots.

These results suggest that a sesbania fallow may increase maize grain yields from the crop

immediately following the fallow and even from the second and third crops planted one and two years later. Beneficial effects were observed at all levels of fertilizer application. As with natural fallows, longer fallow periods have a greater positive effect on subsequent crop yields. For fallows of the same length, the beneficial effect appears to be greatest when the trees are planted at the densest spacing.

Data on soil chemical and physical properties were collected throughout the experimental period. Information on soil nitrogen, organic-matter content and other factors will now be analysed and compared with data on tree and crop production.

The encouraging results from this experiment have led to further trials, both on station and on farmers' fields. Improved experimental techniques assure that comparisons between fallows of different lengths are not confounded with seasonal differences. Steps have also been taken to prevent possible interference between experimental plots, and controls of suitable crop rotations and natural fallows have been included.

The extension of experimentation to farmers' fields gives access to sites that have been under crops for many seasons. Differences in tree growth six months after planting underscore the importance of working closely with farmers to standardize field operations and of inoculating sesbania seedlings with the appropriate *Rhizobium* strain when introducing the species to new areas.

Relay cropping

The small size of landholdings in parts of Southern Africa precludes the widespread use of fallows and limits the introduction of agroforestry technologies in which trees occupy a high proportion of cropland. Given these constraints, ICRAF's collaborative programme at Makoka, Malawi, launched an experiment in December 1989 to test a relay-planting arrangement designed to maintain the full recommended population of maize plants while utilizing the soil-improving capability of the sesbanias.

Maize was planted on ridges at a spacing of 30 cm within rows and 75 cm between rows and sesbania seedlings were interplanted at four stages of maize growth—at sowing, at the time of rapid stem elongation, at tasselling, and at maturity. Two levels of fertilizer were applied—the full recommended amount for

Table 32. First- and second-rotation maize yields under relay cropping with Sesbania sesban *plus different fertilizer levels, Makoka, Malawi.*

Time of Tree Planting	Fertilizer[a] Applied	Grain Yield in 1990 (t/ha)	Woody Biomass Removed in 1990 (t/ha)	Green Manure Applied in 1990 (t/ha)	Grain Yield in 1991 (t/ha)
At maize planting	0	0.68	4.0	2.44	2.15
	50	2.69	5.6	2.99	6.04
	100	2.86	5.1	2.62	7.42
At node formation	0	1.08	0.7	0.85	1.80
	50	3.78	1.0	0.85	5.86
	100	3.53	0.5	0.61	7.31
At tasselling	0	0.87	0.3	0.30	1.62
	50	3.27	0.1	0.16	5.60
	100	3.60	0.5	0.32	7.13
Control (no trees)	0	0.88	—	—	1.56
	50	3.25	—	—	5.39
	100	3.33	—	—	7.72
SED		0.43			0.26

[a]As a percentage of the recommended rate.

Malawi (14 kg N/ha and 10 kg P/ha, plus 42 kg N/ha as top dressing) or 50% of this amount—or none.

After harvesting the maize, the sesbanias were allowed to grow until the end of the dry season. Then they were harvested and the leaves, flowers, pods, twigs and small branches were incorporated into the soil. Maize was replanted in December 1990.

Both tree growth and crop yield were poor in the first year due to below-average rainfall. Maize yields were only slightly reduced on plots where maize and sesbania were planted at the same time, but sesbania growth was poor on plots where the trees were planted late in the growing season (Table 32).

In 1991, the maize crop benefited from the sesbania mulch applied at the end of the previous season. Maize grain yields on all plots with sesbania were slightly higher than on control plots without trees but with the same levels of fertilizer. Woody biomass production from the first rotation of trees ranged from 0.1 to 5.6 t/ha (dry wt). As in the previous year, results from 1991 suggest that it may be possible, at a minimum, to produce fuelwood from sesbanias under this arrangement without reducing maize yields. The experiment is continuing in order to observe performance over a longer period.

Improved fallows for the humid tropics

Low soil fertility is an important constraint on food-crop production in much of the humid tropics. The humid lowlands of Cameroon are no exception. Here, farmers have traditionally maintained soil fertility by shifting cultivation, allowing fields to lie fallow under natural vegetation for periods of more than 10 years. As pressure on land has increased and fallow periods have become shorter, inherently low soil-fertility levels are declining even further. Improved fallows with nitrogen-fixing trees might accelerate the restoration of soil fertility, allowing shorter fallow periods without further impoverishing the soil. Research in Cameroon has focused on identifying potentially suitable species for improved fallows in the region and on devising appropriate management practises.

There are two growing seasons a year. Farmers begin the cropping cycle by clearing small plots, often of less than 0.5 ha, burning the residues and planting an indigenous vine—*ngon* (a member of the Cucurbitaceae)—which is an important food crop and which also plays a role in the decomposition of fallow residues. In the next season, they plant cassava, cocoyam, maize, groundnut, plantain, banana, sugarcane and vegetables, all mixed together. Seasonal crops are harvested as they mature and longer-duration crops, such as cassava, remain in the fields. Starting about one year after planting, cassava roots are harvested as needed, with the plot thus serving as a storage facility.

Since no other cultivation takes place, the land begins to revert to natural fallow, with the weed *Chromolaena odorata* frequently appearing as the first colonizer. The decision to bring the plot back into cultivation depends on the availability of land and labour—the fallow period may vary from 3 to 15 years.

One problem with the introduction of improved fallows in this situation is the absence of a clear demarcation between the end of the cropping cycle and the beginning of the fallow period. Another problem is the practice of planting seven or more crops with widely different growth patterns on the same plot, and not in any defined arrangement. When do you introduce the fallow species, and where?

At current high densities of cropping, it is difficult to introduce multipurpose trees during the growing season without negative effects on crop production. However, keeping fields free

Table 33. Maize grain yields after two-year improved fallows in Yaoundé, Cameroon.

Fallow Species	Maize Grain Yield (t/ha)
Cajanus cajan	5.1
Pueraria sp.	5.1
Pueraria sp. plus *Mucuna utilis*	4.8
Crotalaria anagyroides	4.7
Cajanus, Crotalaria plus two *Desmodium* spp.	4.7
Desmodium discolor	4.2
Desmodium distortum	4.2
Natural fallow	3.3
SED	0.5

Fallow Residue Management	Maize Yield (t/ha dry weight)	Groundnut Yield (t/ha dry weight)
Residue burned	1.4	0.98
Residue applied as mulch	1.7	0.35
Residue incorporated as green manure	2.3	0.55
Residue removed	1.2	0.20
SED	0.2	0.04

Table 34. Maize and groundnut grain yields in response to management of fallow residues, Yaoundé, Cameroon.

of weeds is extremely labour intensive and farmers are not likely to clear land at other times of year just for fallow species that do not provide any direct products.

ICRAF researchers began a trial in 1989 to evaluate the effects of one-, two- and three-year fallows with six leguminous species singly and in various combinations. These were the shrubs *Cajanus cajan*, *Crotalaria anagyroides*, *Desmodium discolor* and *Desmodium distortum* and the herbaceous legumes *Mucuna utilis* and *Pueraria* sp. Results were compared with those from a natural fallow that established itself on the trial site, previously used for pineapple production.

The pueraria and the natural fallow gave the highest yields of leafy biomass one and two years after planting. Total biomass, including the woody component, was highest for crotalaria and desmodium after the first year and for pigeonpea and a mixture of the four shrub species after the second. These measurements do not include litter fall.

After the fallows, all woody biomass was removed and all leafy biomass was incorporated into the soil. Maize and groundnut interplanted after a one-year planted fallow gave considerably higher yields than the same crop mixture after a natural fallow, but differences between fallow species were not significant. Sole maize planted after two-year improved fallows was also much more productive than maize yields after a natural fallow of the same duration (Table 33). The highest grain yields were associated with pueraria, pigeonpea, pueraria plus mucuna, and pigeonpea plus crotalaria plus the two desmodium species.

Traditionally, fallow residues are either burned or removed during land preparation. Another study at Yaoundé compared four approaches for managing pigeonpea fallow residues: burning, incorporating fallow material into the soil (green manuring), mulching or removing the residues.

Maize yields were highest with green manuring, while groundnut yields were highest when residues were burnt (Table 34). This can be explained by the fact that maize demands high nitrogen levels, made available by incorporating green manure but lost by burning. By contrast, groundnut is nitrogen fixing but benefits from the minerals made available by burning.

Another experiment was initiated in 1990 to compare different options for the introduction of multipurpose-tree fallows into the cropping cycle. These are:

- Maize, cassava and pigeonpea are all planted at the beginning of the first cropping season. Maize is harvested after one season, while cassava and pigeonpea remain through the second season. At the end of the year, the cassava is harvested, the pigeonpea is cut back and prunings applied as mulch, and the cycle begins again.
- Maize and cassava are planted at the beginning of the first cropping season. After one season the maize is harvested, the cassava is pruned, and pigeonpea is planted. At the end of the year, the cassava is harvested, the pigeonpea is cut back and prunings applied as mulch, and the cycle begins again.
- Pigeonpea is grown in pure stand for one year, cut back, the prunings applied as mulch, and

maize is grown with cassava the following year. The two years are repeated in rotation, resulting in a one-year fallow system.

These alternatives are compared with the traditional cycle of maize and cassava intercropping. On some control plots, the cassava is pruned at the end of the first cropping season, while on others it is not.

Pigeonpea interplanted with maize and cassava produced 17.5 t/ha (dry wt) of leafy biomass, while pigeonpea planted after the maize harvest produced 16.6 t/ha. As expected, the highest leafy biomass production (30.2 t/ha) was from sole pigeonpea planted as a one-year fallow.

In the first year, the best cassava tuber yields were obtained under the traditional system, without pruning or introducing pigeonpea (Table 35). In fact, pruning reduced cassava tuber yields by more than 30%. The introduction of the competitive, fast-growing shrubs at the beginning of the cropping cycle reduced cassava yields by nearly 75% and suppressed nearly all the maize. In the following season, maize grain yields responded favourably to pigeonpea, either interplanted or as a one-year fallow.

Hedgerow intercropping

Hedgerow intercropping, also known as alley farming, has long been proposed as an agroforestry system that can contribute to soil fertility under appropriate site conditions and with high management and labour inputs. ICRAF's hedgerow-intercropping work concentrates in the subhumid tropics of Eastern and Southern Africa and in the humid region of West Africa, as shown in Table 36.

Research focuses on the evaluation of alternative hedgerow species and provenances, on hedgerow management, and on the impact of hedgerows on the intercrop, usually maize. The effects of hedgerow intercropping are evaluated in terms of hedge biomass production, changes in soil-nutrient status, the performance of the intercrop, and the impact on subsequent crop responses to fertilizer.

The principal species under evaluation are *Leucaena leucocephala*, *Calliandra calothyrsus*, *Gliricidia sepium*, *Cassia siamea*, *Flemingia congesta*, *Sesbania sesban* and *Cajanus cajan*. Different provenances of gliricidia, sesbania, cassia and leucaena are also being compared.

Management factors include tree establishment techniques, spacing between hedgerows, plant spacing within hedgerows, the timing and frequency of pruning, and the timing and method of mulch application to crops. Some studies also involve a livestock component: the direct use of hedgerow prunings as mulch is compared with the impact of feeding prunings to goats or dairy cattle and returning the manure to the intercrop.

Table 35. Cassava tuber yields and maize grain yields in the first and second year of intercropping with pigeonpea, Yaoundé, Cameroon.

Planting Pattern	Maize Yield in 1990 (t/ha)	Cassava Yield in 1990 (t/ha)	Maize Yield in 1991 (t/ha)
Maize, cassava and pigeonpea planted in first season	0.83	2.6	1.02
Maize and cassava planted in first season, pigeonpea in second	0.97	6.5	1.50
Sole pigeonpea in first year, maize and cassava in second	—	—	1.85
Maize and unpruned cassava	1.16	10.2	0.75
Maize and pruned cassava	0.91	7.1	0.80
SED	0.05	0.8	0.08

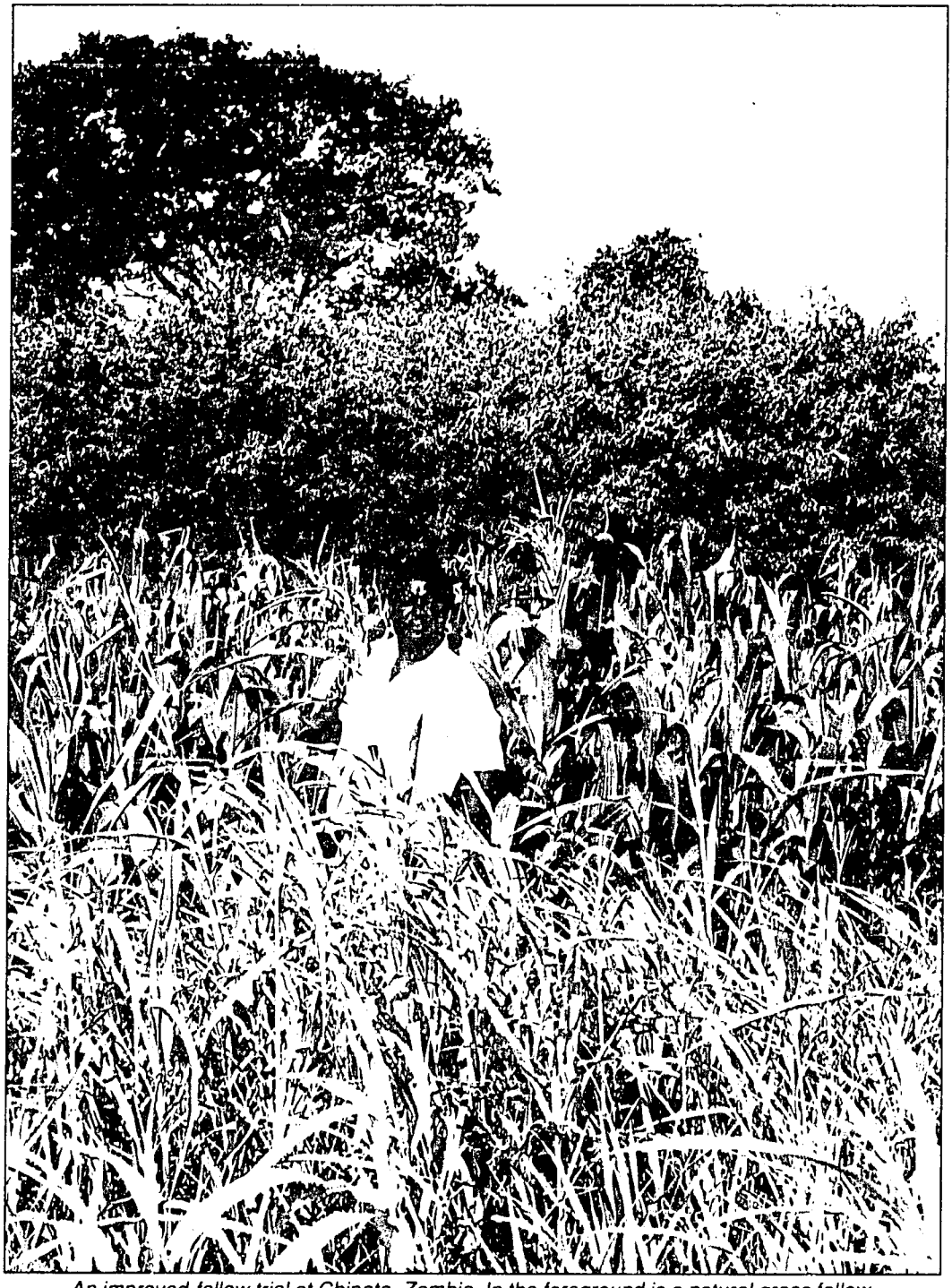


Photo: A. Njenga

An improved-fallow trial at Chipata, Zambia. In the foreground is a natural grass fallow. Behind it is a maize plot previously under an improved fallow, and at the back is an improved fallow of one-year-old Sesbania sesban.

Site	Year Initiated	Experimental Factors
Chalimbana, Zambia	1987	Tree species, fertilizer level, tree management
Tabora, Tanzania	1987	Tree management, cropping systems
Yaoundé, Cameroon	1987	Tree species
Maseno, Kenya	1988	Tree species
Maseno, Kenya	1988	Cropping systems, fertilizer level
Maseno, Kenya	1988	Hedge architecture
Rwerere, Rwanda	1988	Tree species
Mashitsi, Burundi	1988	Tree species
Mashitsi, Burundi	1988	Cropping systems, fertilizer level
Chipata, Zambia	1988	Tree species, tree management, fertilizer level
Yaoundé, Cameroon	1988	Tree species, fertilizer level
Ebolowa, Cameroon	1988	Tree species, tree management
Machakos, Kenya	1989	Systems comparison
Chalimbana, Zambia	1989	Hedge architecture, mulch management
Makoka, Malawi	1990	Tree species
Domboshawa, Zimbabwe	1990	Mulch management
Makoholi, Zimbabwe	1990	Mulch management
Cinzana, Mali	1991	Tree species, fertilizer level
Nioro, Senegal	1991	Tree species

Table 36. ICRAF's major hedgerow-intercropping trials in 1991.

Hedgerow-intercropping research in West Africa concentrates on *Leucaena leucocephala*, *Gliricidia sepium*, *Calliandra calothyrsus* and *Acacia auriculiformis*. In addition to standard hedgerow-intercropping systems, one experiment in Cameroon assesses a rotational system in which hedgerows are intercropped with maize or groundnut for two years and left as fallow for two years. During the fallow period, sheep are allowed to browse the hedgerows and their manure is returned to the plot.

If hedgerow intercropping is to contribute substantially to soil fertility, it requires large biomass production from hedgerows. In dry areas, this leads inevitably to competition between hedges and crops for water. Thus, hedgerow intercropping is unlikely to be widely successful in arid or semi-arid environments. However, a few trials have been initiated in West Africa's semi-arid zone. This are in progress at early stages at sites of relatively high rainfall in Mali and Senegal.

Hedgerow-intercropping trials in the semi-arid tropics include *Leucaena leucocephala*, *Gliricidia sepium*, *Cassia siamea*, *Albizia lebbeck* and *Moringa oleifera*. The intercrop in this region is millet.

Results from on-station and on-farm hedgerow-intercropping trials at Chipata and Machakos are reported here.

Hedgerow intercropping in the subhumid zone

Results are now available from three years of hedgerow intercropping at Chipata combining maize with *Flemingia congesta*, *Cassia siamea* or *Leucaena leucocephala*.

The hedgerows were cut twice a year, at the beginning and end of the growing season, and all prunings were applied to the maize grown in the alleys. Two cutting heights were tested: 50 and 100 cm. Fertilizer was applied to half the plots at the full recommended rate of 112 kg N/ha.

The cassia hedgerows consistently produced the most biomass, but there were no significant differences in maize yields among hedgerow species or cutting heights. Maize grain yields are presented in Table 37 as averages for the two cutting heights. These show no clear trends over the three-year period. In general, there was little difference in yields between hedgerow systems and controls apart from a consistent and substantial response to fertilizer application.

Hedgerow Species	Nitrogen Fertilizer (kg/ha)	Maize Grain Yields (t/ha) 1989	1990	1991
Leucaena leucocephala	0	2.5	2.0	2.0
	112	5.9	4.7	5.3
Cassia siamea	0	1.6	2.5	2.7
	112	5.0	5.6	5.5
Flemingia congesta	0	2.1	2.2	1.5
	112	6.5	5.3	5.1
Control (no hedgerow)	0	2.8	2.4	1.9
	112	6.6	5.3	6.4
SED		0.30	0.42	0.64
Rainfall (mm)		1130	795	707

Table 37. Maize grain yields over three seasons from a hedgerow-intercropping trial with three tree species and two levels of nitrogen fertilizer, Chipata, Zambia. Yields are averages of plots in which hedgerows were cut at 50 and 100 cm above ground.

The strong response to nitrogen in fertilizer—but not to nitrogen in mulch—suggests the importance of competition between hedgerows and crops for water. This is further illustrated by comparison of yields from crop rows next to the hedgerows and in the middle of the alleys. For all tree species and cutting heights, yields were severely depressed in maize rows next to the hedgerows.

In 1991, yields from the maize rows next to flemingia hedgerows were 23% to 44% of yields from rows in the middle of the alleys. The comparable range for maize yields next to leucaena hedgerows was 52% to 58%, and for maize next to cassia it was 82% to 87%. The differences in maize yields that appear to be developing between hedgerow species require monitoring over time. These results underline the need for long-term studies on nutrient dynamics and tree/crop interactions in such systems.

The potential of hedgerow intercropping for sustained production has been demonstrated in the humid and subhumid tropics, but its potential in the semi-arid tropics is not well established. In this environment, the tree component may compete with annual crops for soil moisture, causing substantial reductions in crop yields. However, contour-aligned hedgerows on sloping land may reduce runoff and soil erosion, indirectly contributing to soil moisture and fertility.

In addition, the establishment and maintenance of hedgerows is labour intensive and it is important to assess whether hedgerow intercropping is feasible and cost effective for a farm household. A system that produces hedgerow prunings for livestock fodder may be more attractive to farmers than a system in which prunings are returned to the soil.

A trial was initiated at ICRAF's Machakos Research Station in 1989 to test four land-use systems on plots of 300 to 500 sq m—large enough to allow the evaluation of labour requirements and economic impact. The station is at the dry edge of Kenya's subhumid zone, approaching semi-arid conditions. The systems tested are based on hedgerow intercropping with *Leucaena leucocephala*. These are compared with systems based on annual crops only, with and without moderate levels of fertilizer (40 kg N/ha and 17 kg P/ha per season). In one of the hedgerow-intercropping systems, the prunings are incorporated into the soil or used as mulch for soil-fertility improvement, and in the other they are fed to oxen, along with crop residues, and the manure is returned to the soil.

Researchers planted a bean crop between the hedgerows during the first season, from November 1989 to March 1990, to minimize competition with the young tree seedlings. Since then, three maize, crops have been grown—from April to July 1990, from October 1990 to February 1991, and from April to July 1991.

The hedgerows were pruned twice during the 1990–1991 growing season and three times during the season from April to July 1991. On the plots testing hedgerow intercropping with green manuring and mulching, an average of 0.94 t/ha (dry wt) of tree leaf biomass was applied to the maize crop during the first season and 1.58 t/ha during the second. On the plots testing hedgerow intercropping with manuring, an average of 1.74 t/ha (dry wt) of manure was applied to the maize crop during the first season and 1.50 t/ha during the second.

Yields from the first bean crop were uniform across all four treatments, suggesting that an 11% area lost to leucaena did not reduce yields significantly at the early stage of hedgerow establishment. In the next season, rainfall was above average (620 mm compared with a normal level of 350 mm) and the young hedgerows were allowed to grow on without pruning. Maize yields in the two hedgerow-intercropping systems were similar, and both were significantly lower than yields from sole maize (Table 38). This was undoubtedly due to competition for water and light from the leucaena, which had grown more than 2 m by the end of the season. The fertilized maize yielded 31% higher than the unfertilized crop, indicating a good response to increased soil nutrients in a season of above-normal rainfall.

Rainfall in the two subsequent seasons was less than normal. Under conditions of moisture stress, the maize crops showed signs of severe competition for water from the well-established leucaena hedgerows—yields were 30% to 45% lower than in sole cropping.

These results show clearly that competition for water outweighed any benefits of nutrients added through leucaena leaf biomass or manure. On sole maize plots the response to fertilizer was also limited, confirming that moisture was the factor limiting crop growth during these two seasons.

Long-term evaluation will include the extra labour required to manage a hedgerow-intercropping system and the economic value of extra outputs, such as wood, fodder and the resulting draught power from oxen. Information is also being collected on weed populations and long-term changes in soil nutrient status.

Scattered trees in cropland

Multipurpose trees left to grow freely in cropland offer some protection from sun and wind and add plant nutrients to the soil through natural litter fall. Such a system is less labour intensive than hedgerow intercropping and does not take land out of production during a fallow period. Surveys of traditional systems in the subhumid zone of Southern Africa focus on tree spacing, management practices and the use of tree products.

Researchers at Chipata are also investigating improvements on the traditional system. Work focuses on *Faidherbia albida* and *Gliricidia sepium* scattered in cropland where maize and

Table 38. Biomass production from Leucaena leucocephala *hedgerows and maize grain yields at Machakos, Kenya.*

	Hedge Biomass (t/ha)		Maize Grain (t/ha)		
	Oct 1990-Feb 1991	Apr-Jul 1991	Apr-Jul 1990	Oct 1990-Feb 1991	Apr-Jul 1991
Hedgerow intercropping + mulch	0.94	1.58	1.73	1.66	0.92
Hedgerow intercropping + manure	0.96	1.51	1.64	1.39	0.87
Sole maize no fertilizer	—	—	2.58	1.90	1.40
Sole maize + fertilizer (40 kg N + 17 kg P/ha)	—	—	3.39	2.48	1.89
SED	0.119	0.149	0.120	0.184	0.156
Rainfall (mm)			620	333	214

beans are grown in rotation. Tree growth and productivity are monitored, including the production of fodder and fuelwood from side branches that are lopped. Leaf fall is analysed to determine the amount and nutrient content of organic material added to the soil.

In one experiment initiated at the end of 1988, researchers planted faidherbia seedlings at spacings ranging from 2 x 2 to 5 x 5 m. During the 1991 cropping season, maize was interplanted under the three-year-old trees with nitrogen and phosphorus fertilizer applied at the full recommended rate.

The trees, which averaged 2.5 m in height, had a negative effect on maize yields. This was most pronounced at higher tree densities (Table 39). The experiment will be continued in 1992, but fertilizer application will be discontinued.

Similar studies have recently been initiated at Saria and Gonsé, two semi-arid sites in Burkina Faso. Here, researchers are evaluating *Faidherbia albida*, *Prosopis africana* and *Albizia lebbeck* growing in millet fields at different densities.

Tree Spacing	Tree Density (trees/ha)	Maize Grain Yields (t/ha)
2 x 2 m	2500	3.68
3 x 3 m	1111	4.05
4 x 4 m	625	4.26
5 x 5 m	400	4.48
Control	0	5.50
SED		0.36

Table 39. Maize grain yields under three-year-old Faidherbia albida *planted at different densities at Chipata, Zambia.*

Fodder production in erosion-control systems

One clear sign of population pressure in rural areas of the tropics is the increased cultivation of sloping land. The result is frequently soil erosion. Agroforestry can help control soil erosion in two ways. Trees may be added as a supplement to conventional erosion-control structures—such as banks, ditches, contour grass strips or terraces—to add stability and to make more productive use of the land. When planted densely in home gardens or in strips along contours, trees can also help control soil erosion on their own.

ICRAF researchers are studying the role of multipurpose trees planted on contour bunds or grass strips at four sites in Eastern and Central Africa (Table 40). Related studies at ICRAF's Machakos Research Station are reported under Programme Three. In addition to erosion control, fodder production is a major function of contour planting at many sites. In some cases, different types of tree are added to increase the overall productivity of the planting, such as *Grevillea robusta* for poles and fuelwood or *Carica papaya* and other fruit species.

Several grass species are being evaluated on contour strips. These include *Pennisetum purpureum*, *Tripsacum laxum*, *Setaria sphacelata* var. *splendida* and *Andropogon gayanus*. In addition to monitoring the overall productivity of tree/grass combinations, trials also focus on the impact of contour plantings on adjacent crops.

Matching fodder production with nutritional requirements

Farmers in the highlands of Rwanda frequently plant contour strips on sloping fields to provide livestock fodder and to prevent soil erosion. Traditionally they plant double rows of one of the fodder grasses *Pennisetum purpureum* or *Setaria sphacelata* var. *splendida*. ICRAF and national colleagues started a trial in 1988 at Rwerere to compare *Calliandra calothyrsus* and *Sesbania sesban* planted on contour bunds in various combinations with the two grass species. The objectives were to determine the fodder yields of the grass and multipurpose trees and to assess the effect of different combinations on adjacent wheat and bean crops.

The trial was established on a hillside facing north at a slope of 45%. Plots consisted of two rows planted along the contour 50 cm apart, with trees and grass spaced within rows at 25-cm intervals and crops on either side. One species was planted in both rows or one row of trees was combined with one row of grass. At least 5 m was left between plots. Beginning six months

after planting, the trees and grass were cut regularly—averaging three times a year—and total biomass and protein content assessed.

Survival rates for the calliandra were excellent, with more than 90% of the trees growing well in April 1991, three years after establishment. As in other trials at Maseno, Kenya, the sesbania was initially twice as productive as the calliandra, but this species began dying about two years after establishment. By April 1991, virtually all the sesbania were dead, casting doubt on the suitability of the species for this agroforestry technology.

Table 41 shows the biomass and crude protein production obtained from cuttings over the three-year period. The greatest biomass was obtained from double rows of pennisetum, followed by pennisetum combined with sesbania or calliandra. Double rows of setaria were also slightly more productive than single rows of this species combined with trees.

The interaction between trees and grass was evaluated by calculating the land-equivalent ratio (LER). This is the length of bund planted to separate stands of pure trees and pure grass that would be required to produce the same biomass as 1 m of the mixture. In each case, the LER was greater than 1, indicating positive interactions between the trees and grass.

Because biomass from contour strips is used primarily as livestock fodder, the percentage of crude protein is an important indication of productivity. Leafy biomass from the two tree species was considerably higher in crude protein than biomass from the grasses. For calliandra, crude protein averaged 23% of biomass (dry wt), while for sesbania the average was 18%. For setaria and pennisetum, the averages were well under 16%. For both tree species, crude protein content was not altered by the presence of grass.

The first bean crop was harvested from 7 x 4-m plots on either side of the contour strips 10 months after the trees were planted. Six months later, the first wheat crop was harvested. A second wheat crop was harvested 22 months after planting the trees, and a second bean crop was harvested six months later. Overall, the best harvests were recorded in association with calliandra and setaria, either together or separately in pure stands. Sesbania and pennisetum, with their higher biomass production, tended to have a stronger inhibitory effect on adjacent crop production.

ISAR has estimated the dry-matter and crude-protein requirements of the two main types of cattle kept in the Rwerere area—the local Ankole and improved crossbreds of Ankole with Jersey or Sahiwal. For the Ankole, with relatively high dry-matter and low protein requirements, double rows of pennisetum appear to provide the best fodder. About 398 m of contour strip under pennisetum would support one animal. An improved crossbred, producing 8 litres or more of milk a day, requires a higher proportion of crude protein. The pennisetum and calliandra mixture has a higher protein content than needed, so the requirements of the cow are best met with some of this mixture plus some pure pennisetum.

However, other systems come to the fore when the crop losses associated with different tree and grass combinations are taken into account. With the local breed, the best system would be double rows of setaria. With improved cattle, a combination of double rows of setaria

Table 40. ICRAF's major experiments on fodder production from contour bunds in 1991.

Site	Year Established	Experimental Factors
Maseno, Kenya	1988	Tree species, with and without grass
Rwerere, Rwanda	1988	Tree species, grass species
Karuzi, Burundi	1988	Establishment
Karuzi, Burundi	1989	Tree species, grass species
Kachwekano, Uganda	1989	Tree and grass mixtures
Maseno, Kenya	1990	Tree management, with and without grass

Species Combination	Biomass (kg/m dry wt)	Land-Equivalent Ratio (LER)	Crude Protein (%)	Bean Production (kg/plot dry wt)	Wheat Production (kg/plot dry wt)
Pennisetum + pennisetum	17.3	—	7	1.4	1.1
Setaria + setaria	5.2	—	8	1.8	3.0
Calliandra + calliandra	3.6	—	23	1.6	2.5
Sesbania + sesbania	3.1	—	18	0.7	1.9
Sesbania + pennisetum	10.2	1.26	9	0.8	1.6
Calliandra + pennisetum	9.9	1.10	11	1.4	1.8
Sesbania + setaria	5.8	1.41	12	1.1	2.1
Calliandra + setaria	5.7	1.30	15	1.6	2.8

Table 41 Total biomass, land-equivalent ratio, crude protein and production of associated crops over 36 months with tree and grass species planted in double rows on contour bunds at Rwerere, Rwanda. The plot size was 28 m sq.

plus single rows of calliandra with setaria would be best.

These results demonstrate an inverse relationship between biomass production of tree/grass strips on contour bunds and the productivity of adjacent crops. A similar pattern was reported in 1990 at Maseno. Clearly, the best selection of tree and grass species in any situation depends on the relative importance of crop and fodder production and on the nutritional requirements of the livestock.

Planting sequence and spacing

A parallel trial was established in 1988 at Karuzi, Burundi, comparing the survival and growth of calliandra and pennisetum planted together in different sequences and at different spacings. Beginning in late 1988, the trees were planted three months before the grass, three months after the grass or at the same time. Early planting, without competition from the grass, gave the trees a head start, but the effect was not lasting. Leafy biomass yields were highest from trees planted before grass in 1989 and 1990, but not in 1991. In all three years, biomass yields were slightly lower for trees planted after the grass.

Pennisetum planted three months before the trees had the highest biomass yields in 1989, but by 1990 and 1991 differences in grass yields were not significant. Combined yields of trees and grass were not affected by the time of planting. Based on these findings, researchers conducting further experiments have planted calliandra and pennisetum at the same time.

In the same experiment, calliandra was also planted at three different spacings—25, 50 and 100 cm. Tree survival rates have generally been high, but somewhat lower for those planted at 25 cm. By 1991, mortality among trees planted at this spacing was 17%, compared to 7% for trees at the other spacings. However, total production of leafy biomass was higher for trees planted at intervals of 25 and 50 cm than at 100 cm.

Grass production was not significantly affected by the spacing of the trees until 1991, when the trees were larger and grass yields were highest with trees at the widest spacing. Total biomass production from trees and crops has not been influenced by tree spacing but, over time, the proportion of tree biomass has increased.

Yields of maize and bean crops planted adjacent to the contour bunds have not been affected by the timing of grass and tree planting or the spacing of the trees. As in other trials, crop yields were lowest from rows next to the bunds.

Cutting heights

Researchers established an experiment at Maseno in 1990 examining the effect of cutting height on *Calliandra calothyrsus* and *Pennisetum purpureum* grown in double rows on contours. The trees were spaced at 25 cm intervals within rows, with 50 cm between rows. Trees and grass were cut together every two

Species	Tree Cutting Height	Biomass (kg/m dry wt) Grass	Trees	Land-Equivalent Ratio (LER)
Pennisetum + pennisetum	—	4.4	—	—
Calliandra + calliandra	10 cm	—	4.1	—
	50 cm	—	4.2	—
	130 cm	—	4.5	—
Pennisetum + calliandra	10 cm	3.9	2.0	1.37
	50 cm	2.7	2.2	1.17
	130 cm	1.9	2.6	1.01

Table 42. Leafy biomass (kg/m) from four cuttings of Calliandra calothyrsus *and* Pennisetum purpureum *planted in double rows on contour strips alone and in combination, Maseno, Kenya.*

months. The trees were cut at 10, 50 and 130 cm above ground, while the grass was cut at ground level. Table 42 shows fresh leafy biomass production from four cuttings in 1991.

As at Rwerere, there was a positive interaction between the trees and the grass. Each species generally produced more from a single row combined with a row of the other species than from a single row combined with another row of the same species.

As would be expected, this general observation was strongly influenced by the height at which the trees were cut. Increasing the cutting height of the calliandra favoured the growth of the trees at the expense of the grass, while reducing the cutting height increased biomass production from the grass but reduced production from the trees. The LER, measuring the extent of interaction, was most positive at the lowest cutting height.

Fodder banks

In many areas of the subhumid and semi-arid tropics, livestock production is seriously constrained by the limited amount and poor quality of animal fodder during the dry season. Draught animals are often particularly weak at the end of the dry season when they are required for ploughing. In these regions, fodder banks of high-quality feed can play an important role in supplementing crop residues and other sources of dry-season grazing.

Table 43. Biomass production from six months' coppice regrowth of Leucaena leucocephala *fodder banks at Chipata, Zambia.*

Spacing	Cutting Height	Biomass Production (t/ha dry wt) Foliage	Wood
0.5 x 0.5 m	50 cm	1.00	2.54
	100 cm	1.50	1.96
1.0 x 1.0 m	50 cm	0.67	1.46
	100 cm	1.24	1.76
2.0 x 2.0 m	50 cm	0.66	1.02
	100 cm	0.84	1.46
SED		0.26	0.50

Site	Year Initiated	Experimental Factors
Kabanyolo, Uganda	1988	Tree species
Kabanyolo, Uganda	1989	Tree species
Kachwekano, Uganda	1989	Tree species
Kabanyolo, Uganda	1989	Management of upperstorey/understorey combinations
Kachwekano, Uganda	1989	Management of upperstorey/understorey combinations
Kachwekano, Uganda	1990	Tree species
Bushenyi, Uganda	1990	Tree species
Namulonge, Uganda	1990	Tree species
Kalengyere, Uganda	1990	Tree species
Kabanyolo, Uganda	1990	Management of upperstorey trees in banana plots
Mashitsi Burundi	1990	Tree species in banana plots
Mashitsi, Burundi	1990	Management of upperstorey trees in banana plots

Table 44. ICRAF's major upperstorey-tree studies in 1991.

ICRAF is assessing the potential of fodder banks in the subhumid tropics at Chipata, Tabora (Tanzania) and Mashitsi (Burundi), and in the semi-arid tropics of West Africa. In the subhumid zone, the principal multipurpose-tree species under evaluation are *Calliandra calothyrsus*, *Leucaena leucocephala*, *Leucaena diversifolia*, *Sesbania sesban*, *Gliricidia sepium* and *Cajanus cajan*. Fodder banks consist of trees alone or in combination with grasses such as *Pennisetum purpureum*, *Andropogon gayanus* and *Tripsacum laxum*.

Management factors include timing and method of establishing trees and grass, spacing, and the timing and height of cutting. Fodder quality is evaluated by laboratory analysis and by assessing the milk production of dairy cattle and liveweight gain of goats with supplementation. Studies of traditional fodder production and conservation systems will also be initiated.

In the semi-arid tropics of West Africa, similar studies are in progress at Faya, Mali. Here work concentrates on *Pterocarpus erinaceus*, *Pterocarpus lucens*, *Leucaena leucocephala* and *Gliricidia sepium*.

Researchers at Chipata established fodder banks of *Leucaena leucocephala* in December 1988. The trees are spaced at 2.0 x 2.0, 1.0 x 1.0 and 0.5 x 0.5 m on plots of 10 x 10 m. They were first harvested in January 1990 by cutting at heights of 50 and 100 cm. They were cut again in January and June 1991, and the coppice regrowth was measured for the six-month period.

Since the beginning of the experiment, individual trees have survived and grown best at the widest spacing, as expected, but trees planted at the closest spacing produced the most total leafy and woody biomass per unit of land (Table 43). Productivity will be monitored for at least two more years, with emphasis on leafy biomass produced during the dry season when shortages of livestock fodder are most acute.

Upperstorey trees on field bunds and boundaries

Many cropping systems of the tropics could potentially be diversified by the introduction of upperstorey trees as sources of timber, poles, fuelwood and fodder. Upperstorey trees may help prevent soil erosion and protect adjacent crops from wind or sun. On the other hand, they may compete for light, water and soil nutrients. Maximizing the benefits, while minimizing competition, requires careful selection of tree species, spacing and management.

Studies on upperstorey trees are in progress at subhumid sites in Uganda and Burundi (Table 44). In Uganda, 24 species are being screened at five sites. Related trials at two sites examine the management of the upperstorey species in-

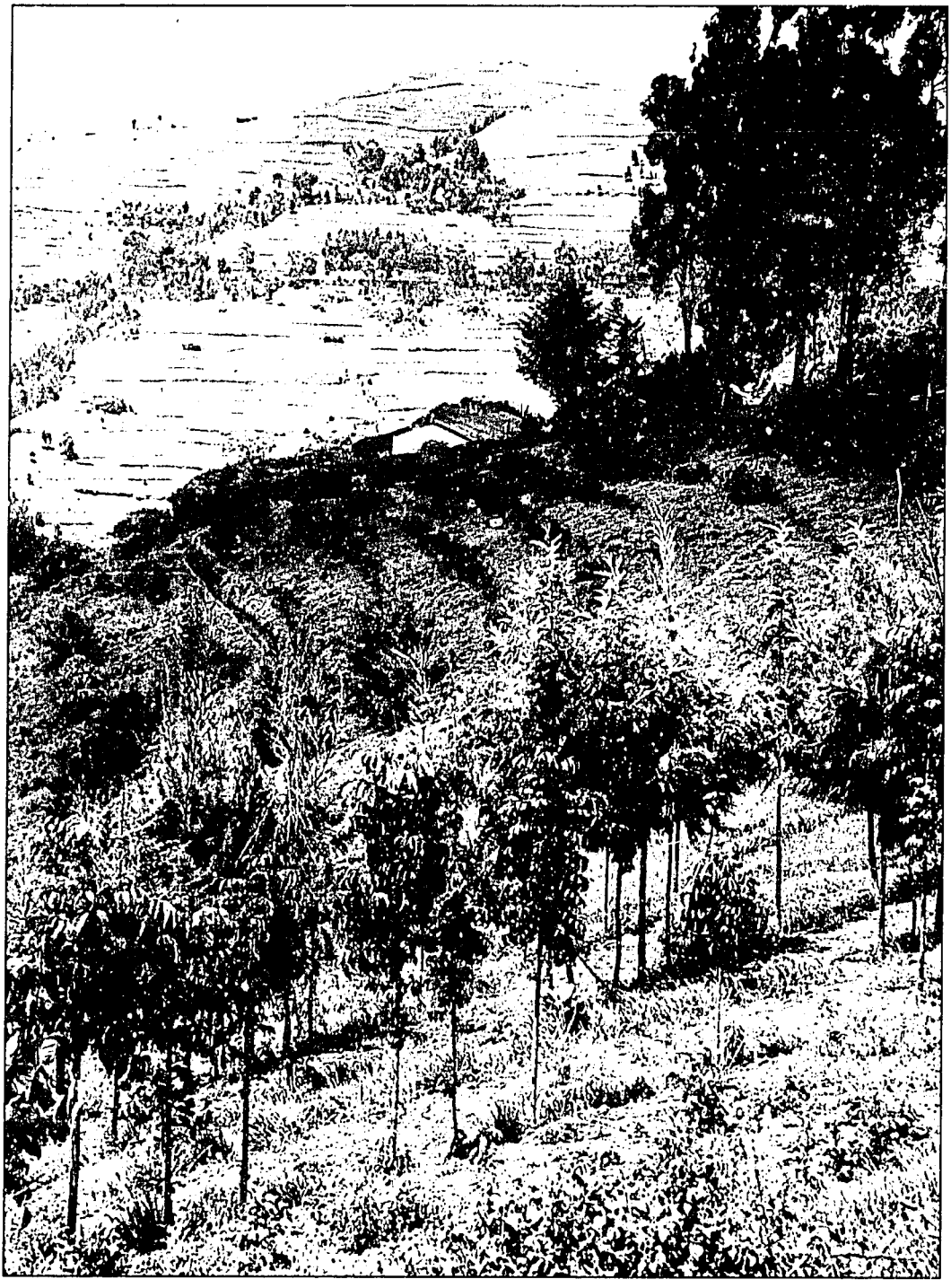


Photo: A. Njenga

ICRAF is testing different tree and grass species to help control soil erosion on steeply sloping fields in Rwanda.

Species	Provenance	Height (m)	Root Collar Diameter (cm)	Crown Diameter (cm)	Stem Volume Index
Grevillea robusta	Namanjala	4.15	9.0	2.44	28
Alnus acuminata	Guatemala	3.85	8.6	2.48	28
Casuarina cunninghamiana	Kibule	4.06	5.7	1.57	12
Casuarina cunninghamiana	Huhande	3.72	5.2	1.39	10
Cupressus lusitanica	Dapaja	3.18	6.0	2.24	10
Alnus nepalensis	Nepal	2.34	4.9	1.87	5
Casuarina equisetifolia	Gede	1.49	2.4	0.79	<1
Markhamia lutea	Kabale	1.30	3.6	0.66	2
Erythrina abyssinica	Nandi	0.55	2.3	0.65	<1
SED		0.41	0.9	0.17	5.5

Table 45. Growth performance of eight upperstorey trees 21 months after planting at Kachwekano, Uganda (altitude 2000 m). Stem volume index is an estimate of wood production based on the assumption that stems are cylindrical.

terplanted on contour bunds with fodder trees and grass. At Kabanyolo (Uganda) and at Mashitsi, researchers are evaluating upperstorey species and planting densities in combination with understorey trees in banana plots.

Species screening

Research on upperstorey trees in Uganda includes eight species-screening trials at different altitudes. All trials consist of single rows of trees spaced at 2-m intervals along the contours, with crops planted on either side. Survival has been high—better than 85%—for all species except *Cordia abyssinica* at the Bushenyi site. Tables 45, 46 and 47 give the growth performance of 15 species in the longer-established trials—one at Kachwekano and two at Kabanyolo.

Grevillea robusta and *Alnus acuminata* grew best at Kachwekano, at an altitude of 2000 m, while *Casuarina equisetifolia*, *Markhamia lutea* and *Erythrina abyssinica* had the poorest performance. At the lower altitude (1250 m) of

Table 46. Growth performance of seven upperstorey trees 26 months after planting at Kabanyolo, Uganda (altitude 1250 m). Stem volume index is an estimate of wood production based on the assumption that stems are cylindrical.

Species	Provenance	Height (m)	Root Collar Diameter (cm)	Crown Diameter (cm)	Stem Volume Index
Melia azedarach	Embu	7.93	19.8	3.16	246
Cordia abyssinica	Meru	3.73	15.2	3.67	71
Maesopsis eminii	Wundaji	4.10	11.8	3.55	48
Maesopsis eminii	Kakamega	4.00	11.5	3.31	44
Markhamia lutea	Osorongai	4.68	9.2	1.68	33
Casuarina equisetifolia	Gede	5.33	6.9	1.97	22
Cupressus lusitanica	Dapaja	3.14	6.7	2.17	12
Alnus acuminata	Guatemala	2.82	4.4	1.58	5
SED of means		0.32	1.9	0.20	9.9

Species	Provenance	Height (m)	Root Collar Diameter (cm)	Crown Diameter (cm)	Stem Volume Index
Cassia siamea	India	5.15	11.4	4.17	54
Jacaranda mimosifolia	India	4.81	10.1	1.53	40
Grevillea robusta	India	4.03	10.0	2.76	34
Grevillea robusta	Kenya	3.74	9.4	2.72	28
Erythrina abyssinica	India	4.50	7.9	2.42	24
Maesopsis eminii	Mabira	3.11	9.2	3.44	23
Casuarina equisetifolia	India	3.81	5.7	2.65	10
Alnus nepalensis	Nepal	1.17	5.6	1.84	6
Cupressus sempervirens	India	0.74	1.4	0.21	
SED		0.37	0.6	0.22	6.2

Table 47. Growth performance of eight upperstorey trees 19 months after planting at Kabanyolo, Uganda (altitude 1250 m). Stem volume index is an estimate of wood production based on the assumption that stems are cylindrical.

Kabanyolo, *Melia azedarach*, *Cassia siamea* and *Jacaranda mimosifolia* showed the best growth performance, while the two cypresses and the two alnus species grew least well.

In the first trial at Kabanyolo, maize was planted under upperstorey trees in both cropping seasons of 1990. Maize yields from rows at different distances from the trees are shown in Figure 13. Tree species ranged from those having little or no effect on the crop (alnus and markhamia) to those causing severe reductions in crop yield (maesopsis).

In the first season, the cordia depressed crop yields by as much as 75% as far as 3 m away from the trees. They were then pruned and in the second season maize yields were only affected up to about 1.5 m from the trees. At Kachwekano, beans were planted under the trees in early 1991. Bean growth was generally poor on the infertile, acid soils at this site, with yields generally lower from rows nearest the trees.

Management trials

Management trials at Kabanyolo and Kachwekano evaluate combinations of two well-known upperstorey trees, *Grevillea robusta* and *Casuarina equisetifolia*, with the smaller multipurpose tree *Calliandra calothyrsus* and the fodder grass *Pennisetum purpureum*. Interplanting with understorey species is particularly important on sloping land where dense plantings on the contour may help control soil erosion and runoff and add stability to terrace structures. Other potential benefits include the production of fuelwood, fodder, mulch and stakes for climbing beans.

The objectives of current management trials are to determine:

- The production potential of upperstorey trees planted at spacings of 1, 3 and 5 m in combination with understorey species
- The interactions between upperstorey trees and understorey species
- The effects of upperstorey/understorey combinations on adjacent food crops.

Casuarina was planted at Kabanyolo at the end of 1988, and grevillea was planted at Kabanyolo and at Kachwekano in the middle of 1989. The understorey species were interplanted at the same time. Associated crops have included maize, beans and sorghum.

In all three experiments, survival of upperstorey trees has been excellent. There have been no significant differences in height growth, but root-collar and stem diameters have generally been smaller in upperstorey trees grown with understorey species than in trees grown alone. At Kachwekano, leafy and woody biomass obtained from side-pruning grevillea

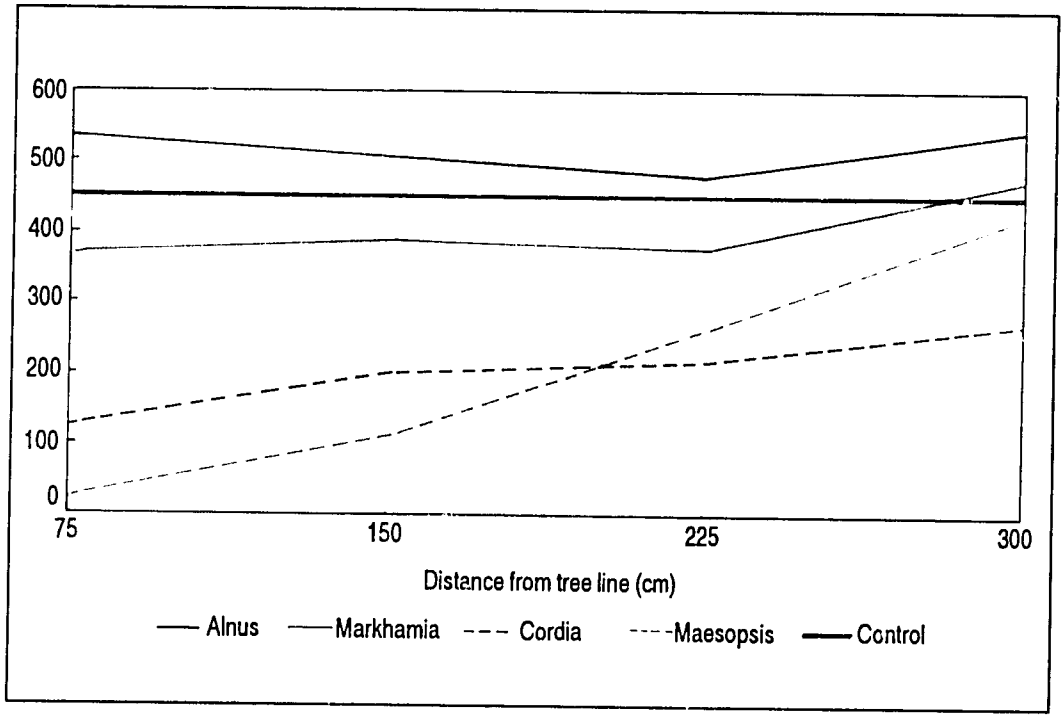


Figure 13. Total maize yield from two harvests, in August and December 1990, at different distances from lines of upperstorey trees, Kabanyolo, Uganda.

has also been higher from trees grown without an understorey.

So far, within-row spacing in the upperstorey has had no significant effect on the growth of the upperstorey trees themselves or on the growth of the understorey species or adjacent crops. Crop yields were generally lowest next to the upperstorey/understorey rows, with pennisetum having the greatest negative effect. Observations suggested that this fodder species might harbour pests and disease that affect adjacent maize crops.

Since the trial was established at Kachwekano, there has been a visible accumulation of soil above tree rows that include calliandra and a positive effect on bean growth on the upslope side. Understorey plantings of this multipurpose tree may be halting runoff, increasing the soil moisture available to the crop.

Photo: A. Njenga

Researchers weigh fresh biomass harvested from a hedgerow of Leucaena leucocephala *in an on-farm hedgerow-intercropping trial near Maseno, Kenya.*

The objective of ICRAF's Research Programme Five—on policy, adoption and impact—is to improve the adoption of agroforestry technologies and enhance their beneficial role in tropical land-use systems. Studies focus on the decision-making processes that influence agroforestry adoption at the household, community and national levels. Farmer constraints and incentives are considered, as well as the framework of national agroforestry research and development programmes and the support policies of the international community. Work is organized in three general areas: factors affecting agroforestry adoption, impact assessment and policy analysis.

In 1991, major research activities were in progress at three sites: Maseno and Kakuyuni in Kenya and Lilongwe in Malawi (Table 48). These were selected on the basis of agro-ecological diversity, opportunities for complementarity with on-station research and support from national institutions. Based on survey results, researchers are working with farmers to design and evaluate agroforestry technologies appropriate for the problems and opportunities that exist in each area (Table 49). In 1991, farmer-designed trials were also introduced, primarily at Maseno.

Results of these major on-farm research activities are described in this report. In addition, ICRAF has initiated on-farm research at other sites in Burundi, Cameroon, Kenya, Malawi, Rwanda, Tanzania, Uganda and Zambia. Table 50 provides a summary of activities at these sites.

Agroforestry adoption and impact assessment

Farmers throughout the tropics are practising traditional agroforestry technologies and considering modified approaches or entirely new initiatives as proposed by development and ex-

tension agencies. Several factors are involved in a farmer's decision to take up a new agroforestry practice or to continue a practice already adopted. Studies on these factors include detailed analyses of land-use problems, farmers' biophysical and economic resources, indigenous knowledge and practices, and community and household decision-making processes.

Impact assessment includes long-term monitoring and evaluation of agroforestry systems as well as short-term observations and analysis. The objective is to quantify the effects of agroforestry on production systems, on the well-being of rural households, and on national and regional economies. Studies cover resource use, labour requirements, yields, provision of food and other needs, income generation, supply and demand of agroforestry inputs and products, and employment generation.

On-farm technology trials assess the potential impact of agroforestry and the likelihood of adoption by farmers. In the subhumid tropics, ICRAF is conducting on-farm trials in Burundi, Kenya, Malawi, Rwanda, Uganda and Zambia. These cover a number of agroforestry technologies—hedgerow intercropping, improved fallows, boundary planting, fodder banks, home gardens and living fences. In the semi-arid tropics, ICRAF has participated since 1985 in trials of hedgerow intercropping, fodder banks, tree planting in home compounds, living fences and tree nursery management at Kakuyuni. In the humid tropics, on-farm trials are in progress in Cameroon testing improved fallows and hedgerow intercropping.

These on-farm research activities are an essential component of the agroforestry technology development process. The objectives are:

- To study existing land-use problems and opportunities, use of multipurpose trees, and farmers' agroforestry systems in order to improve on-station and on-farm research planning and analysis
- To design and test agroforestry technologies that can be expected to contribute to the improved productivity and sustainability of farming systems
- To evaluate the acceptability and potential socio-economic impact of agroforestry technologies
- To develop on-farm research methods for wider use through ICRAF's collaborative programmes; these must be cost effective and scientifically rigorous and must ensure the active participation of farmers.

On-farm studies in the subhumid zone of Eastern Africa

In 1990, researchers based at the Maseno Agroforestry Research Centre in western Kenya started a participatory trial on 23 farms to test the feasibility, requirements and benefits of hedgerow intercropping. On-farm research in this area is supported by the Rockefeller Foundation, USAID, SIDA and the Government of the Netherlands.

In February 1991, research was extended to an additional 39 farms. The trial consists of two plots of 500 to 1000 m sq on each farm, one with hedgerows about 4 m apart and one without hedgerows. The researchers supply the seed-

Table 48. Characteristics of the major sites for ICRAF's on-farm research activities in 1991.

	Maseno	Lilongwe	Kakuyuni
Altitude (m)	1500	1180	1200
Annual rainfall (mm)	1800 (bimodal)	890 (unimodal)	600 (bimodal)
Dominant soil types	acrisols, ferralsols, nitosols	luvisols	ferralsols
Population density (person/sq km)	400–1000	110	70
Average farm size (ha)	<1.0–1.5	2.0	4.1
Labour availability	limited–high	high	limited
Off-farm income	high–moderate	low	moderate

Maseno	Lilongwe	Kakuyuni
Soil fertility and erosion		
75% acid soils; low phosphorus; erosion hazard; low use of manure and fertilizer	Continuous cropping; light soil with low organic matier; very low use of manure and fertilizer	Manure unavailable
Wood supply		
Shortage of fuelwood, poles, timber; depletion of popular species; seedlings expensive	Deforestation; shortage of fuelwood for tobacco drying	Rapid decrease of fuelwood; use of low-quality substitutes
Fodder supply		
Unproductive traditional system; strong demand for milk, manure, traction; opportunity for improved dairy cows with zero grazing	Limited grazing especially in dry season; poor-quality crop residues; livestock diseases; introduction of improved dairy cows with zero grazing	Limited grazing especially in dry season; limited crop residues; draught oxen weak at ploughing time; interest in dairying
Fruit production		
High demand for planting material	Poor management, good potential market for fruit	Market for fruit; interest in fruit production; poor tree establishment, management
Control of livestock		
Not a serious problem	Communal access to cropland in dry season; fences required to protect hedgerows, home gardens, fruit trees	Communal access to cropland in dry season; fences required to protect hedgerows, home gardens, fruit trees

Table 49. Constraints and potentials identified in the three major target areas for ICRAF's on-farm research programme in 1991.

lings and offer technical advice, while the farmers conduct all operations. Tree species include *Leucaena leucocephala*, *Calliandra calothyrsus* and *Leucaena diversifolia*.

In the long rains of 1991, the 39 new participating farmers established the equivalent of 5900 trees/ha on plots averaging 780 m sq. The farmers grew 18 different crop combinations on these plots, which complicated research results. Maize/bean mixtures (43% of plots) and sole maize (23%) were the most common.

No farmer applied fertilizer to tree seedlings, but 41% applied farmyard manure in the planting holes. Most (72%) farmers planted the trees themselves, while the rest used casual labour. About two-thirds of the farmers reported that labour requirements for weeding were unaffected by the presence of the hedges, while the remainder thought that weeding their crops took longer with hedges.

Tree survival rates six months after planting ranged from 75% to 100%, compared with 25% to 99% for the first group of farmers who planted during the previous short rains. Termite damage was the most common cause of seedling death, sometimes exacerbated by late or poor planting. Termite-control measures included removal of crop residues from around the seedlings, application of wood ash and, occasionally, treatment with insecticide.

Six months after planting out, tree heights varied widely among the different farms (Table 51). On 27% of the farms where trees were planted in 1990, *Leucaena leucocephala* grew poorly due to browsing by antelope, but there was little browsing of trees planted in 1991.

Photo: A. Njenga

A field technician shows a group of women farmers near Lilongwe, Malawi, how to prune the roots of tree seedlings before planting.

Poor growth of *Leucaena leucocephala* and *Leucaena diversifolia* at some sites appeared to be related to nutritional disorders. Soil and plant samples are being analysed to identify them.

Growth rates were much slower on most farms than on-station results achieved at the Maseno Agroforestry Research Centre. However, trees planted on station each received 25 g of diammonium phosphate fertilizer and were intercropped with fertilized beans. Root-collar diameters at six months averaged 1.3 cm for *Leucaena leucocephala* on farm compared with 2.2 cm on station; for calliandra, root-collar diameters averaged 1.5 cm on farm and 2.9 cm on station.

The slow and variable growth rates of hedgerows planted on farm (Table 52) complicate decisions on the time of first cutting. Trees were often too small to cut at the start of the season after they were planted, but some hedgerows that were left uncut clearly inhibited crop growth later in the season due to competition for light. However, cutting hedgerows after crops were planted required extra care and labour to avoid damaging the crops.

On balance, in order to avoid competition and crop damage farmers might be advised to cut hedgerows at the start of the season after they are planting out regardless of tree size. Further work is needed on station to determine the effects of cutting small trees on subsequent shoot growth and root distribution.

On average, 62% of total dry-matter yield from the first cut was returned to the soil, rather than harvested as fuelwood. In the first year of establishment, this amounted to about 2 t/ha (dry wt), with another 1 t/ha (dry wt) harvested.

Labour requirements for pruning hedgerows and spreading mulch were significantly affected by the presence of an intercrop. Without crops, a worker could prune from 1.1 to 3.8 m of hedge per minute, with an average of 2.2 m based on 24 observations. With crops, cutting speeds ranged from 0.6 to 2.1 m per minute, with an average of 1.1 m based on 14 observations.

More than 50% of the participating farmers were women but, out of 85 observations, women only cut hedgerows on six occasions (7% of observations) and only spread prunings on 15 occasions (18% of observations). In 12 cases (14% of observations), hired male labourers cut hedgerows, while in most cases (67 observations or 79% of the total), hedgerows were cut by male household members.

On 80% of the farms, maize was planted at rates of 20,000 to 50,000 plants per ha. The recommended rate is 44,000. About 50% of 107 plots with maize yielded less than 1 t/ha (13% moisture content), while less than 10% yielded more than 2.5 t/ha. Only 8% of 61 plots with

Table 50. Sites for recently initiated on-farm research activities.

Site	Research activities
Gitega, Burundi	Economics of seedling production in nurseries, grass/shrub associations for livestock fodder, D&D survey
Yacundé, Cameroon	Hedgerow intercropping and rotational fallows to improve soil fertility
Embu, Kenya	Ethnobotanical survey, evaluation of home gardens, planting understorey trees in existing boundary plantings of *Grevillea robusta*, planting shrub species in existing fodder banks
Rwerere and Gakuta, Rwanda	Species testing, upperstorey/understorey combinations, trees planted in fallow fields for stake production, diagnostic study of tree/banana associations
Moshi, Tanzania	Evaluation of home gardens
Kabale, Uganda	Upperstorey tree planting, diagnostic study of tree/banana associations
Chipata, Zambia	Improved fallows with *Sesbania sesban*, fodder banks with *Leucaena leucocephala* in protected bottomland plots

Species	Date Planted	Range of Heights in cm (number of farms) < 50	51–100	101–150	>100	Average Height (cm)
Leucaena leucocephala	Sep 1990	7	6	9	0	80
Leucaena leucocephala	Apr 1991	2	2	1	0	65
Leucaena diversifolia	Apr 1991	1	1	2	2	123
Calliandra calothyrsus	Apr 1991	0	3	4	2	142

Table 51. Range of tree heights and overall average, six months after planting under hedgerow intercropping on farms near Maseno, Kenya.

beans yielded more than 0.4 t/ha; 41% yielded less than 0.1 t/ha.

Nutrient input levels were also low: only 17% of farmers used fertilizer on their hedgerow plots, and only 45% used farmyard manure. The farmers who did use fertilizer applied an average of 90 kg/ha diammonium phosphate. Among the farmers who used manure on their hedgerow plots, applications averaged 1.8 t/ha dry wt. Fertilizer and manure applications were slightly higher on control plots, but the differences were not significant.

Across the farms as a whole, average crop yields were not significantly different with or without hedgerows. However, comparisons between hedgerow and non-hedgerow plots were not strictly valid because of differences among plots in inherent soil fertility and because the farmers tended to manage their control and hedgerow plots differently. About 23% of the farmers felt that there were inherent differences in soil fertility between their hedgerow and control plots: most of these had deliberately planted hedgerows on less fertile sites, a reasonable strategy considering that the objective of the hedgerows was to improve soil fertility.

Some of the farmers reported that they applied different amounts of fertilizer and manure to hedgerow and control plots (23%), that they weeded the two plots differently (16%), or that they prepared and planted the plots differently (14%). The researchers had decided to let the farmers manage the plots independently to see how they evaluated the hedgerow technology, rather than trying to maintain strict uniformity.

Concerning overall performance, 51% of the farmers observed that competition from the trees had a negative impact on crop yields, 21% reported that the trees had a positive effect on crop yields, and 32% observed no effect. The farmers are hopeful that positive effects will increase in future years.

These results demonstrate the importance of farmer participation in designing and evaluating an agroforestry technology. However, they also show how difficult it is to compare the biophysical performance of alternative agroforestry practices with participating farmers. They high-

Table 52. Biomass yields of hedgerows on farms near Maseno, Kenya.

Species	Date Planted	Date Cut	Yield (t/ha dry wt)
Leucaena leucocephala	September 1990	April 1991	1.0
Leucaena leucocephala	September 1990	September 1991[a]	2.0
Leucaena leucocephala	September 1990	November 1991[b]	0.8
Calliandra calothyrsus	April 1991	September 1991	1.9

[a]First cut of season.
[b]Second cut of season.

light the need for complementary studies under realistic conditions, but with a high degree of researcher control. They also show the low level of inputs and associated low level of crop production often encountered in the subhumid tropics. Monitoring is continuing and results are being compiled for economic analysis.

Twelve farmers in five areas around Maseno took part in another experiment in 1991 to test the feasibility of establishing the multipurpose tree, *Sesbania sesban*, directly from seed. The objective was to develop a low-cost method of tree establishment for rotational hedgerow-intercropping and improved-fallow systems.

Most of the farmers sowed sesbania seed in lines 4 m apart, along with maize, at the beginning of the cropping season in February 1991. Rainfall was average at two study sites and 10% to 17% below average at the other three.

On four of the farms, the trees failed to establish because seeds were washed away or seedlings were browsed by animals. On the eight other farms included in the study, the seedlings established satisfactorily under the maize canopy and grew rapidly after the maize was harvested. Six months after planting, tree heights on two of these farms averaged more than 2 m. On the other six farms, tree heights ranged from 50 cm to 2 m.

One farmer planted the trees in rows only 2 m apart. This alternative provided a dense stand of sesbania, which could be thinned later on.

At the beginning of the next growing season, the eight farmers with trees had two options: they could leave the land fallow or plant another crop. Four farmers left the land fallow and four planted maize. Maize yields with the trees averaged 820 kg/ha, while yields from unfallowed control plots averaged 390 kg/ha. The farmers reported that they would need more time to assess the effects of this technology. On-station experiments on depleted land could help quantify the potential biophysical benefits of such a system.

In a third trial at Maseno, farmers conducted their own experiments with five multipurpose trees—the shrub species *Leucaena leucocephala*, *Leucaena diversifolia* and *Calliandra calothyrsus* and the upperstorey species *Grevillea robusta* and *Casuarina cunninghamiana*. The objectives were to:

- Observe how farmers experiment with new tree species and and how they evaluate them
- Assess how these five species perform on farmers' fields under farmer management
- Discover where farmers plant new trees and how they manage and use them.

A total of 50 farmers from 13 different farmer groups were involved in the trial. In group meetings, researchers discussed tree characteristics and uses and distributed seedlings. The farmers were able to observe some of the species in previously established on-farm trials.

Information was collected from 44 of the participating farmers. About half were men and half women. On average, each received 273 seedlings at the beginning of the growing season in September 1991 (Table 53). The range was 250 to 500. Three quarters of the farmers

Table 53. On-farm planting trial in western Kenya: number of seedlings delivered to farmers, seedling survival rates and observations of termites.

Species	Average Number of Seedlings Delivered to Each Farmer	Seedling Survival Rate (%)	Farmers Observing Termites (%)
Leucaena leucocephala	56	73	23
Leucaena diversifolia	29	73	20
Calliandra calothyrsus	103	84	16
Grevillea robusta	54	79	36
Casuarina cunninghamiana	31	46	48

Species	Excellent	Good	Fair	Poor	Very Poor	Total
Grevillea robusta	15	17	7	2	2	43
Casuarina cunninghamiana	4	8	13	8	10	43
Leucaena leucocephala	7	6	14	11	5	43
Leucaena diversifolia	7	11	13	8	4	43
Calliandra calothyrsus	23	6	7	4	3	43

Table 54. Responses of 43 farmers asked to rate five tree species in terms of growth three months after planting at Maseno, Kenya.

planted all their seedlings—others gave some away or sold them. Because it was still dry when the seedlings were delivered, 40% of the farmers delayed planting for more than one week.

About 67% of the farmers planted the shrub species in hedgerows. Others planted them on external or internal boundaries, on terraces or in fallow land. About 50% planted grevillea on external boundaries, 36% on internal boundaries, and 11% around their homes. About 33% planted casuarina on external boundaries, 33% on internal boundaries, and 25% around their homes. Only a few of the farmers planted any of the species in blocks or scattered on their cropped fields.

Farmers reported that they planned to use the grevillea and casuarina for timber and poles and the leucaena and calliandra for soil fertility improvement, fuelwood and fodder. Only 11% of the farmers expected to use any of the species for soil conservation.

On average, the farmers spaced the leucaena seedlings in hedgerows at about 1.5 m and the calliandra at about 1.0 m apart, much wider than the recommended spacing of 0.5 m. They justified this wide spacing on the basis that they had received only a few trees. Spacing between grevillea seedlings averaged 1.7 m and between casuarina 2.5 m. About 67% of the farmers said they decided on the spacing between seedlings independently: 33% said they followed advice from others.

Farmers assessed the species according to several criteria. They gave calliandra and grevillea the highest ratings for survival and growth (Table 54). The leucaenas were next, followed by casuarina. All except casuarina were rated highly for termite resistance.

Monitoring will continue with a formal survey every year and the trial will expand in 1992 with an additional 50 farmers. The project will also provide larger numbers of seedlings so that farmers can choose spacing and planting arrangements more freely.

On-farm studies in the subhumid zone of Southern Africa

A national on-farm research project began in 1990 in the area around Lilongwe, with collaboration from ICRAF. Based at the Chitedze Research Station, the project builds on the research programme of the Ministry of Agriculture's Agroforestry Commodity Team. Funding is provided by IDRC, USAID, CIDA and the Rockefeller Foundation.

Maize and other agricultural crops predominate on the plains around Lilongwe and livestock play an important role. The average farm size is only 2 ha and cultivation is intensive. Major problems mentioned by farmers in earlier D&D studies included declining soil fertility, lack of fodder and fuelwood, poor control of livestock in areas of permanent cultivation, underdevelopment of fruit and vegetable gardens and shortages of cash. The objective of the on-farm project is to evaluate agroforestry technologies that may help alleviate these problems. Activities are designed to complement on-station research that has been in progress since 1986.

By the end of 1991, 42 farmers were participating in the project. One experiment in progress on 16 farms tests the potential of hedgerow intercropping to improve soil fertility. Maize is intercropped with hedgerows of *Leucaena leucocephala* without fertilizer and with fertil-

Species	Height (cm)	Basal Diameter (cm)	Number of Branches
Acacia karroo	25.2	0.49	4.3
Acacia nigrescens	18.8	0.60	3.0
Acacia nilotica	36.6	0.70	8.1
Caesalpinia decapetala	66.8	1.00	1.7
Ziziphus mauritiana	48.0	0.50	7.0
Ziziphus mucronata	29.1	0.76	10.3

Table 55. Growth and branching habits of six living-fence species one year after introduction by farmers in Lilongwe, Malawi.

izer applied at a rate of 45 kg N/ha, which is half the recommended rate for the region.

Due to the high costs (averaging US$113/ha) and labour requirements (17 person-days/ha) of establishing hedgerows from seedlings, the trial began with hedgerow establishment by direct seeding. This approach cost only US$20 and required only five person-days/ha. Germination averaged 60%, with a range of 40% to 100%. The most effective method involved planting inoculated seed in shallow furrows at a spacing of about 10 cm followed by thinning. Some supplementary planting with seedlings was required to fill in gaps.

With direct seeding, establishment and early growth tended to be slow. Eleven months after planting out, trees established from seed averaged 30 cm in height, while trees planted as seedlings averaged 90 cm. For this reason, farmers indicated that they preferred to plant seedlings, despite higher costs and labour requirements.

A major problem occurred during the dry season when farmers had to erect temporary fencing to protect their hedgerows from grazing livestock. Alternatives include the introduction of living fences, the use of non-palatable hedgerow species such as *Cassia spectabilis*, or the implementation of community agreements to control livestock.

Termites were another serious problem. About 33% of the farmers reported serious termite attacks, losing up to 30% of hedgerow plants. Project researchers have achieved some temporary success using leaves of *Azadirachta indica* (neem) to control termites, but another approach would be to plant a termite-resistant hedgerow species, such as *Gliricidia sepium*.

From an assessment of efficiency and timeliness of operations, 30% of the farmers were rated as very good, 40% as good, 13% as fair and 6% as poor. Only two of the original participants dropped out—because their plots were unsuitable.

Due to the slow initial growth of leucaena hedgerows, farmers may have to wait two years or longer to see any benefits from this agroforestry technology. This is a definite disadvantage. On the other hand, they have not seen any drop in maize yield. About 45% expressed an interest in expanding hedgerow intercropping on their farms and 50% reported that their neighbours were interested in participating in the trial. Farmers were not accustomed to being consulted by research and development workers, and they only began expressing their own views and ideas after long-term interaction.

Fourteen farmers are participating in a second experiment to test the introduction of fruit trees in home gardens and *dimba* (bottomland) plots. Researchers provided seedlings and technical information, and the farmers have made all decisions on planting and management.

The farmers planted seedlings of orange, lemon, tangerine, mango, papaya, guava, banana and passion fruit. Survival rates have averaged 80% to 90%. They combined fruit trees with a wide variety of vegetable and root crops.

Farmers have very little knowledge or experience with fruit-tree production, but have shown considerable enthusiasm. Constraints include limited access to seedlings, labour requirements, and moisture stress during the long dry season. All plots with fruit trees have to be fenced for protection against grazing livestock.

A third trial began in 1991 to test the effectiveness of different species as living fences and to develop appropriate management practices. Initially only five farmers were included, but the trial will expand as more planting material becomes available.

Farmers around Lilongwe traditionally plant sisal as living fences, but these broad plants take a strip of at least 1 m out of crop production. In this study, farmers planted single rows of *Acacia karroo*, *Acacia nigrescens*, *Acacia nilotica*, *Caesalpinia decapetala*, *Ziziphus mauritiana* or *Ziziphus mucronata*. Overall, *Ziziphus mauritiana* demonstrated the best growth at one year (Table 55), although it showed some susceptibility to termite damage. *Caesalpinia decapetala* grew more quickly and had large thorns, but the trees had poor branching habits and failed to form a thick mesh.

Although establishment costs and labour requirements are high, farmers have a strong interest in planting living fences to protect their fruit and vegetable plots. Most of the species under investigation are localized in the region, but limited planting material is still a serious constraint.

Farmers in the Lilongwe area often retain *Acacia albida* trees in their cropland and are well aware of the contribution this species makes to soil fertility through the build up of organic matter from leaf and pod fall. Scientists began a trial in 1991 to assess the potential of planting these trees systematically.

Researchers provide farmers with 50 acacia seedlings plus technical information. The farmers plant trees at an initial spacing of 10 x 5 m and then thin them gradually to reach an optimum spacing of 20 x 20 m. So far seedling survival rates have been low, averaging 30%. The main problem appears to be poor identification of tree seedlings when fields are weeded. This technology entails modest costs and labour requirements, and farmers are interested in adoption in spite of the poor performance so far.

On-farm research project in Kenya's semi-arid zone

In 1984, KEFRI initiated a Dryland Agroforestry Research Project in the area around Machakos, with ICRAF acting in an advisory capacity. The goal is to develop improved land-management systems using agroforestry for mixed-farming areas in Kenya's semi-arid zone.

The on-farm component of this project is based at Kakuyuni, near Machakos. Three local farmers began working with the project in 1985, and six more joined in 1988. One local school also participates. They all made plots available for hedgerow-intercropping trials, with hedgerows managed by project staff and crops managed by the farmers. Hedgerow species are *Cassia siamea*, *Gliricidia sepium* and *Leucaena leucocephala*. In 1989, the farmers took over complete management of the trials.

Biomass production from hedgerows has been low, ranging from 2.9 t/ha fresh wt per season for cassia to 5.0 t/ha for gliricidia. Leucaena hedgerows have suffered high losses due to browsing. Farmers also complain that the presence of hedgerows interferes with ox ploughing. They have modified the technology to alleviate this problem by cutting the hedgerows at 20 cm above ground instead of at 50 cm as was recommended.

Labour for hedgerow pruning is another constraint. A single pruning requires 27 person-hours/ha. The problem is especially acute at the beginning of the cropping season, when labour is required for land preparation, and later when crops must be weeded.

Although farmers have few options for addressing their soil-fertility problems, they are not yet convinced of the value of hedgerow intercropping. One participating farmer has abandoned the trial, two have expanded the area under hedgerow intercropping and two neighbouring farmers have introduced the technology. However, in 1991, maize yields were higher on hedgerow plots than on control plots (Figure 14). During the year, 10 additional farmers from neighbouring villages joined the trial.

From the outset of the project, farmers expressed particular interest in fruit trees—including citrus, papaya, mango and guava—a reflection of good marketing potential in the area. However, increased fruit-tree production was limited by poor survival rates, ranging from 7% for guava to 50% for rough lemon. In 1990,

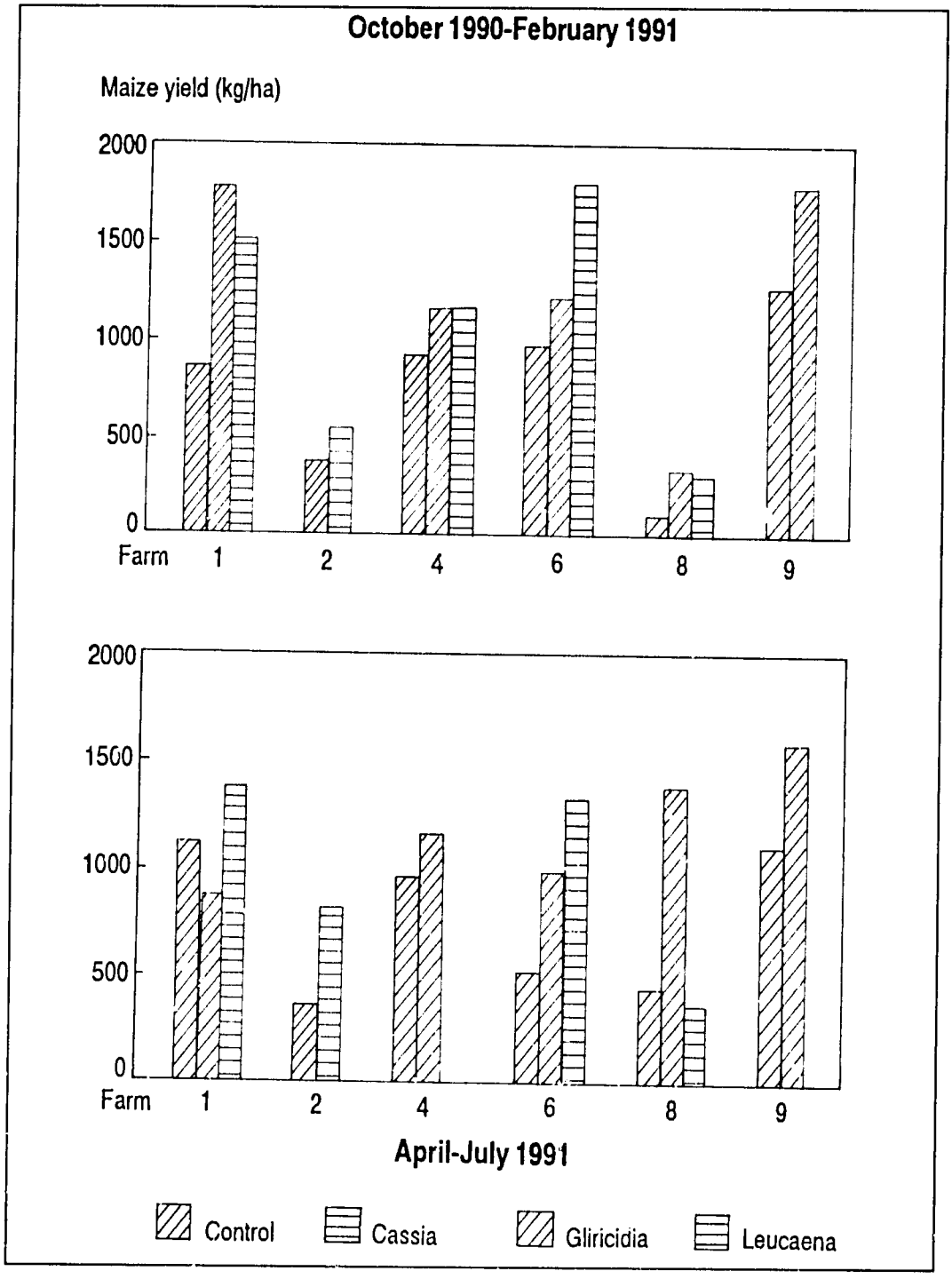


Figure 14. Maize yields from hedgerow-intercropping trials on farms at Kakuyuni, Kenya, during two growing seasons of 1991.

a concerted effort to improve planting methods included enlarging planting holes to a width and depth of 50 cm, pruning seedling roots before planting, and applying manure. As a result, seedling survival rates increased up to 90%.

Field researchers conducted a detailed socio-economic survey in the Kakuyuni area from February to April 1991, to compare the problems, preferences and agroforestry practices of farmers participating and not participating in the project. The study covered the nine farmers participating at that time plus 14 others chosen at random in the area. All the farmers noted labour constraints, animal disease, insect pests and uncontrolled browsing as serious problems.

Altogether, the team identified eight fruit species and 37 other tree species on farms in the area. Farmers participating in the project had on average 66 trees in their home compounds, compared to 22 for non-participating farmers. The number of trees in cropland was similar for the two groups. Participating farmers had planted a much higher proportion of the trees on their farms: 77% of those on home compounds, compared to 38% for non-participating farmers, and 46% of trees on cropland, compared to 16%.

When asked which trees they preferred, all farmers ranked *Cassia siamea*—an exotic species—first, followed by *Terminalia mentalis*, a local species that is not planted but occurs naturally. Farmers participating in the project ranked leucaena third, while non-participating farmers mentioned *Eucalyptus camaldulensis*. Among fruit species, all farmers ranked papaya first, followed by citrus and banana. Although farmers tended to mention *Eucalyptus camaldulensis* as a preferred species, these trees are highly susceptible to termite attack and there are, in fact, few in the area.

All farmers ranked fuelwood as the number-one tree product, followed by shade. Participating farmers next listed green manure and windbreaks, while non-participating farmers mentioned timber and charcoal. All farmers were interested in improving their fencing, particularly around cropland.

Other on-farm research activities include testing leucaena fodder banks, living fences to control livestock, and woodlots consisting of mixtures of *Grevillea robusta*, *Eucalyptus* spp., *Cassia siamea*, *Cassia spectabilis*, *Acacia tortilis* and *Melia azedarach*. The project also helps six primary-school nurseries and two group nurseries that, together, produced and distributed 10,000 seedlings in 1991.

In September 1991, all collaborating institutions came together to review the project's achievements and decide on future priorities. One proposal was to emphasize on-farm work, with most on-station research and training provided by ICRAF's Machakos Research Station.

Survey on the potential of hedgerow intercropping

Hedgerow-intercropping trials and demonstrations have been in progress at ICRAF's

Table 56. Characteristics of farmers interested primarily in livestock fodder or soil fertility at Machakos, Kenya.

	— Farmer's Primary Interest —	
	Fodder Production	Soil Fertility
Number of respondents	37	28
Mean farm size	4.0 ha	3.2 ha
Mean livestock holdings (ruminants)	4	3
Mean reported maize yields		
With fertilizer	1.6 (t/ha)	1.4 (t/ha)
Without fertilizer	0.7 (t/ha)	0.6 (t/ha)
Number of farmers using:		
Ox plough	27	7
Fertilizer	21	5

Photo: A. Njenga

School children at Kakuyuni, Kenya, learn how to graft citrus seedlings as part of ICRAF's collaborative agroforestry project.

Machakos Research Station for several years. Researchers conducted a survey in 1991 to determine how farmers in the area currently maintain soil fertility and to assess the potential impact of introducing hedgerow intercropping.

Sixty farms were selected at random on the hills around Machakos and a profile of the farmers was developed using a formal, pretested questionnaire. Interestingly, they appeared to fall into two distinct groups—those who were concerned primarily with producing more fodder for their livestock and those who were more concerned with soil fertility to produce food crops (Table 56).

Farmers who were most interested in livestock fodder were more likely to plough their fields with oxen, rather than cultivating by hand, and to apply fertilizer. They also tended to be generally better informed about hedgerow intercropping.

The farmers estimated that fertilizer application doubled their maize yields, indicating the low inherent soil fertility of the region. However, the benefits of hedgerow intercropping are likely to be more immediate and more visible to farmers if at least some hedgerow biomass is used to feed livestock and manure returned to the soil.

Feasibility of farmer-managed nurseries

FAO is managing an integrated rural-development project at Gitega, Burundi, where ICRAF conducts agroforestry research with ISABU. Both groups are concerned with helping smallholders produce fodder and wood without impinging on foodcrop production. One promising technology is the introduction of fodder trees and grasses on contour strips in sloping fields.

Farmers wishing to introduce this technology have a ready supply of planting material for fodder grasses, but seedlings of appropriate tree species are not available. To overcome this bottleneck, the FAO project has arranged with two local farmers to produce seedlings of *Leucaena diversifolia*. Social scientists from ICRAF were called in to assess the economics and labour requirements for on-farm tree nurseries.

Costs were highest at the initial development stage for nursery establishment, which included construction of a shelter to shade the seedlings, ground levelling, soil preparation, manuring and filling plastic tubes. Labour requirements were substantial—for initial development, transporting and mixing soil and manure, watering, and weeding. The farmers or their helpers spent an average of four hours a day watering seedlings during the dry season and weeded the seedlings every 7 to 14 days throughout the year. Input costs were fairly low, in part because some inputs—such as inoculant, plastic tubes and seeds—were provided free by the project. Inputs purchased or supplied by the farmers included land, labour, manure and fertilizer.

In a six-month period one nursery produced 11,280 seedlings with a labour input of 223 person-days. The other produced 20,000 seedlings using 504 person-days. Production costs averaged US$0.016 per seedling. A preliminary estimate of the unsubsidized production cost would be about US$0.020 per seedling.

A more long-term question concerns the feasibility of on-farm seedling production in general. Given the costs and labour requirements, other methods of providing planting material are being explored. For example, it might be more efficient to produce multipurpose-tree seedlings in community nurseries than on individual farms. In Burundi, community nurseries have already proven successful for the production of coffee seedlings.

Workshop on socio-economic research

In September 1991, ICRAF hosted a Regional Workshop on Socio-Economic Research for Agroforestry Systems Development. Funding was provided primarily by IDRC. The objective was to develop guidelines and proposals for socio-economic research within the AFRENA programme for Eastern and Southern Africa. Altogether, 34 participants came to the workshop from national and international programmes in 11 countries of subsaharan Africa. Eight of these were women. Twelve were specialists in the natural sciences and 22 were social scientists.

The participants presented papers and case studies on three main research areas—problem diagnosis, technology design and agroforestry

adoption. Working groups reviewed research proposals and formulated general guidelines for socio-economic research in agroforestry. These focused on: key variables and indicators for determining impact, methods and issues related to data collection, and general methods and models that could be used in socio-economic analysis for agroforestry development.

Agroforestry extension and the institutional base

In 1990, ICRAF and KEFRI began collecting and reviewing published literature and other materials on agroforestry extension, with funding provided by the Ford Foundation. The project also included field visits to agroforestry extension projects in Eastern and Central Africa. The goal was to help define information gaps and priority topics for further research.

Results of this work have shown that traditional extension methods are often inappropriate for agroforestry. Rather than developing improved 'packages' and passing these on to farmers, agroforestry programmes have tended to involve farmers in the process of research and technology design. One reason for this has been the recognition that farmers possess valuable knowledge and experience on the use of trees in land-use systems. New extension approaches are required that can tap this local knowledge and, at the same time, introduce improvements based on outside research. These new approaches, in turn, require innovative thinking about the institutional basis for agroforestry research and extension.

The review team contacted extension agencies and non-governmental organizations directly and published a request for material in ICRAF's quarterly magazine, *Agroforestry Today*. As a result of these requests, they received 151 extension reports and other material. Another 69 publications were available in the ICRAF library.

The team visited extension workers, project managers, on-farm researchers and farmers in Burundi, Kenya and Uganda. Interviews covered agroforestry extension delivery systems, constraints on extension, agroforestry adoption, and farmers' perceptions of agroforestry.

The project resulted in an annotated bibliography on agroforestry extension and a working paper covering institutional aspects of agroforestry extension in Eastern Africa. Material covering Africa (63%), Asia and the Pacific (23%), Latin America (5%), North America (1%), and global considerations (8%) described a variety of approaches already in use for agroforestry extension. These include farm visits, group meetings and training sessions, on-station technology demonstrations and, to a lesser extent, mass-media campaigns and participatory problem-solving sessions with farmers. By far the most frequently mentioned source of technology recommendations was adaptation from other projects.

Several problem areas were mentioned:

- Lack of institutional coordination – often several ministries and non-governmental organizations are undertaking agroforestry research and extension independently
- Inadequate technical information on agroforestry, particularly on economic aspects
- Poor information on local social and cultural factors that influence agroforestry adaptation
- Difficulties in motivating farmers who favour investments that will result in immediate economic gains
- Limited resources, such as transport and operational costs
- Shortage of extension staff with the breadth of technical knowledge required for agroforestry development.

Three priority areas were identified for further research: the role of agroforestry in improving production on small farms for subsistence and cash; factors and incentives that influence the adoption of agroforestry; and comparative assessment of different extension approaches and institutional arrangements, including their cost effectiveness.

Photo: A. Njenga

Farmers inspect Leucaena leucocephala *leaf fodder during a field day at ICRAF's Machakos Research Station.*

Because agroforestry is a new science, ICRAF places a special emphasis on agroforestry training and education. Training is conducted in close cooperation with national programmes and with ICRAF's own research work.

One important objective of ICRAF's training programme is to provide support to ongoing collaborative research. In addition, the programme has a global mandate, offering training in agroforestry to researchers and development specialists from all over the world. As agroforestry research becomes more sophisticated, ICRAF is organizing more technical courses, often conducted in collaboration with other organizations whose specialized experience and expertise complements that of ICRAF.

Tables 57 and 58 show ICRAF's major training activities in 1991. Group training included both general and specialized courses, workshops and field trips. At the individual level, ICRAF offered fellowships to graduate students and internships to support student participation in the research programme.

Agroforestry research for development

ICRAF's main training activity for a global audience is a three-week introductory course on agroforestry research for development, conducted every year since 1983. This course is intended for researchers, planners, policy makers and extension workers from developing countries.

The goal is to provide the technical background information necessary to plan and implement sound agroforestry research. Since 1987, financial support has been provided by the programme for Direct Support to Training Institutes in Developing Countries (DSO) of the Government of the Netherlands.

ICRAF conducted three introductory courses on agroforestry in 1991. One course, conducted in May, has become an annual event in the ICRAF calendar. Two others represented important innovations.

The first introductory course of the year was held over a two-week period in April at Arusha, Tanzania. This was the first general introductory course offered on a regional basis, with instruction provided by national scientists as well as ICRAF staff. There were 15 participants from Malawi, Tanzania, Zambia and Zimbabwe, including five women. The regional focus, with visits to nearby research sites, ensured that instruction was closely attuned to local problems and conditions. It will also facilitate follow-up activities with course participants. Funding was provided by CIDA.

The May course, offered in French in 1991, attracted 38 participants from 19 developing countries in Africa and Asia, including 10 women. The course was conducted at ICRAF headquarters, with a field trip to agroforestry research sites in Burundi.

Because ICRAF's annual May course always attracts many more applicants than can be accommodated, a third general introductory course was offered in October and November for 39 participants with outside sponsorship. Instruction was in English and French with simultaneous interpretation. Fourteen national and international organizations provided financial support for participants from 21 countries of Africa, Asia and Latin America, including six women. Instruction at ICRAF headquarters was followed by a field trip to agroforestry research projects at the Kenya coast.

These courses consist of lectures, poster presentations by participants, group sessions and discussions, individual meetings with the instructors, and field visits to research sites. The content is becoming more technical over the years, reflecting advances in agroforestry research. Courses will continue for participants with outside sponsorship and the number of regional courses will increase, particularly as ICRAF expands activities in Asia and Latin America.

Table 57. ICRAF group training activities in 1991.

Region	Main Topic	Venue and Duration	Participants
Global	Agroforestry research for development	Kenya: 3 weeks	38
Global	Agroforestry research for development	Kenya: 3 weeks	39
Southern Africa	Agroforestry research for development	Tanzania: 2 weeks	15
Eastern and Southern Africa	Experimental methods and data collection	Kenya: 4 weeks	15
Eastern and Southern Africa	Mycorrhizae & *Rhizobium* in agroforestry	Kenya: 1 week	25
Eastern and Southern Africa	Socio-economic research methods	Kenya: 1 week	18
Global	Teaching methods & curriculum development in agroforestry	Kenya: 1 week	14
Semi-arid West Africa	Computerized data handling in agroforestry research	Niger: 2 weeks	15
Semi-arid West Africa	Information & documentation management	Senegal: 3 weeks	10

Region	M.Sc. and Ph.D. Fellowships	Student Attachments
ICRAF headquarters and research stations	2	25
Eastern and Central Africa AFRENA	3	5
Southern Africa AFRENA	7	8
Humid lowlands of West Africa AFRENA	1	6
Total	13	44

Table 58. ICRAF training activities for individuals in 1991.

Field experimental methods and data collection

Many field technicians working in agroforestry research projects are trained in a single discipline but not in the management of complex land-use systems or in the collection, handling and storage of data on all the factors crucial to agroforestry experimentation. Thus, in 1989, ICRAF started a new course for field technicians working in agroforestry. This course is now offered on an annual basis.

In 1991, the third course on field experimental methods and data collection was held at ICRAF's Machakos Research Station. Instruction took place over four weeks in November and December. Participants were field technicians working in Kenya, Malawi, Tanzania, Zambia and Zimbabwe. IDRC provided financial support.

With only 15 participants, the approach was informal, emphasizing practical, hands-on sessions in the field. Instruction covered:

- Preparation of agroforestry field experiments, including experimental design and field layout, use of contour lines, soil sampling, and methods of tree propagation
- Implementation and maintenance of agroforestry field experiments, including calculations of plant density, spacing, use of fertilizer and other chemicals, planting techniques, and tree management
- Observations, measurements and data collection in agroforestry experiments, including weather, microclimate, soil, trees, crops, animals, pests and diseases.

Symbiotic nitrogen fixation in agroforestry

Many of ICRAF's collaborative research programmes are working with nitrogen-fixing trees, and scientists in the field have identified a need for better understanding of the role of root symbionts in the important process of nitrogen uptake and fixation. ICRAF organized a six-day training workshop on mycorrhizae and *Rhizobium* in agroforestry in collaboration with the Institute of Terrestrial Ecology (ITE). Sessions were held at ICRAF headquarters, the Machakos Research Station, the National Museums of Kenya, and the KEFRI laboratories.

Twenty-four participants from 12 African countries investigated the different types of root symbiosis and their importance for plant growth and nutrition. The workshop participants also learned techniques for manipulating root symbionts and discussed research questions related to biological nitrogen fixation. Finally they considered interactions between different plants and the implications for agroforestry.

Specialized courses for the sahelian region

After a two-year planning phase, participants in the SALWA research programme identified training needs in computerized data handling and information and documentation management as priorities for the region. In response, two courses were conducted in 1991 with funding provided by CIDA.

Photo: A. Njenga

An environmental science student from the Kenya Polytechnic sorts a collection of tree-root samples at the Machakos Research Station during her attachment at ICRAF.

ICRAF joined ICRISAT and the Institut national de recherches agronomiques du Niger (INRAN) to conduct a training course on standardized data collection, management and analysis for agroforestry experiments using the Datachain and Genstat 5 computer programs. The two-week course was held in Niamey in December. There were 15 participants, including two women, from Burkina Faso, Mali, Niger and Senegal.

Information and documentation specialists came to Bamako in August for a 2-week training course on information management. This course is described under ICRAF's Information and Documentation Programme.

Individual training

Opportunities for individual training at ICRAF include degree fellowships for M.Sc. and Ph.D. candidates, non-degree fellowships at the post-graduate and post-doctoral levels, a visiting-scientist programme, and student attachments. As with group training activities, there is a trend towards placing students at sites in the field rather than concentrated at ICRAF headquarters.

In 1991, 13 M.Sc. and Ph.D. candidates were undertaking research with ICRAF—2 at headquarters and 11 at field sites in Eastern, Southern and West Africa. They came from Cameroon, Ethiopia, Kenya, Malawi, Sudan, Uganda, Zambia, Austria, Canada and the UK. Individual students were sponsored by CIDA, IDRC and the Ford Foundation.

In 1991, four of these students completed M.Sc. courses at universities in Canada and the USA and returned to national research institutions in Southern Africa. All conducted the field-research component of their degree programmes at AFRENA sites in the region. Their training was supported by CIDA.

Finally, ICRAF offered 44 student attachments in 1991, ranging from two months to four years. Students were based at ICRAF headquarters and at field sites in Eastern, Southern and West Africa. They came from universities, tech-

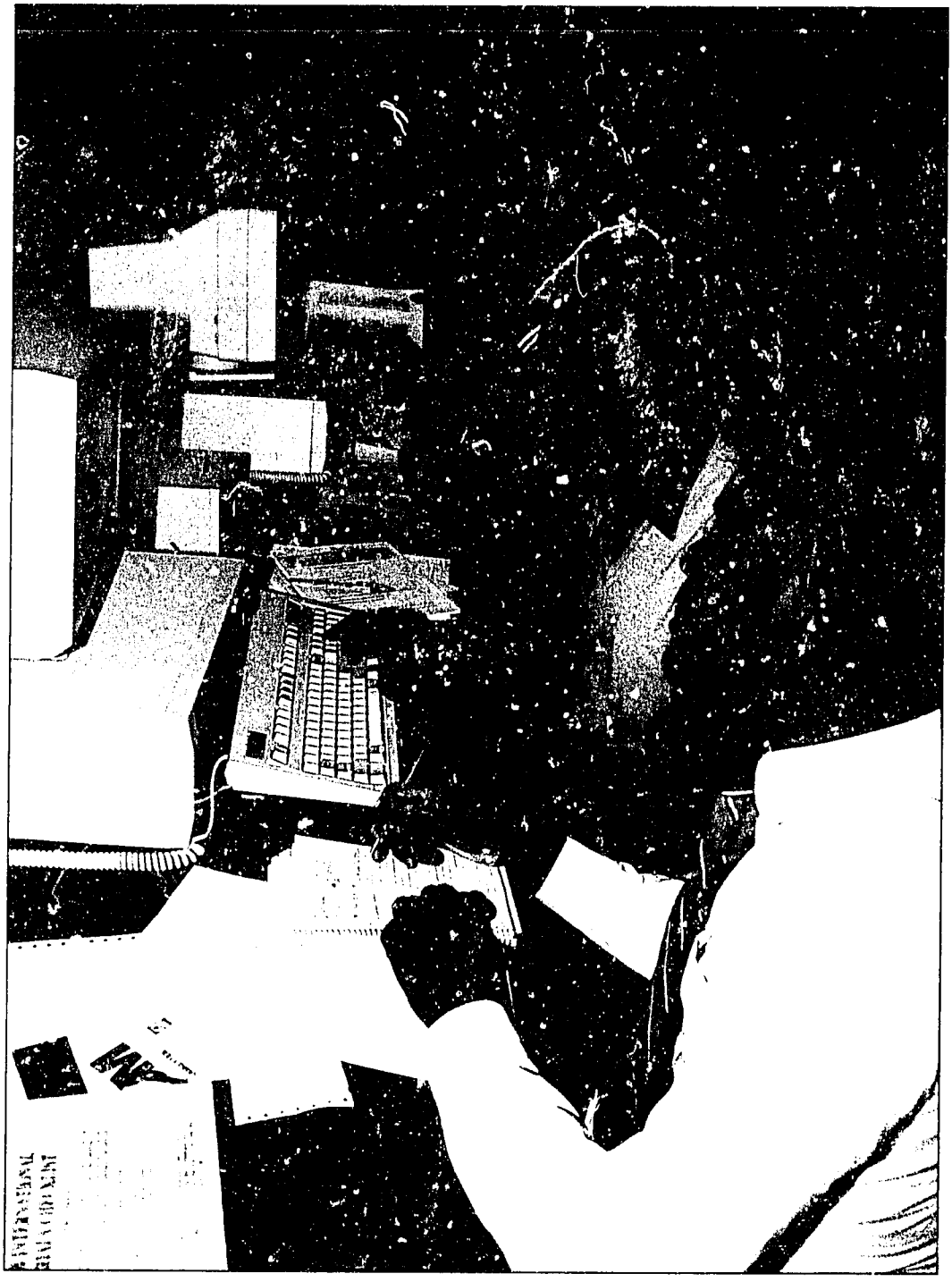


Photo: A. Njenga

Participants in many of ICRAF's training courses become familiar with the computerized databases that provide important information for agroforestry research.

nical colleges and national agricultural research institutes in eight African countries. Six were women. Two worked on database-management systems within ICRAF's Information and Documentation Programme, while the others were involved in agroforestry field research.

Funding for individual fellowships, visiting scientists and student attachments was provided by BMZ, CIDA, IDRC, IFAD, NORAD, USAID, the African Development Bank, and the Ford and Rockefeller Foundations.

Visiting scientists

Seven visiting scientists came to ICRAF in 1991 on one-year fellowships (Table 59). These were staff members of universities and national research institutes in Bangladesh, Ghana, India, Malawi, Nigeria and the UK. Four worked at ICRAF headquarters and three were attached to field sites in Eastern and Southern Africa. Two conducted research on fruit trees in agroforestry and the others completed studies on the economics of home gardens, insect pests, nutrient recycling, soil/water relations, and agroforestry adoption.

Agroforestry training for farmers and extensionists

Farmers near ICRAF's research sites often show a keen interest in learning more about agroforestry. Although national institutions have the primary responsibility for training farmers and extension agents, ICRAF's field researchers may be called upon to conduct short training sessions and to give advice.

In all of ICRAF's research programmes, farmers attend meetings, visit experimental stations and participate in field days. Many of these farmers are members of women's groups. This type of activity is increasing as ICRAF's research expands to include more farmer participation and on-farm experiments.

During 1990 and 1991, 270 farmers participated in D&D meetings in western Kenya and visited the experiments at the Maseno Agroforestry Research Centre. About 70% of the farmers were women. Extensionists attended many of the meetings for farmers, and ICRAF staff conducted four one-day training workshops for divisional extensionists. The on-farm research team also made presentations at 12 extension field days and seminars.

The Machakos Research Station received 1610 visitors in 1991, including 395 farmers and 316 extension agents. Most of the farmers came to the station with their District Agricultural Officers or in groups taking courses at Farmer Training Centres. Staff of the research station have been in contact with neighbouring farmers since 1981, and these individuals took part in an exercise in 1991 to judge the adoptability of hedgerow intercropping in the area around Machakos.

In southwestern Uganda, ICRAF and collaborating researchers provided tree seedlings to a number of women's groups and helped 10 groups establish their own nurseries. Project staff also initiated a seminar series on

Table 59. Participants in ICRAF's visiting scientist programme in 1991.

Home Institution and Country	Research Topic	Programme or Region	Duration
University of Ibadan, Nigeria	Fruit trees	One	4 months
BARI, Bangladesh	Home garden economics	Five	6 months
ICAR, India	Insect pests	Three	12 months
UST, Ghana	Agroforestry adoption	Five	12 months
University of Malawi	Indigenous fruit trees	Malawi	12 months
University of Reading, UK	Nutrient recycling	Eastern Africa	12 months
Forestry Research Institute, Malawi	Soil/water relations	Southern Africa	12 months

Region	Main Topic	Venue and Duration	Participants
Africa	*Faidherbia albida*	Niger: 1 week	40
Global	Agroforestry and soil fertility	Kenya: 3 days	17
Global	Multipurpose-tree assessment methods	Thailand: 1 week	15
Southern Africa	Agroforestry research for development	Malawi: 2 weeks	15
Eastern Africa	Preliminary results and research methods	Kenya: 3 days	68
Southern Africa	Research planning	Zimbabwe: 1 week	25
Eastern and Southern Africa	Socio-economic research methods	Kenya: 1 week	36
Africa	Agroforestry teaching	Kenya: 4 days	14

Table 60. ICRAF conferences and workshops in 1991.

agroforestry for district extensionists and organized a one-day national agroforestry workshop at Kampala for researchers and extension agents.

At Lilongwe, Malawi, ICRAF organized two workshops for extension staff to learn about agroforestry and on-farm research methods and to plan research implementation. National scientists collaborating with ICRAF research projects in all countries also participate regularly in training courses, workshops and research planning sessions.

In 1991, the IRA/ICRAF project team in Cameroon trained 50 farmers in nursery techniques and tree planting for hedgerow intercropping. Many of these farmers established group nurseries and are now raising seedlings. The project staff also collaborated with IITA's Testing and Liaison Unit to conduct a series of training sessions and demonstrations on tree management for farmers participating in hedgerow-intercropping trials.

Preparation of teaching materials

Training courses at ICRAF headquarters and in the field are supported by the compilation of teaching materials, lecture notes, case studies and selected readings. Some of this material is prepared in both English and French. By the end of 1991, teaching materials had been prepared for the courses on agroforestry research for development, on field experimental methods and data collection, on socio-economic research methods, and on computerized data handling.

This area of work will expand considerably in 1992. A five-year project is being launched to develop agroforestry teaching materials with support from DSO (Netherlands). Well produced and widely distributed agroforestry teaching materials will provide a major resource for national training programmes and will facilitate the decentralization of ICRAF's own training activities.

Photo: A. Njenga

A Ph.D. fellow conducting field work with ICRAF's research programme in Malawi takes soil samples under Faidherbia albida *trees growing on farmers' fields.*

Many universities and agricultural training institutes in Africa have introduced agroforestry courses in recent years, but most teachers and curriculum-development specialists have never studied agroforestry themselves and they are often uncertain about where to find appropriate teaching materials. ICRAF's education programme focuses on support to agroforestry teaching at the diploma, certificate and postgraduate levels.

A project was launched in 1988 to develop curricula for agroforestry education in African universities, particularly at the M.Sc. level. In 1990, a related project was introduced to support agroforestry curriculum development in technical colleges at the certificate and diploma levels. Both projects were funded by SIDA.

The university-level project has involved several workshops and consultative meetings with African academics. In 1991, project staff visited the University of Science and Technology at Kumasi, Ghana, the University of Zimbabwe, the University of Zambia, and the University of Malawi's Bunda College of Agriculture.

These meetings, combined with consultations in 1990, have resulted in the formulation of a model curriculum for an M.Sc. programme in agroforestry. In addition, curricula have been developed for M.Sc. programmes in agriculture, forestry and livestock production with strong agroforestry components.

Between 50% and 80% of graduates from technical institutions work as government extension officers or as field staff in non-governmental organizations, suggesting that support for agroforestry education at technical colleges has an important impact on farmers. In 1991,

Photo: A. Njenga

A farmer practising agroforestry in western Kenya discusses soil-fertility problems with a field technician.

ICRAF's technical education project included consultative visits to 10 institutions in eight countries of Eastern and Southern Africa These technical training colleges all teach aspects of agroforestry, but they lack textbooks, teaching material and instructions for field exercises, and their teaching staff lack specific agroforestry training.

As a step towards filling these gaps, 14 lecturers and teachers from universities and technical colleges in Ethiopia, Kenya, Malawi, Tanzania and Zambia took part in ICRAF's introductory course on agroforestry research for development in October 1991. These participants stayed on for a four-day workshop after the course to discuss teaching methods for agroforestry, with a focus on field exercises and instructional material. The workshop was sponsored by SIDA, FAO and the Finish International Development Agency (FINNIDA).

The workshop participants reviewed a number of model curricula and teaching materials and evaluated their suitability for their home institutions. They recommended changes and suggested guidelines for further curriculum development and material preparation.

This approach—combining participation in a general course on agroforestry with a subsequent workshop on agroforestry teaching—turned out to be an effective way to train teaching staff. The participants particularly appreciated the opportunity to meet the research scientists who also participated in the agroforestry course.

During 1991, the post-graduate diploma course in agroforestry at Ghana's University of Science and Technology expanded into a full M.Sc. degree programme with the registration of five students. This initiative may provide a model for post-graduate degree programmes in other African universities. ICRAF is providing teaching materials and opportunities for field work through collaborative research programmes in the region.

Based on current work in agroforestry education at the university and technical-college levels, a proposal for a larger project to support agroforestry education was finalized in 1991 and submitted for donor funding. The goals are to establish an African Network for Agroforestry Education (ANAFE), based at ICRAF headquarters, and to support implementation of the model curricula that have been developed.

ANAFE will be open to institutions and staff members involved in professional and technical agroforestry education in Africa. In addition to normal network activities—such as meetings, exchange programmes and information sharing—the project will include components for long- and short-term teacher training and development of instructional materials.

Photo: A. Njenga

In 1991, ICRAF gained access to two major bibliographic databases on CD-Rom, substantially increasing the information resources available to staff and collaborating scientists.

The primary objective of ICRAF's Information and Documentation Programme is to advance agroforestry research and development through the identification, acquisition, processing and dissemination of information. The audience is wide—including agroforestry researchers, trainers, policy makers and development agents. ICRAF specialists are also working to strengthen the agroforestry information-management capabilities of national institutions through training, advice and computer support.

Expanding ICRAF's information resources

One major activity in 1991 was the restructuring and verification of ICRAF's in-house bibliographic database—AFBIB. At the same time, about 2500 new records were entered into the database during the year, bringing the total size to 20,000. AFBIB should be ready for dissemination to selected institutions in 1992.

The range of bibliographic information available at ICRAF increased substantially in 1991 with the acquisition of two bibliographic databases on CD-ROM. These are *CAB Abstracts*, containing abstracts, bibliographic details and indexing from nearly 50 abstracting journals published by CAB International (CABI) in the UK and *KIT Abstracts*, containing all abstracts published in *Abstracts on Tropical Agriculture* and *Abstracts on Rural Development in the Tropics* by the Royal Tropical Institute of the Netherlands. Between them, these two databases contain millions of records

from the literature on tropical agriculture and forestry.

These two acquisitions enhance ICRAF's other outside information resources—the databases of the United States Department of Agriculture (AGRICOLA) and FAO's International Information System for Agricultural Sciences and Technology (AGRIS). ICRAF also released its own *Multipurpose Tree and Shrub Database* in 1991.

During the year, ICRAF's library subscribed to 111 journals and acquired more than 800 books and 2100 reprints, bringing the total collection to 6800 books and 15,000 reprints. Most titles are selected on the recommendation of the scientific staff.

Improving information services and products

In 1991, information staff undertook a major review aimed at improving the range and quality of ICRAF's information services. One specific objective was to expand services to agroforestry research and training institutions in Asia and Latin America.

Using the in-house and external databases plus the library resources available at ICRAF, information staff provide several different services and products. In 1991, they responded to nearly 500 requests for literature searches, as well as about 80 requests for information from the *Multipurpose Tree and Shrub* database.

The information and documentation team publishes and distributes a *Bimonthly Accessions List* to 335 libraries and individuals worldwide. This periodical was considerably enhanced in 1991 with the addition of informative abstracts. Information staff also helped prepare and publish an annotated bibliography, *Agroforestry for Development in Kenya*, covering 345 documents from ICRAF's in-house database.

ICRAF copublishes a quarterly abstracting journal, *Agroforestry Abstracts*, with CABI. In addition to providing review articles and identifying suitable documents to cover in the journal, ICRAF sponsors 500 free subscriptions to key research institutes and individuals around the world. CABI provides abstracts and bibliographic information from the journal on diskette for inclusion in ICRAF's in-house database.

ICRAF also copublishes the international journal, *Agroforestry Systems*, and provides 120 subscriptions to selected research institutions in developing countries free or on an exchange basis. An important component of ICRAF's internal review of information services in 1991 was a detailed survey of the recipients of *Agroforestry Abstracts*, *Agroforestry Systems* and the *Bimonthly Accessions List*.

The information and documentation staff serve as a focal point for agroforestry information within the United Nations Environment Programme's (UNEP) environmental information network—INFOTERRA. Information staff also provide material to FAO's AGRIS database and serve as a distribution point for Micro CDS/ISIS, the textual database management package developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO). In 1991, ICRAF issued copies of this important documentation tool to eight institutions in Africa.

ICRAF's selective dissemination of information (SDI) service is being expanded to include coverage of external databases. Information staff prepared a new information form for wide distribution to provide a basis for user profiles. When fully operational, a selected group of agroforestry researchers will receive ICRAF's SDI service—known as *Agroforestry Updates*—on a monthly basis.

The ICRAF library also improved its services during the year. This has involved extending the open hours, providing user access to the CD-ROM databases, and improving the photocopy service.

Strengthening national information-management capabilities

ICRAF provides training, professional advice and other assistance to help strengthen the capacity of national research systems to manage and disseminate information on agroforestry. In 1991, the major focus was on the French-speaking countries participating in the SALWA region. This work was funded by CIDA.

The information staff conducted a two-week training course and planning workshop in August 1991 for 14 information specialists from national agricultural research systems in Burkina Faso, Mali, Niger and Senegal, plus the information network for the region, Réseau sahélien de documentation (RESADOC) of INSAH. During the planning workshop, held in Bamako, Mali, participants outlined the information requirements for agroforestry research in the sahelian region and formulated a detailed two-year plan for the delivery of information services at the national, regional and international level, including requirements for material and financial resources.

The training course covered various aspects of agroforestry information management, with emphasis on Micro CDS/ISIS. Based on the needs identified during the planning workshop, operational funds and equipment have been provided to national focal points for agroforestry information in each of the four countries and to RESADOC.

In addition to the course in West Africa, seven information specialists from national agricultural research systems came to ICRAF headquarters for on-the-job training during the year. These included five from Kenya and two from Ghana.

A documentalist enters information into ICRAF's bibliographic database—AFBIB.

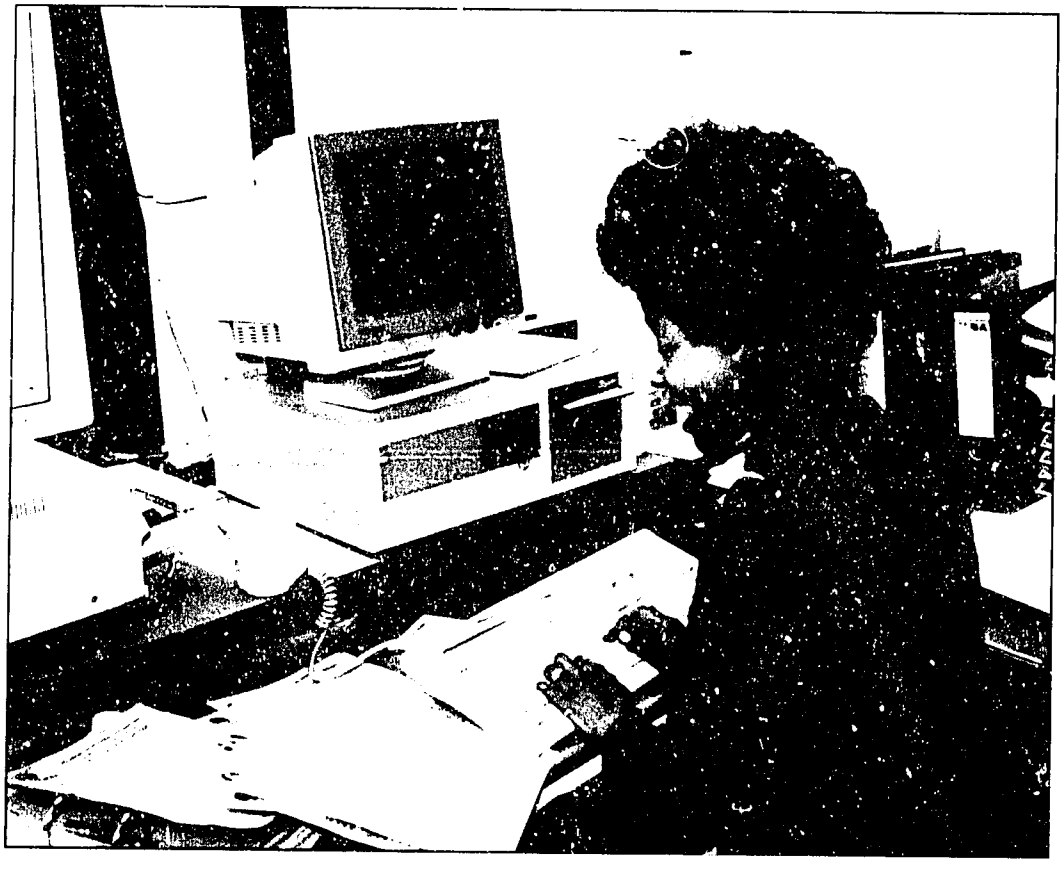


Photo: A. Njenga

Photo: A. Njenga

In November 1991, the Communications Programme organized an International Centres Day to celebrate ICRAF's entry into the CGIAR. The International Plant Genetic Research Institute (IPGRI) was one of 11 participating research organizations.

The Communications Programme helps ensure that agroforestry research results, information about agroforestry development activities and general information about ICRAF all reach a range of appropriate target audiences. These include researchers, development specialists, policy makers, trainers, educators and extensionists, in addition to the broader public around the world.

To meet these goals, communications activities include publication, translation, distribution, audiovisual production and services, and public awareness. All communications work is conducted in close collaboration with ICRAF's research and training programmes.

Publications in 1991

ICRAF staff contribute to the international literature on agroforestry through journal articles, scholarly books and conference papers. In 1991, staff members published 20 articles in refereed journals, 11 articles in ICRAF's magazine *Agroforestry Today*, five books and two computer software packages.

ICRAF's major periodical publications are the quarterly magazine, *Agroforestry Today*, and the annual report. ICRAF also publishes monographs, computer programs, conference proceedings, field guides, sourcebooks and annotated bibliographies on different aspects of agroforestry.

Produced for a broad audience, *Agroforestry Today* serves both a communications and a promotional function. Articles cover the field of agroforestry as a whole, not just activities at ICRAF, with substantial contributions from researchers and development workers all over the world. Half of the magazine is devoted to feature articles and the other half to departments, including letters from readers, news items, a question-and-answer section, book reviews, and notices of conferences and training courses.

The annual report contains information for readers concerned more specifically with

ICRAF. As more results become available from ICRAF's strategic and collaborative research programmes, the annual report is becoming a forum for substantial reports on agroforestry research in different ecological zones.

In addition to its own periodicals, ICRAF copublishes *Agroforestry Systems*, an international scholarly journal, with Kluwer Academic publishers in the Netherlands. ICRAF scientists are frequent contributors to the journal and senior staff play a major role in the journal's peer-review and policy-making functions.

Eight major book-length publications appeared in 1991. One of these, *A Tree for All Reasons*, is a field manual for the introduction and evaluation of multipurpose trees. This 168-page guidebook is designed to help agroforestry field workers evaluate tree survival and early growth, as evidence of site adaptability, and assess tree phenology and morphology, as indications of suitability for specific agroforestry technologies. The manual includes a checklist of principle tree characteristics and products, a list of tree assessments with sample formats, detailed 'how-to' explanations of appropriate experimental designs, and summary plans for 10 types of experiment.

ICRAF's *Multipurpose Tree and Shrub Database*, also published in 1991, is a computerized software package containing practical information on 1093 woody species suitable for agroforestry in the tropics and subtropics. A companion 336-page sourcebook, *Multipurpose Trees and Shrubs: Sources of Seeds and Inoculants*, identifies seed sources for more than 900 woody species, plus inoculants to facilitate biological nitrogen fixation.

Another research tool released in 1991 was version 2.1 of Datachain, a computer program designed for recording and processing the complex data that typically emanate from agroforestry field experiments. Datachain helps the researcher specify an experimental design, enter values measured in the field, and select, sort, combine and convert these values in preparation for statistical analysis. Once preprocessing is completed, Datachain writes programs for passing the data on to an appropriate statistics package. Since the first version was released in 1989, more than 150 copies of this software have been distributed to national and international organizations conducting agroforestry research.

Members of the scientific and development communities are increasingly concerned with understanding how agroforestry systems work in farmers' fields. With this interest has emerged a clear need to identify and evaluate methods for on-farm agroforestry research and to guide researchers towards successful approaches and techniques. To address this need, ICRAF organized a series of reviews culminating in an international workshop held in Nairobi in 1990, with financial support from the Ford Foundation.

A selection of the papers presented at the workshop was published in 1991 as a special issue of *Agroforestry Systems*, and a brief summary of the presentations and discussions was published separately by ICRAF. These publications are part of a long-term research commitment, which will include a follow-up workshop on socio-economic and on-farm agroforestry research in 1992.

Apart from contributing to an increasingly important area of agroforestry research, these linked publications represent a careful consideration of how best to publish material emanating from conferences and workshops. An international conference on agroforestry in the subhumid zone of Southern Africa, held in 1991, will result in a similar pair of publications in 1992—a stringent selection of papers will appear as a special issue of the international journal *Forest Ecology and Management* and a brief summary of the conference proceedings will be published separately by ICRAF.

Information on agroforestry tends to be scattered among a variety of published and unpublished documents, making it difficult for researchers to identify and obtain the material they need. The broad and varied scope of agroforestry as a field of study makes information tools such as bibliographies particularly valuable. As part of an ongoing series, ICRAF published two annotated bibliographies in 1991—one on the economic analysis of agroforestry technologies and another on the rich array of agroforestry research and development work that has taken place in Kenya.

In addition to these major publications, ICRAF achieves rapid and inexpensive dissem-

ination of research results through three series of informal reports. These are made available for comment and discussion and to inform interested colleagues about work in progress. Many are eventually revised and published in more permanent form. In 1991, ICRAF scientists published 17 of these informal documents—four Working Papers, 11 AFRENA Reports, and one Training and Education Report.

Staff of the Communications Programme also compile ICRAF's internal newsletter, *Teleraf*. This is distributed weekly to all headquarters and outposted staff plus members of the Board of Trustees.

Translation and publication in French

In view of the potential role of agroforestry in much of francophone Africa and the valuable contribution of several francophone countries to the AFRENA programme, ICRAF is strongly committed to translating major publications into French. In 1991, the annual report and all issues of *Agroforestry Today* were translated and published in French. The French edition of the magazine, *L'agroforesterie aujourd'hui*, is more than a simple translation: it is increasingly tailored for a francophone audience with relevant news items, letters, announcements, calendar notes and book reviews.

In 1991, ICRAF also published one Working Paper, five AFRENA Reports, and various instructional materials, posters, brochures and course notes in French. In addition, translation staff continued work on a computerized English-French glossary and thesaurus of agroforestry-related terms. Translation work is complemented by a continuous effort to verify and expand ICRAF's distribution list of francophone readers.

Distribution

Agroforestry Today is distributed free to readers around the world. In early 1992, the mailing list for the magazine comprised 8743 confirmed addresses, a 41% increase from the beginning of 1991 (Table 61).

In light of this rapid expansion, communications staff are particularly careful to ensure that growing printing and distribution costs are well justified. Following a verification exercise completed in 1990, all recipients who failed to con-

Table 61. Distribution of Agroforestry Today *readers by geographic region, as of March 1992.*

East Africa	1965
Central Africa	360
Southern Africa	646
West Africa	1128
North Africa	65
Total Africa	**4164**
Middle East	102
South Asia	1022
Southeast and East Asia	597
Oceania	299
Total Middle East, Asia and Oceania	**2020**
South America	357
Central America	198
Caribbean	150
Total South America, Central America and Caribbean	**705**
North America	831
Europe	1023
Overall Total	**8743**
Total as of 31 December 1990	**6200**
Net increase in 14.5 months	**2543**
Percentage increase in 14.5 months	**41%**

firm their continued interest in *Agroforestry Today* were deleted from the mailing list. New readers who ask for the magazine are sent a single copy with a reader survey form. Only when the completed form is returned are their names added to the list for future issues.

All other ICRAF publications are announced in *Agroforestry Today* and copies are sent out on request. Prices are set on a cost-recovery basis but are waived for many readers in developing countries. In 1991, ICRAF distributed 7914 books on request, as well as large numbers of reprints, Working Papers, AFRENA Reports and other publications.

In addition to distribution on request, all publications are sent to outposted staff, members and former members of the Board of Trustees, representatives of donor organizations, and specialized libraries.

Audiovisual and graphic production and services

ICRAF's computerized database of colour slides increased from around 5000 to 7744 in 1991, reflecting a major effort over the course of the year. The collection of black-and-white photographs increased from around 5000 to 7992. More than 150 slides and black-and-white photographs were distributed on request, primarily for use in outside publications, and 102 copies of ICRAF's slide sets were sold or given away during the year.

ICRAF's photographs, posters, publications and video presentation, *The Promise of Agroforestry*, were featured in several exhibitions, agricultural shows, meetings and conferences. Not the least was an extensive, permanent photographic exhibit on agroforestry and agroforestry research prepared in 1991 for ICRAF's headquarters building. Smaller, related exhibits were prepared for the AFRENA offices around Africa.

Communications staff also provided technical support for all ICRAF conferences. They supplied artwork, desktop-publishing and paste-up services for all ICRAF publications, and prepared overheads, slides and posters for conference presentations by ICRAF staff and national collaborators. Finally, communications staff helped ICRAF scientists make photographic records of agroforestry systems and experimental work.

Public awareness

Many ICRAF staff members are involved in promotional activities to increase public awareness of agroforestry and of ICRAF. These include interviews with journalists, preparation of press releases, and appearances on local radio and television. ICRAF is also an active participant in the global public-awareness campaign sponsored by the CGIAR. The Communications Programme's two major public-awareness activities in 1991 were the production of a series of posters on agroforestry and the organization of an International Centres Day to celebrate ICRAF's entry into the CGIAR.

ICRAF first produced a series of five large posters in 1987 to celebrate its tenth anniversary. Although these were produced in English only and focused on agroforestry activities in Kenya, they proved extremely popular with a wider audience.

In 1991, ICRAF produced a new series of five posters in English, French and Spanish, depicting the benefits of agroforestry from the farmer's viewpoint and illustrating agroforestry activities across a range of continents and climatic zones. At the same time, the old posters were reprinted, so that ICRAF now has a good collection of large (84 x 59 cm), colourful display material for distribution to agroforestry research and development organizations around the world.

On 19 November 1991, hundreds of government officials, academics, and staff of non-governmental organizations and donor agencies came to ICRAF headquarters for International Centres Day. Ten other agriculture, livestock, environment and forestry research institutes working in Kenya joined ICRAF to mount displays, give demonstrations, make talks and meet the guests. These were six centres within the CGIAR, two United Nations agencies and two Kenyan national research institutes--the International Laboratory for Research on Animal Diseases (ILRAD), ICRISAT, the International Maize and Wheat Improvement Centre

(CIMMYT), the International Potato Centre (CIP), ILCA, IPGRI, UNEP's Global Resources Information Database (GRID), UNESCO's Tropical Soil Biology and Fertility Programme (TSBF), KEFRI and KARI.

The all-day programme featured displays and demonstrations and a seminar on topics of particular interest to Kenyans. Participating institutions displayed everything from protozoan parasites to furniture made of Kenyan wood to computerized environmental monitoring systems. There was also a special exhibit of brochures and display material from all the CGIAR centres not represented in Nairobi. The sheaves of grain, multipurpose-tree seedlings and baskets of rice, beans, potatoes and cassava clearly demonstrated the breadth of research in progress when all the international centres join their efforts. The participating institutions have plans to make International Centres Day a regular event, to be hosted by different centres in the group.

In 1991, staff of ICRAF's Communications Programme helped produce *Agroforestry: a sustainable system*, a 23-minute television documentary made by the Kenya Broadcasting Corporation and featuring ICRAF's research work. Communications staff also prepared an *ICRAF Information Kit* with text and photographic slides and overheads for use by all ICRAF staff members when making presentations.

Communications staff provide background information, arrange field trips and schedule interviews for visiting writers and broadcasters that result in publicity on agroforestry for audiences overseas. In 1991, ICRAF received a radio broadcaster from the British Broadcasting Corporation (BBC), a film crew from the Australian television series *Beyond 2000*, and a science writer from the German newspaper, *Die Welt*.

In addition, staff members prepare press releases and work with local journalists and television crews in all the countries where strategic and collaborative research is in progress. As ICRAF does not employ a clipping service, it is difficult to gauge the number of articles on ICRAF appearing in the world press. However, in 1991, at least 35 articles on ICRAF appeared in national newspapers in India, Kenya, Malawi, Mali, Uganda, and Zimbabwe, and five articles appeared in international newsletters and magazines. ICRAF staff also made several appearances on local television.

Training and institution building

As resources allow, communications staff provide training and support in the form of editing, translating, audiovisual services and graphic design to other sections of ICRAF and to collaborating institutions. In 1991, a member of ICRAF's communications staff led a session on scientific writing for a regional training course conducted by AFNETA. Training sessions on aspects of scientific writing and photography were also conducted for ICRAF headquarters and outposted staff.

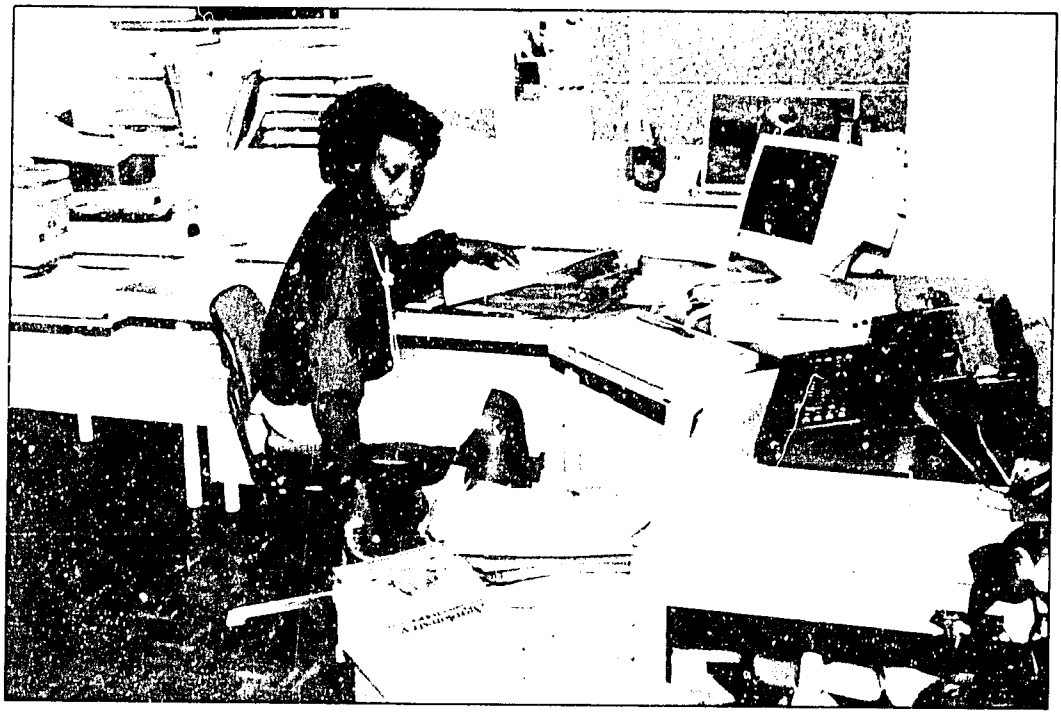


Photo: A. Njenga

ICRAF publications are distributed to a wide audience in developed and developing countries.

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Photo: A. Njenga

It takes a lot of people to conduct agroforestry research: scientists and field workers with ICRAF's collaborative project at the Chalimbana Agricultural Field Station in Zambia.

Name	Position/Discipline (Nationality)	Date Joined (Left)	Duty Station
Office of the Director General			
Dr Björn Lundgren	Director General (Sweden)	1.9.81 (31.8.91)	Nairobi
Mr Edmund Barrow	Senior Scientist/Agroforestry (Ireland)	9.1.90	Nairobi
Dr Peter Huxley	Principal Research Advisor (UK)	4.1.79	Nairobi
Dr Elizabeth Migongo-Bake	Research Officer/ Range Management (Kenya)	12.11.90	Nairobi
Mr George Mbiriri	Protocol Officer (Kenya)	3.6.91	Nairobi
Dr Pedro Sanchez	Director General (USA)	1.10.91	Nairobi
Mr R. Bruce Scott	Deputy Director General (Canada)	1.1.88	Nairobi
Mrs Joyce Kasyoki	Secretary (Kenya)	13.2.89	Nairobi
Miss Anne Kinyanjui	Bilingual Secretary (Kenya)	10.9.90	Nairobi
Mr Albert Kirima	Messenger (Kenya)	1.7.87	Nairobi
Miss Terry Knudsen	Principal Secretary (Kenya)	1.11.83	Nairobi
Mrs Florence Mboya	Principal Secretary (Kenya)	1.9.78	Nairobi
Mrs Lucy Munge	Cleaner/Tea Lady (Kenya)	1.6.88	Nairobi
Mrs Carmen Rohr	Principal Secretary (Nicaragua)	1.11.91	Nairobi
Finance and Administration			
Mr Derek Sickelmore	Director of Finance and Administration (UK)	1.1.86	Nairobi

Name	Position/Discipline (Nationality)	Date Joined (Left)	Duty Station
Mr Augustine Aghaulor	Head of Finance (Nigeria)	1.8.89	Nairobi
Mr Ramneek Bhabra	Head of Operations (Kenya)	17.9.90	Nairobi
Mr Jairos Granados	Information Systems Manager (Colombia)	1.12.90	Nairobi
Mrs Virginia Guerrero	Head of Human Resources (Venezuela)	1.4.89	Nairobi
Mr George Maina	Financial Accountant (Kenya)	1.10.89	Nairobi
Mrs Neena Sood	Associate Travel and Conference Officer (Iran)	1.11.89	Nairobi
Miss Alyce Achungo	Senior Secretary (Kenya)	9.8.90	Nairobi
Mr Julius Akhatsika	Cleaner (Kenya)	1.11.85	Nairobi
Mrs Frashia Chege	Tea Lady/Cleaner (Kenya)	1.7.87	Nairobi
Mrs Margaret DeSouza	Personnel Assistant (Kenya)	1.10.87	Nairobi
Mr Lawi Gakombe	Cleaner (Kenya)	1.7.87	Nairobi
Mr Ernest Gatoru	Assistant Accountant-Projects (Kenya)	1.9.88	Nairobi
Mr John Gitau	Mail/Filing Clerk (Kenya)	1.3.84	Nairobi
Mr Bernard Hware	Photocopy Operator (Kenya)	15.7.87	Nairobi
Mr Isaac Inanga	Driver (Kenya)	1.8.91	Nairobi
Mr Barnabas Inyaa	Administrative Officer-Operations (Kenya)	7.6.91	Nairobi
Mr Theophilus Ivati	Mechanic (Kenya)	1.7.81	Nairobi
Mrs Margaret Kabaya	Tea Lady/Cleaner (Kenya)	1.6.90	Nairobi
Mr James Kagiri	Photocopy Operator (Kenya)	1.10.85	Nairobi
Mrs Dorothy Kamaan	Receptionist/Telex Operator (Kenya)	1.8.87	Nairobi
Mr Thaddeus Kamundi	Computer Operator (Kenya)	1.8.88	Nairobi
Mr Joseph Kanyonyo	Senior Driver (Kenya)	1.1.91	Nairobi
Mr Peter Kang'ethe	Driver (Kenya)	1.6.87 (18.11.91)	Nairobi
Mr Peter Kanyasya	Assistant Accountant-General Ledgers (Kenya)	15.9.89	Nairobi
Mr James Kariuki	Driver (Kenya)	1.7.87	Nairobi
Mrs Bithia Kedeng'e	Principal Secretary (Kenya)	1.3.86	Nairobi
Mr Kariuki King'aru	Administrative Assistant-Transport (Kenya)	1.9.87	Nairobi
Mr Michael Kuria	Storekeeper (Kenya)	1.9.83	Nairobi
Mr Hudson Luvinzu	Cleaner (Kenya)	1.8.88	Nairobi
Mr Arthur Makindu	Cashier (Kenya)	1.1.88 (28.2.91)	Nairobi
Mr John Mbugua	Messenger (Kenya)	1.11.85 (30.11.91)	Nairobi
Mr William Mburu	Disbursement Clerk (Kenya)	20.2.90	Nairobi
Mr David Michino	Accounts Clerk-Receivables (Kenya)	1.8.88	Nairobi
Miss Jane Moraa	Filing Clerk (Kenya)	1.7.87	Nairobi
Mr Josphat Muli	Carpenter (Kenya)	1.10.87	Nairobi
Mr Daniel Mungai	Cashier (Kenya)	2.9.91 (19.11.91)	Nairobi
Mr David Musili	Cleaner (Kenya)	1.10.87	Nairobi
Miss Margaret Mutua	Information Systems Assistant-Accounts (Kenya)	1.10.85	Nairobi
Mrs Wanjiru Nduati	Secretary (Kenya)	1.10.91 (31.12.91)	Nairobi
Mr Francis Ndungu	Senior Messenger (Kenya)	1.2.85	Nairobi
Mrs Teresia Ng'ang'a	Secretary (Kenya)	1.8.86	Nairobi
Miss Faith Ngari	Tea Lady/Cleaner (Kenya)	1.6.83	Nairobi
Mrs Grace Ngugi	Receptionist/Telex Operator (Kenya)	1.8.87	Nairobi

Name	Position/Discipline (Nationality)	Date Joined (Left)	Duty Station
Miss Gladwell Njenga	Senior Secretary (Kenya)	1.1.91	Nairobi
Mrs Irene Njiraini	Assistant Accountant-Projects (Kenya)	1.3.90	Nairobi
Mr David Nyaga	Messenger (Kenya)	1.12.87	Nairobi
Mr Banabas Nyachienga	Senior Driver (Kenya)	1.5.88	Nairobi
Mr Anthony Okello	Electrician (Kenya)	1.11.87	Nairobi
Mrs Margaret Oluoch	Assistant Accountant-Payroll (Kenya)	19.9.83	Nairobi
Miss Catherine Omega	Cleaner (Kenya)	19.3.90	Nairobi
Mr Samuel Omondi	Junior Carpenter (Kenya)	1.10.90	Nairobi
Mr John Opande	Driver (Kenya)	1.10.87 (15.6.91)	Nairobi
Ms Rose Thuo	Senior Secretary (Kenya)	24.8.87	Nairobi
Mrs Lucy Wambua	Procurement Clerk (Kenya)	1.4.83	Nairobi
Ms Lucy Wanjau	Receptionist (Kenya)	1.6.87	Nairobi
Mr Humprey Wanjohi	Cleaner (Kenya)	1.11.88	Nairobi
Research Division			
Dr Peter Cooper	Divisional Director /Agronomy (UK)	1.11.90	Nairobi
Mr Elijah Akunda	Research Officer/Crop Physiology (Kenya)	1.1.86	Nairobi
Dr Ekow Akyeampong	Scientist/Agronomy (Ghana)	1.1.87	Burundi
Dr Marcelino Avila	Principal Scientist/ Agricultural Economics (Belize)	13.7.87	Nairobi
Dr Bahiru Duguma	Scientist/Forestry (Ethiopia)	1.2.87	Cameroon
Mr Bashir Jama	Research Assistant (Kenya)	1.9.86	Nairobi
Dr Dale Bandy	Coordinator-Latin America and Asia (USA)	1.11.91	Nairobi
Dr Michel Baumer	Senior Scientist/Range Management (France)	1.9.83 (31.12.91)	Nairobi
Dr Douglas Boland	Senior Scientist/Silviculture (Australia)	1.1.91	Nairobi
Dr Eduard Bonkoungou	Regional Coordinator/Ecology (Burkina Faso)	1.7.90	Burkina Faso
Ms Elisabeth von Capeller	Research Associate/Agronomy (Switzerland)	6.11.89 (31.10.91)	Cameroon
Mr Peter von Carlowitz	Senior Research Scientist/Forestry (GTZ) (Germany)	26.6.82 (30.6.91)	Nairobi
Mr Richard Coe	Senior Scientist/Biometry/Statistics (UK)	15.10.90	Nairobi
Dr Mamadou Djimdé	Scientist/Animal Science (Mali)	1.5.85	Nairobi
Dr Belson Dzowela	Senior Scientist/Agroforestry (Malawi)	1.2.91	
Ms Marie-Paul Enilorac	Scientist/Forestry (France)	5.5.91	Kakuyuni
Mr Francis Esegu	Consultant (Uganda)	1.2.91	Maseno
Dr Steve Franzel	Senior Scientist/Agricultural Economics (USA)	1.5.91	Nairobi
Mr Arne Heineman	Research Associate/Forestry (Netherlands)	17.11.87	Maseno
Mr Dirk Hoekstra	Regional Coordinator/Agricultural Economics (Netherlands)	1.3.82	Nairobi
Dr Cherrnor Kamara	Senior Scientist/Soil Science (Sierra Leone)	1.9.88	Zambia

Name	Position/Discipline (Nationality)	Date Joined (Left)	Duty Station
Dr Moses Karachi	Scientist/Agronomy (Kenya)	1.8.88	Tanzania
Mr Paul Kiepe	Research Associate/Soil Science (Netherlands)	12.10.87	Nairobi
Dr Freddie Kwesiga	Senior Scientist/Forestry (Uganda)	1.4.85	Zambia
Dr David Ladipo	Scientist/Agroforestry (Nigeria)	1.11.90	Nigeria
Dr Jumanne Maghembe	Senior Scientist/Forestry (Tanzania)	1.6.87	Malawi
Mr. Jeremiah Maroko	Associate Research Officer/Soil Science (Kenya)	1.1.91	Nairobi
Dr Susan Minae	Scientist/Socio-Economics (Kenya)	1.8.85	Malawi
Mr Peter Muraya	Research Officer/Computer Applications (Kenya)	1.5.85	Nairobi
Dr David Ngugi	Regional Coordinator/Agronomy (Kenya)	1.11.85	Malawi
Mr Amadou Niang	Scientist/Forestry (Senegal)	15.1.89	Rwanda
Mr Peter Oduol	Associate Research Officer/Forestry (Kenya)	1.10.85 (30.6.91)	Nairobi
Ms Eva Ohlsson	Research Associate/Agronomy (Sweden)	1.1.90	Maseno
Dr Michael O'Neil	Senior Scientist/Agroforestry (USA)	17.10.91	Embu
Dr Chin Ong	Senior Scientist/Crop Physiology/ Microclimatology (Malaysia)	1.5.91	Nairobi
Dr Robert Otsyina	Scientist/Agroforestry (Ghana)	1.6.91	Tanzania
Dr Frederick Owino	Senior Scientist/Tree Breeding (Kenya)	10.8.87	Nairobi
Mr Barrack Owuor	Associate Research Officer/Tree Breeding (Kenya)	1.1.89	Maseno
Mrs Geeta Patel	Associate Administrative Officer (Kenya)	26.1.88	Nairobi
Dr Donald Peden	Senior Scientist/Range Management (Canada)	21.4.89	Uganda
Mr Andrew Pinney	Graduate Fellow (UK)	9.5.87	Nairobi
Mr Hendrik Prins	Research Associate/Forestry (Netherlands)	1.1.88	Malawi
Dr Meka Rao	Principal Scientist/Experimental Agronomy (India)	1.6.88	Nairobi
Dr Keith Shepherd	Scientist/Agronomy (Rockefeller) (UK)	14.12.89	Nairobi
Ms Erika Styger	Research Associate/Entomology (Switzerland)	15.1.90	Rwanda
Mr Rob Swinkels	Research Associate/Agricultural Economics (Netherlands)	12.5.89	Maseno
Mr Henricus Thijssen	Associate Expert/Agriculture (Netherlands)	5.6.88	Nairobi
Dr Emmanuel Torquebiau	Senior Scientist/Forest Ecology (France)	9.10.87	Nairobi
Mr Dennis Wambugu	Associate Research Officer/Agronomy (Kenya)	1.12.82	Nairobi
Dr John Weber	Scienitst/Forestry (USA)	2.9.91	Niger
Mr Gregory Wolf	Scientist/Forestry (GTZ) (Germany)	4.11.86 (30.6.91)	Nairobi
Dr Anthony Young	Principal Scientist/Soil Science (UK)	4.1.83	Nairobi
Mrs Halima Abdalla	Principal Secretary (Kenya)	1.7.88	Nairobi
Mrs Zarina Dossa	Senior Secretary (Kenya)	7.5.90	Nairobi
Miss Hannah Gitere	Tea Lady/Cleaner (Kenya)	1.8.87	Nairobi

Name	Position/Discipline (Nationality)	Date Joined (Left)	Duty Station
Miss Peniah Hassan	Bilingual Secretary (Kenya)	1.5.90	Nairobi
Ms Margaret Kiarie	Secretary (Kenya)	1.6.90	Nairobi
Mrs Josina Kimotho	Secretary (Kenya)	1.9.86	Nairobi
Mr Obadiah Kyunguti	Field Assistant (Kenya)	15.10.91	Muguga
Mrs Thecla Lohay	Administrative Assistant (Kenya)	1.6.84	Nairobi
Mr Abel Mageto	Messenger (Kenya)	15.7.87	Nairobi
Miss Stella Muasya	Secretary (Kenya)	26.8.82	Nairobi
Ms Claire Momoh	Senior Bilingual Secretary (Kenya)	1.3.88	Nairobi
Mrs Jennifer Muriuki	Secretary (Kenya)	1.1.89	Nairobi
Miss Laura Mwandawiro	Senior Bilingual Secretary (Kenya)	1.2.88	Nairobi
Mrs Judith Njagi	Secretary (Kenya)	1.1.89	Nairobi
Mr James Obande	Field Attendant (Kenya)	10.2.89	Maseno
Mrs Sarah Okoth	Secretary (Kenya)	1.8.87	Nairobi
Mrs Jane Waweru	Senior Secretary (Kenya)	1.3.80	Nairobi
Mr Paul Waweru	Senior Driver (Kenya)	1.1.79	Nairobi

Field Station—Machakos

Mr Peter Kurira	Assistant Research Officer/Farm Manager (Kenya)	1.8.81	Machakos
Mr Moses Mathuva	Associate Research Officer/Agronomy (Kenya)	1.6.89	Machakos
Mr Paul Ambani	Senior Field Assistant (Kenya)	1.9.88	Machakos
Mr Robin Chacha	Labourer (Kenya)	1.6.91	Muguga
Mr Kennedy Chondo	Labourer (Kenya)	1.1.88	Machakos
Mr Boniface Kamba	Labourer (Kenya)	1.1.88	Machakos
Mr George Kiilu	Labourer (Kenya)	1.1.83	Machakos
Mr George Kilonzo	Gardener (Kenya)	1.9.88	Machakos
Mr Sammy Kimau	Field Attendant (Kenya)	1.8.91	Machakos
Mr Muthoka Kioko	Labourer (Kenya)	1.1.88	Machakos
Mr Japheth Kyengo	Field Attendant (Kenya)	1.5.89	Machakos
Mr William Kyule	Labourer (Kenya)	8.9.81	Machakos
Mr Elijah Letaulo	Labourer (Kenya)	1.1.88	Machakos
Mr Muthoka Mailu	Field Attendant (Kenya)	1.7.90	Machakos
Mr John Malonzah	Labourer (Kenya)	1.7.88	Machakos
Mr Peter Mbiti	Field Assistant (Kenya)	1.9.86	Machakos
Mr Samuel Muga	Labourer (Kenya)	1.8.91	Muguga
Mr Joshua Mulinge	Laboratory Attendant (Kenya)	1.8.91	Muguga
Mr Zakayo Musembi	Labourer (Kenya)	1.7.88	Machakos
Mr Elijah Mutinda	Labourer (Kenya)	8.1.88	Machakos
Mr Patrick Mutua	Labourer (Kenya)	20.1.88	Machakos
Mr Leonard Mutunga	Labourer (Kenya)	1.1.88	Machakos
Mr Gilbert Mwasambu	Field Assistant (Kenya)	1.12.82	Machakos
Mr Maweu Ndambuki	Labourer (Kenya)	1.1.88	Machakos
Mr Muli Ndiku	Labourer (Kenya)	1.1.91	Machakos
Mr Philip Nzioka	Labourer (Kenya)	1.7.88	Machakos

Name	Position/Discipline (Nationality)	Date Joined (Left)	Duty Station
Mr Thomas Ondieki	Labourer (Kenya)	1.1.88	Machakos
Mr Gregory Waema	Labourer (Kenya)	1.1.90	Machakos

Training and Information Division

Dr Ester Zulberti	Divisional Director/Education (Argentina)	26.4.82	Nairobi
Dr E.O. Asare	Senior Visiting Fellow/Agronomy (SIDA) (Ghana)	19.2.89 (27.2.91)	Nairobi
Mr Jan Beniest	Scientist/Horticulture (Belgium)	16.1.89	Nairobi
Mr Bofete Bondole	Associate Information Officer (Zaire)	7.3.88	Nairobi
Mr David Brett	Editor/Writer (Australia)	4.8.90	Nairobi
Mr Michael Hailu	Coordinator/Information (Ethiopia)	1.3.91	Nairobi
Mr Bjorn Hansson	Research Associate/Curriculum Development (Sweden)	1.3.90	Nairobi
Ms Kellen Kebaara	Assistant Editorial Officer (Kenya)	3.12.84	Nairobi
Mr Jimmy Kiio	Training and Information Officer (Kenya)	3.6.91	Nairobi
Ms Annie Leymarie	French Translator/Reviser (France)	1.9.88 (31.12.91)	Nairobi
Mrs Milcah Mbindyo	Associate Administrative Officer (Kenya)	19.9.88	Nairobi
Mr Stephen Mburu	Associate Information Officer/ Computer Programmer (Kenya)	1.1.89	Nairobi
Mrs Hilda Munyua	Information Officer (Kenya)	1.5.86	Nairobi
Mr Anthony Njenga	Associate Audiovisual Officer (Kenya)	1.2.88	Nairobi
Ms Damary Odanga	Assistant Graphic Arts Officer (Kenya)	5.10.88	Nairobi
Mr Stephen Okemo	Library Coordinator (Kenya)	25.1.82	Nairobi
Ms Lucille Teemba	Information Officer (Kenya)	1.3.79	Nairobi
Mr James Wahome	Research Officer/Animal Science (Kenya)	1.8.84	Nairobi
Ms Sidney B. Westley	Coordinator/Communications (USA)	1.8.88	Nairobi
Mrs Alice Aduol	Senior Secretary (Kenya)	1.9.86	Nairobi
Mr Bainitus Alenga	Graphic Technician (Kenya)	18.8.90	Nairobi
Mrs Lucy Chege	Secretary (Kenya)	1.1.85	Nairobi
Mrs Eunice Gimode	Principal Bilingual Secretary (Kenya)	9.11.87	Nairobi
Miss Rebecca Kairu	Secretary (Kenya)	17.6.91	Nairobi
Ms Marion Kanyugo	Senior Secretary (Kenya)	18.10.89	Nairobi
Mrs Colleen Kimwemweh	Bilingual Secretary	1.7.90	Nairobi
Mrs Marie Kimenye	Secretary (Kenya)	1.8.86	Nairobi
Mr Samuel Maina	Messenger (Kenya)	1.11.85	Nairobi
Mrs Janet Muga	Secretary (Kenya)	1.1.88	Nairobi
Miss Ezzy Muhenge	Secretary (Kenya)	1.9.86	Nairobi
Mr Alfred Mureithi	Library Assistant (Kenya)	1.1.89	Nairobi
Ms Mercy Mwangi	Senior Bilingual Secretary (Kenya)	1.11.88	Nairobi
Mrs Josephine Ngugi	Junior Documentalist (Kenya)	1.4.91	Nairobi
Miss Lucy Ngugi	Secretary (Kenya)	3.6.91	Nairobi
Miss Dolly Ogonda	Bilingual Secretary (Kenya)	10.9.90 (9.6.91)	Nairobi
Miss Marie Song'e	Bilingual Secretary (Kenya)	13.5.91	Nairobi
Mrs Penina Wandhala	Tea Lady/Cleaner (Kenya)	1.11.85	Nairobi

CORE FUND—REVENUE AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31 DECEMBER 1991

	1991 (US$'000)	1990 (US$'000)
Revenue		
Unrestricted core grants	4771	4050
Restricted project grants	5982	4982
Sundry income	243	251
Total revenue	**10996**	**9283**
Expenditure		
Research	5690	5267
Training and information	2360	1485
Board and management	1078	703
Finance and administration	1481	1077
Depreciation of capital assets	340	1207
Total expenditure	**10949**	**9739**
Surplus (deficit) of revenue over expenditure for the year before the following items:	47	(456)
Provision for renewal of fixed assets	(120)	—
Provision for budget deficit	250	(250)
Transfer from funds invested in fixed assets	—	1207
Surplus (deficit) for the year	**177**	**501**
Statement of accumulated core funds		
Balance as at 1 January	(165)	(666)
Surplus (deficit) for the year	177	501
Balance as at 31 December	12	(165)

Note: The complete 1991 audited financial statements will be supplied upon request.

BALANCE SHEET AT 31 DECEMBER 1991

	1991 (US$'000)	1990 (US$'000)
Fixed assets	**3663**	**2999**
Current assets		
Stocks	96	70
Donor debtors	938	949
Other debtors and prepaid expenses	594	707
Bank balances and cash	761	1026
	2389	**2752**
Current liabilities		
Restricted projects fund	494	773
Donations received in advance	217	784
Creditors and accrued charges	1543	1223
	2254	**2780**
Net current assets (liabilities)	**135**	**(28)**
Net assets	**3798**	**2971**
Funded by:		
Funds invested in fixed assets	3663	2999
Capital fund	32	—
Core funds	12	(165)
Long-term loan	91	137
	3798	**2971**

STATEMENT OF CHANGES IN FINANCIAL POSITION FOR THE YEAR ENDED 31 DECEMBER 1991

	1991 (US$'000)	1990 (US$'000)
Source of funds		
Surplus (deficit) for the year	177	501
Adjustment for items not involving movement of funds:		
Depreciation of fixed assets	340	1207
Provision for renewal of fixed assets	120	—
Funds generated from operations	**637**	**1708**
Funds from other sources		
Increase in funds invested in fixed assets	664	423
Increase in donations received in advance	—	784
Decrease in debtors and prepaid expenses	113	—
Increase in creditors	320	472
Decrease in donor debtors	11	—
Proceeds from sale of fixed assets	50	—
	1795	**3387**
Application of funds		
Additions to fixed assets	1142	423
Decrease in long-term loan	46	43
Increase in stock and goods in transit	26	28
Increase in donor debtors	—	506
Increase in debtors and prepaid expenses	—	68
Decrease in restricted projects fund	279	493
Decrease in donations received in advance	567	—
Decrease in fixed assets	—	1207
	2060	**2768**
Changes in net liquid funds		
(Decrease)/Increase in cash and bank balances	**(265)**	**619**

CORE SUPPORT GRANTS FOR 1990 AND 1991

	1991 (US$'000)	1990 (US$'000)
Canada (CIDA)	867	825
Japan	493	415
Netherlands	409	399
Sweden (SIDA)	397	—
Finland (FINNIDA)	393	294
Switzerland	354	290
Norway	305	309
Australia	296	183
African Development Bank	250	250
Sweden	234	244
World Bank (IBRD)	230	460
Germany	173	—
Belgium	150	162
Ford Foundation	150	150
France	61	69
Total	**4771**	**4050**

RESTRICTED PROJECT GRANTS FOR 1990 AND 1991

	1991 (US$'000)	1990 (US$'000)
Canada (CIDA)	1932	946
United States of America (USAID)	1114	1123
German Ministry for Economic Cooperation (BMZ)	443	279
Rockefeller Foundation	385	34
International Fund for Agricultural Development (IFAD)	353	500
Norwegian Agency for International Development (NORAD)	299	170
International Development Research Centre (IDRC)	254	270
Direct Support to Training Institutes in Developing Countries (DSO)—Netherlands	212	185
Denmark	120	—
Overseas Development Association (ODA)—UK	116	—
Switzerland	112	125
Sweden (SIDA)	102	635
Swedish Agency for Research Cooperation with Developing Countries (SAREC)	67	245
Ford Foundation	43	98
France	—	75
Australia (AIDAB)	—	42
Other	430	255
Total	**5982**	**4982**

ANALYSIS OF RESTRICTED PROJECT FUNDS AT 31 DECEMBER 1991 (US dollars)

	Balance at 1.1.1991	Income Received 1991	Income Accrued 1991	Total Available 1991	Personnel Costs	Supplies and Services	Travel	Fixed Assets Purchases	Total Expenditure	Balance
Ford Foundation										
Graduate Training	14 202	—	—	14 202	74	—	—	—	74	14 129
India—Bangladesh	50 985	—	—	50 985	26 538	10 387	14 060	—	50 985	0
Research Trainee	24 581	—	—	24 581	7 864	459	—	—	8 323	16 258
On-Farm Research Workshop	14 608	—	—	14 608	—	14 608	—	—	14 608	0
On-Farm Research Publication & Distribution	18 389	—	—	18 389	18 389	—	—	—	18 389	0
Senior Fellowship	—	42 730	—	42 730	1 724	6 401	1 008	3 370	12 503	30 227
CIDA										
Southern Africa AFRENA	—	1 351 476	60 654	1 412 130	903 116	234 373	127 452	147 189	1 412 130	0
SALWA	—	519 500	—	519 500	124 818	152 766	54 733	140 866	473 183	46 317
GTZ										
MPT Germplasm	104 119	320 734	—	424 853	200 295	124 981	52 954	45 349	423 579	1 274
Fellowships	—	122 546	—	122 546	79 074	29 449	—	—	108 523	14 023
SIDA										
Senior Fellowship	22 080	—	—	22 080	18 237	1 840	2 003	—	22 080	0
Agroforestry for Development in Kenya	45 169	—	—	45 169	—	12 788	—	—	12 788	32 381
Associate Expert (1)	26 505	—	3 817	30 322	10 500	15 496	4 326	—	30 322	0
Teacher Training Workshop	—	41 577	1 132	42 709	41 844	865	—	—	42 709	0
Associate Expert (2)	25 933	—	3 098	29 031	10 500	11 878	4 803	1 850	29 031	0
Publications Distribution	20 237	—	—	20 237	—	20 237	—	—	20 237	0
Eastern and Central Africa AFRENA—Embu	—	50 128	2 301	52 429	38 550	4 732	3 147	6 000	52 429	0
SAREC										
ICRAF/Zambia Agroforestry Research	183 271	—	66 669	249 940	120 777	84 531	17 820	26 812	249 940	0
USAID										
Eastern and Central Africa AFRENA	—	1 025 358	—	1 025 358	599 198	282 523	54 029	27 289	963 039	62 319
ICRAF/OSU/IITA MPT Evaluation	22 626	88 330	—	110 956	57 839	14 397	11 220	(1 701)	81 755	29 201

ANALYSIS OF RESTRICTED PROJECT FUNDS AT 31 DECEMBER 1991, CONTINUED (US dollars)

	Balance at 1.1.1991	Income Received 1991	Income Accrued 1991	Total Available 1991	Personnel Costs	Supplies and Services	Travel	Fixed Assets Purchases	Total Expenditure	Balance
IDRC										
IRA/ICRAF—Cameroon	—	64 898	11 600	76 498	34 510	30 711	11 277	—	76 498	0
Humid Lowlands—Ghana	7 521	—	11 341	18 862	9 702	187	8 973	—	18 862	0
Data Handling & Management Training Course	—	57 452	—	57 452	29 682	21 650	757	5 363	57 452	0
Socio-economic Project	—	109 019	—	109 019	25 683	17 287	6 093	50 373	99 435	9 584
Netherlands—DSO										
ICRAF/DSO Training Course	—	211 385	828	212 213	189 862	18 666	3 685	—	212 213	0
IFAD										
SALWA	39 414	352 850	—	392 264	242458	63 506	32 886	53 414	392 264	0
Rockefeller Foundation										
On-Farm Research	—	315 900	6 188	322 088	216 151	81 301	14 937	9 500	322 088	0
Policy Adoption/Impact	—	40 000	—	40 000	9 717	—	—	—	9 717	30 283
Ph.D. Fellowship	—	2 500	—	2 500	—	2 500	—	—	2 500	0
Nutrient Cycling	—	20 750	—	20 750	12 702	7 038	—	—	19 740	1 010
Switzerland										
Associate Expert—Cameroon	20 030	66 504	—	86 534	50 053	14 604	—	—	64 657	21 877
Associate Expert—Rwanda	17 998	45 150	—	63 148	42 690	12 490	—	—	55 180	7 968
NORAD										
Agroforestry in Arid Areas	52 376	144 928	—	197 304	98 004	22 993	4 999	—	125 996	71 308
Southern Africa AFRENA—Shinyanga	—	150 907	3 648	154 555	56 089	24 984	11 163	62 319	154 555	0
DANIDA										
MPT Germplasm Centre	—	119 990	—	119 990	312	1 728	138	12 101	14 279	105 711
ODA										
Nutrient Cycling	—	—	87 137	87 137	38 910	33 099	—	15 128	87 137	0
On-farm Research	—	—	29 016	29 016	24 183	3 598	1 235	—	29 016	0
OTHERS										
Research for Development Training Course	—	203 887	—	203 887	172 506	26 017	4 378	986	203 887	0
International Centres Day	—	3 529	—	3 529	—	3 529	—	—	3 529	0
Grevillea robusta Workshop	6 542	—	—	6 542	—	6 542	—	—	6 542	0
TOTAL	**716 585**	**5 472 028**	**287 429**	**6 476 041**	**3 512 550**	**1 415 140**	**448 076**	**606 208**	**5 982 172**	**493 869**

AFBIB	Agroforestry Bibliography (ICRAF's bibliographic database)
AFNETA	Alley Farming Network for Tropical Africa (Ibadan, Nigeria)
AFRENA	Agroforestry Research Networks for Africa (coordinated from ICRAF)
AGRICOLA	Database of the National Agricultural Library (Beltsville, Maryland, USA)
AGRIS	International Information System for the Agricultural Sciences and Technology (Rome, Italy)
AGRITEX	Agricultural Technical and Extension Services (Harare, Zimbabwe)
AIDAB	Australian International Development Assistance Bureau (Canberra, Australia)
ANAFE	African Network for Agroforestry Education (coordinated from ICRAF)
BARC	Bangladesh Agricultural Research Council (Dacca, Bangladesh)
BARI	Bangladesh Agricultural Research Institute (Joydebpur, Bangladesh)
BBC	British Broadcasting Company (London, UK)
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit/German Ministry for Economic Cooperation (Bonn, Germany)
C	centigrade
CABI	CAB International (Wallingford, UK)
CASAWAC	Committee for Agroforestry, Soil and Water Conservation (Harare, Zimbabwe)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Turrialba, Costa Rica)
CD-ROM	compact disk—read-only memory
CDS/ISIS	Computerized Documentation System/Integrated Set of Information Systems
CGIAR	Consultative Group on International Agricultural Research (Washington, DC, USA)
CIAT	International Centre of Tropical Agriculture (Cali, Colombia)
CIDA	Canadian International Development Agency (Hull, Quebec, Canada)
CIMMYT	International Maize and Wheat Improvement Centre (Mexico DF, Mexico)
CIP	International Potato Centre (Lima, Peru)
CIFOR	Centre for International Forestry Research
cm	centimetre
CSIRO	Commonwealth Scientific and Industrial Research Organization (Canberra, Australia)
CTFT	Centre technique forestier tropical (Nogent-sur-Marne, France)
cv	cultivar
D&D	Diagnosis and design
DANIDA	Danish International Development Agency (Copenhagen, Denmark)
DRPF	Direction des recherches sur les productions forestières (Dakar-Hann, Senegal)
DSO	Direct Support to Training Institutes in Developing Countries (The Hague, Netherlands)
FAO	Food and Agriculture Organization of the United Nations (Rome, Italy)
FINNIDA	Finnish International Development Agency (Helsinki, Finland)
g	gram
GRID	Global Resources Information Database (UNEP) (Nairobi, Kenya)
GTZ	Gesellschaft für Technische Zusammenarbeit/German Agency for Technical Cooperation (Eschborn, Germany)
ha	hectare
HASHI	Hifadhi Ardhi Shinyanga (Shinyanga, Tanzania)
IBRD	International Bank for Reconstruction and Development (World Bank) (Washington, DC, USA)
ICAR	Indian Council of Agricultural Research (New Delhi, India)
ICARDA	International Centre for Agricultural Research in the Dry Areas (Aleppo, Syria)
ICRAF	International Centre for Research in Agroforestry (Nairobi, Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (Hyderabad, India)
IDRC	International Development Research Centre (Ottawa, Canada)
IFAD	International Fund for Agricultural Development (Rome, Italy)
IFDC	International Fertilizer Development Centre (Muscle Shoals, Alabama USA)
IFPRI	International Food Policy Research Institute (Washington, DC, USA)
IICA	Inter-American Institute for Cooperation in Agriculture (San José, Costa Rica)
IIMI	International Irrigation Management Institute (Colombo, Sri Lanka)
IITA	International Institute of Tropical Agriculture (Ibadan, Nigeria)
ILCA	international Livestock Centre for Africa (Addis Ababa, Ethiopia)
ILRAD	International Laboratory for Research on Animal Diseases (Nairobi, Kenya)
INFOTERRA	International Referral System for Sources of Environmental Information (UNEP) (Nairobi, Kenya)
INIBAP	International Network for the Improvement of Banana and Plantain (Montferrier-sur-Lez, France)
INRAN	Institut national de recherches agronomiques du Niger (Niamey, Niger)
INSAH	Institut du Sahel (Bamako, Mali)
IPGRI	International Plant Genetic Resources Institute (Rome, Italy)

IRA	Institut de la recherche agronomique (Yaoundé, Cameroon)
IRAZ	Institut de recherche agronomique et zootechnique (Gitega, Burundi)
IRRI	International Rice Research Institute (Los Baños, Philippines)
IRZ	Institut de recherches zootechniques (Yaoundé, Cameroon)
ISABU	Institut des sciences agronomiques du Burundi (Bujumbura, Burundi)
ISAR	Institut des sciences agronomiques du Rwanda (Butare, Rwanda)
ISNAR	International Service for National Agricultural Research (The Hague, Netherlands)
ISRA	Institut sénégalais de recherches agricoles (Dakar, Senegal)
ITE	Institute of Terrestrial Ecology (Cambridge, UK)
IUFRO	International Union of Forestry Research Organizations (Vienna, Austria
KARI	Kenya Agricultural Research Institute (Nairobi, Kenya)
KEFRI	Kenya Forestry Research Institute (Muguga, Kenya)
kg	kilogram
km	kilometre
KIT	Royal Tropical Institute (Amsterdam, Netherlands)
LER	land-equivalent ratio
m	metre
MIDP	Machakos Integrated Development Project (Machakos, Kenya)
mg	milligram
mm	millimetre
M.Sc.	Master of Science
n	number
N	nitrogen
NDFRC	National Dryland Farming Research Centre (Katumani, Kenya)
NORAD	Norwegian Agency for International Development (Oslo, Norway)
OAU	Organization of African Unity (Addis Ababa, Ethiopia)
ODA	Overseas Development Administration (London, UK)
ODI	Overseas Development Institute (London, UK)
ORSTOM	Office de la recherche scientifique et technique d'outre-mer (Paris, France)
OSU	Oregon State University (Corvallis, Oregon, USA)
P	phosphorus
Ph.D.	Doctor of Philosophy
RESADOC	Réseau sahélien de documentation (Bamako, Mali)
SACCAR	Southern African Centre for Cooperation in Agricultural Research and Training (Gaborone, Botswana)
SADCC	Southern Africa Development Coordination Conference (Gabarone, Botswana)
SAFGRAD	Consultative Advisory Committee on Semi-Arid Food Grains Research and Development (Ouagadougou, Burkina Faso)
SALWA	Semi-Arid Lowlands of West Africa (AFRENA programme)
SAREC	Swedish Agency for Research Cooperation with Developing Countries (Stockholm, Sweden)
SDI	Selective dissemination of information
SED	standard error of differences
SHISCAP	Shinyanga Soil Conservation and Afforestation Programme (Shinyanga, Tanzania)
SIDA	Swedish International Development Authority (Stockholm, Sweden)
sp	species (singular)
spp	species (plural)
sq	square
t	tonne (metric)
TARO	Tanzania Agricultural Research Organization (Dar-es-Salaam, Tanzania)
TAC	Technical Advisory Committee, CGIAR (Rome, Italy)
TSBF	Tropical Soil Biology and Fertility Programme (UNESCO) Nairobi, Kenya
UK	United Kingdom
UNEP	United Nations Environment Programme (Nairobi, Kenya)
UNESCO	United Nations Educational, Scientific and Cultural Organization (Paris, France)
USA	United States of America
USAID	United States Agency for International Development (Washington, DC, USA)
UST	University of Science and Technology (Kumasi, Ghana)
var	variety
WARDA	West African Rice Development Association (Bouaké, Côte d'Ivoire)
wt	weight

Members

Chairperson	Dr G. Holmes (UK) (appointed 15 March 1991)
Chairperson	Professor H.A. Steppler (Canada) (retired 15 March 1991)
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Meetings during 1991

Board of Trustees	19th meeting: 9, 14 and 16 March
	20th meeting: 10–12 October
Executive and Finance Committee	
	14th meeting: 11 January
	15th meeting: 14 March
	16th meeting: 10 October
Programme Committee	22th meeting: 9–10 and 13 March
	23th meeting: 8–9 October
Audit Committee	2nd meeting: 13 March
Nominations Committee	1st meeting: 13 March
	2nd meeting: 10 October

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Certified Public Accountants
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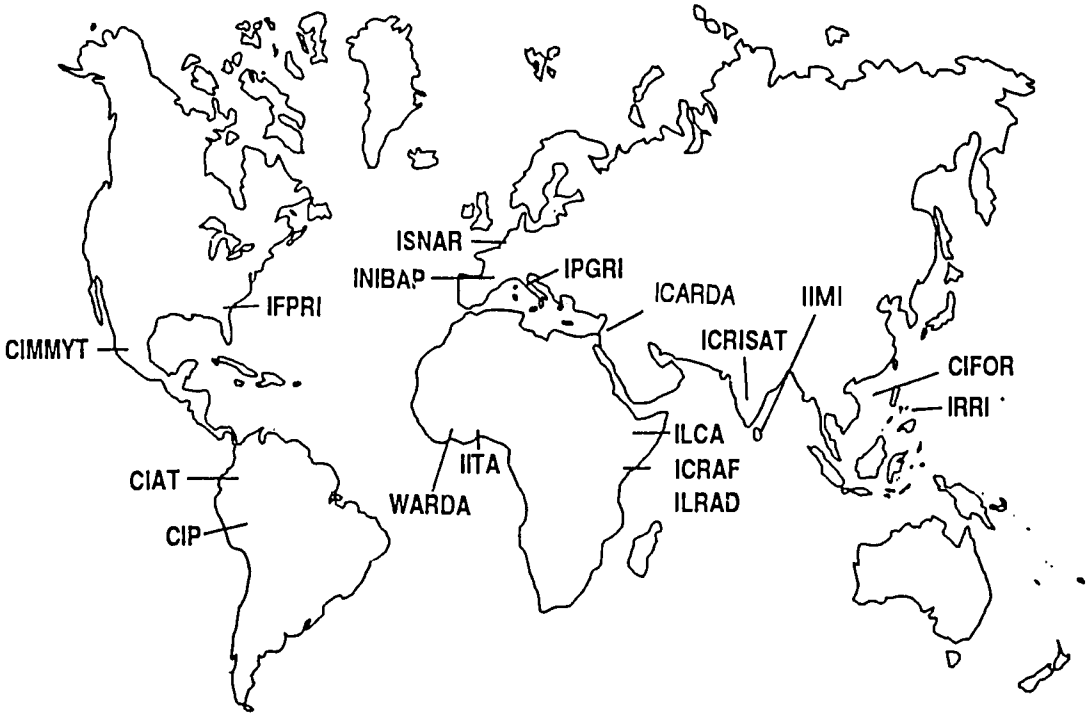
The Consultative Group on International Agricultural Research (CGIAR), established in 1971, is an informal association of some 50 countries, international and regional organizations, and private foundations working together to support a network of 17 agricultural research centres around the world. By the end of 1992, the CGIAR included 40 donor organizations, with projected annual pledges of US$300 million.

The original philosophy that supported the establishment and growth of the CGIAR is that sustained, coordinated research can lead to new agricultural production technologies that will provide more food for people in developing countries. In recent years, growing concern about environmental issues has led the CGIAR into a careful study of whether the system as a whole should also take new initiatives in natural resource management and environmental protection.

After an intensive dialogue with researchers all over the world, the donors decided to extend the CGIAR's mandate to agroforestry, forestry and irrigation management. As a result of these deliberations, ICRAF became a member of the CGIAR in May 1991.



The CGIAR supports the work of 17 international agricultural research centres around the world.

Compiled by Sidney B. Westley
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