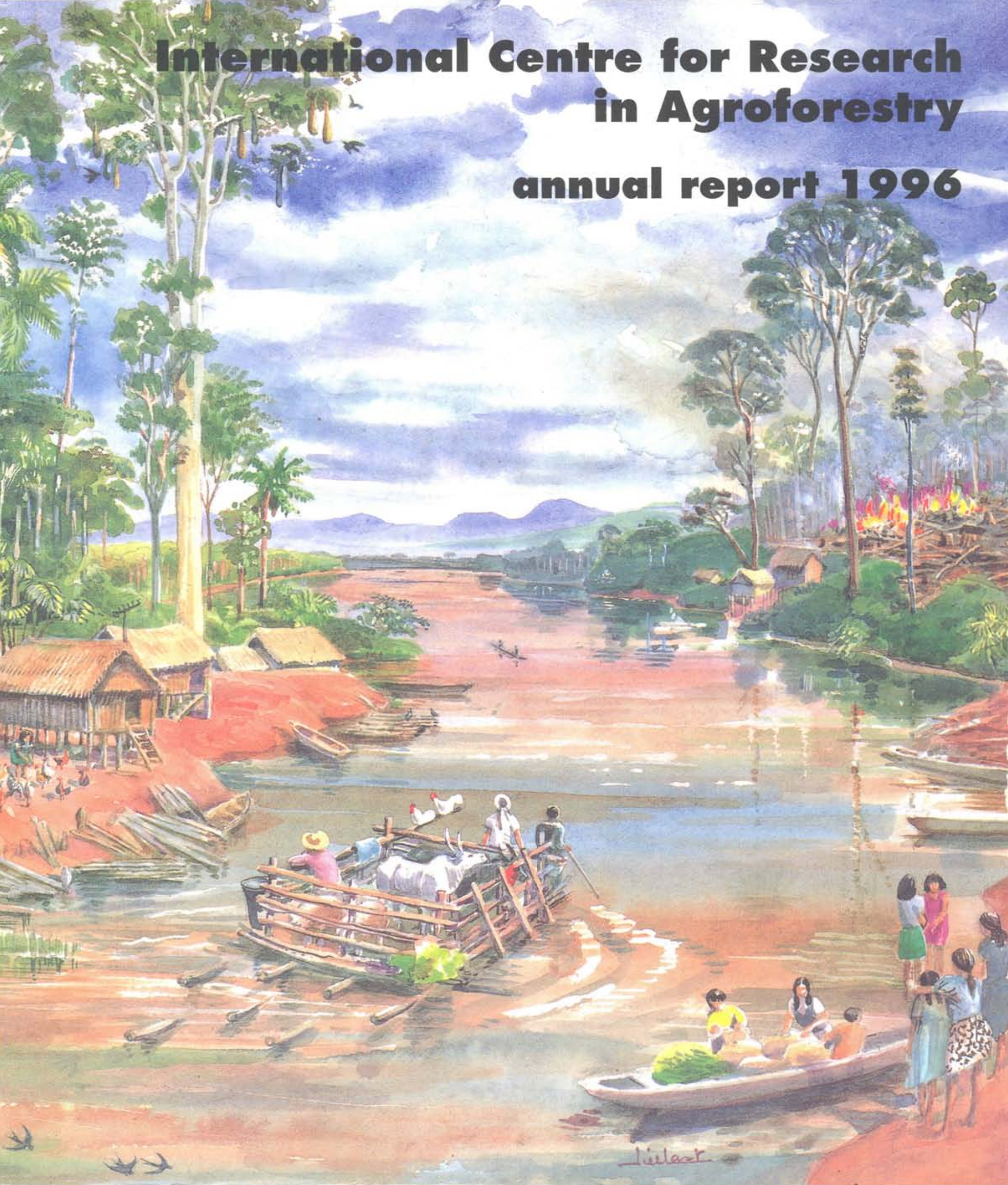
International Centre for Research in Agroforestry

annual report 1996



Message from the Director General

Our financial health was restored in 1996, which allowed us to devote our energies to carrying out research and to charting our future. Developing ICRAF's medium-term plan for 1998–2000—and beyond —occupied much of 1996, with consultations with partners, our staff, our Board of Trustees, donors and the Technical Advisory Committee of the CGIAR. The 14-month process culminated in May 1997 with CGIAR approval of the plan.

Tree domestication efforts took off in West Africa with *Prunus africana,* and in Latin America with capirona *(Calycophyllum spruceanum)* and bolaina blanca *(Guazuma crinita),* all priority species—selected with farmers—that have never before been systematically collected. A major project on indigenous fruit trees in southern Africa was initiated.

Research on soil fertility replenishment in western Kenya moved on farm, where large increases in crop yield were obtained with combinations of improved fallows, biomass transfers of *Tithonia diversifolia,* and indigenous phosphate rock. A major symposium on this topic was held at the American Society of Agronomy in the USA, and a workshop on NGO approaches to soil fertility replenishment was held in Nairobi, cosponsored by the CGIAR NGO Committee and the Tropical Soil Biology and Fertility Programme. The World Bank incorporated soil fertility as one of its top priorities in Africa, and the government of Kenya has started a pilot project in Nyanza and Western provinces.

Policy research in Southeast Asia made advances in indigenous tenure systems, imperata grassland rehabilitation, and the value of rubberwood for export. We are organizing a CGIAR-wide conference in 1998 on how to assess the impact of natural resource management research.

The rate of impact of applied research and adoption of improved fallows in southern Africa and West Africa and of tree fodder for periurban milk production in eastern and southern Africa is accelerating. A worldwide symposium on short-term improved fallows was held in Malawi in 1997. The Alternatives to Slash-and-Burn Programme (ASB) identified 5 best-bet alternatives, which are currently being evaluated throughout the humid tropics.

To strengthen institutional capacity, we devolved the introductory agroforestry course to lead institutions in the ecoregions, continued strengthening the agroforestry education network, and facilitated email and Internet connectivity to NARS. And we launched ICRAF's homepage in the World Wide Web.

Several donors and partners who participated in the CGIAR mid-term meeting in Jakarta gained first-hand impressions of agroforestry technologies through a 4-day field trip to ASB sites in Sumatra organized with the Indonesian NARS and CIFOR.

ICRAF's Board underwent important changes. Dr Yemi Katerere from Zimbabwe is the new chair, succeeding Professor David Thorud of the USA, who completed 6 years of service. Prof Uraivan Tan-Kim-Yong from Thailand is the new vice-chair. We are grateful to retiring members Prof Bo Bengtsson of Sweden and Prof Edward W Tyrchniewicz of Canada for their distinguished service to ICRAF. At the same time, we are pleased to welcome 3 new members—Ms Lucie Edwards (Canada), Dr Gill Shepherd (UK) and Mr Richard Beahrs (USA).

I am also pleased to announce the appointment of Dr Anne-Marie Izac as our new Director of Research, replacing Dr Roger Leakey, who returned to the UK after completing his secondment here.

We are extremely grateful for the support of all our donors for helping overcome the financial difficulties we experienced in 1995.

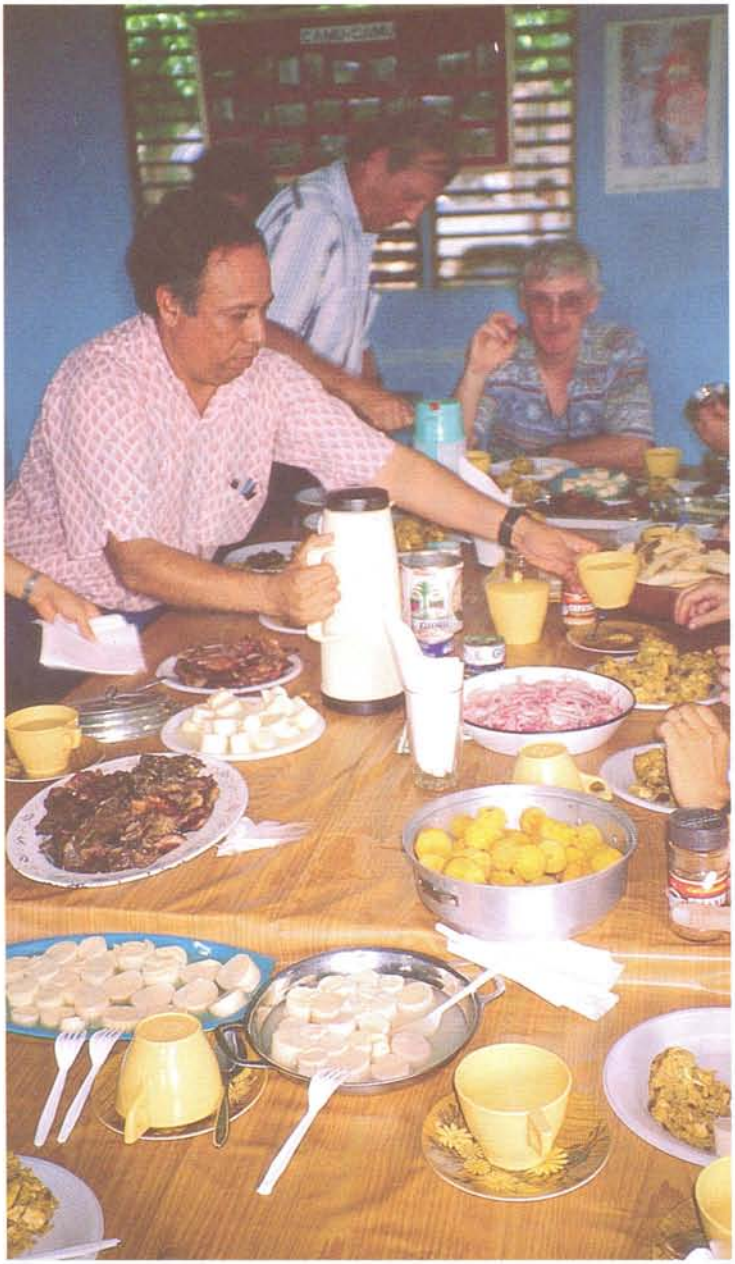
Pedro Sanchez
Director General

International Centre for Research in Agroforestry

annual report 1996

CONTENTS

United Nations Avenue
PO Box 30677
Nairobi, Kenya



Research scientists savour an agroforestry breakfast in Pucallpa, Peru. There for the sampling, along with the morning coffee, are chunks of heart-of-palm and other indigenous delicacies.

Partners in agroforestry research and development

PARTNERS, PARTNERS . . . EVERYWHERE

Just how many people use agroforestry products and services? Scientists at ICRAF put the figure at more than 1.2 billion, nearly a quarter of the world's population. Rural and urban dwellers every day of their lives—knowingly or not—cook with, eat, drink, take as medicine, sit on, wear or wash with products from tropical trees grown on farms in agroforestry systems.

Of course, this is not news to farmers throughout the tropics. They have been harvesting tree products on their farmland and benefiting from the services that trees provide for thousands of years.

As prices rise, more and more people are relying more and more on their own on-farm resources. This has led to rapidly increasing interest in traditional agroforestry systems among development and extension agents, and among researchers in a broad range of disciplines. It has also lent urgency to ICRAF's research and development activities, which aim to understand, improve and expand these systems to increase food and nutritional security and ease rural poverty in the tropics.

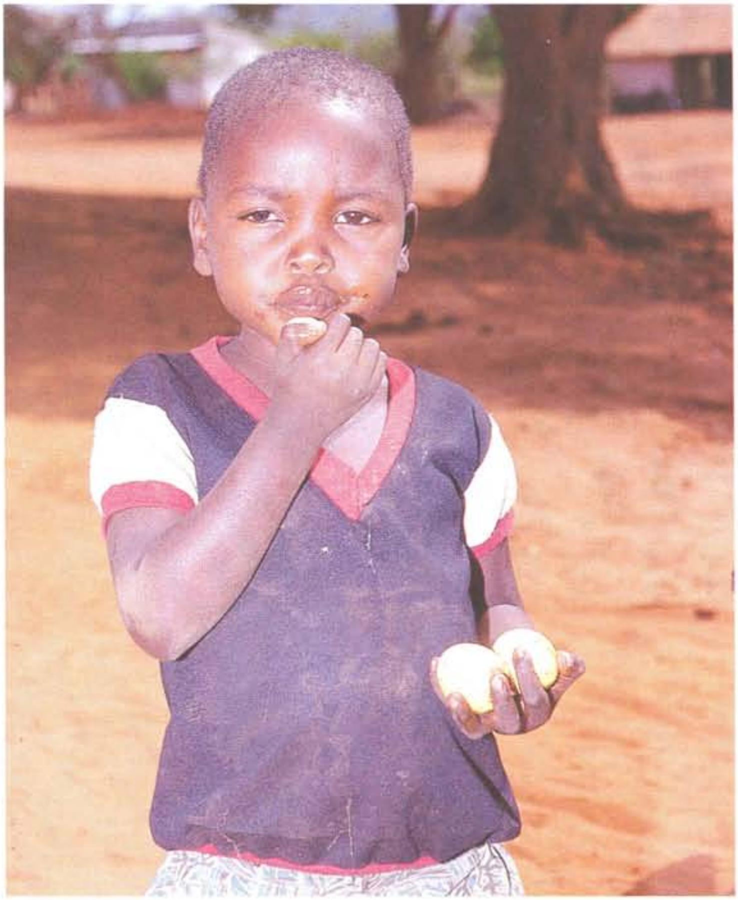
Here we turn our attention to people—our partners—with whom we work to develop, promote and disseminate agroforestry technologies in the tropics.

Farmers are our partners, certainly, but they are by no means the only ones. Many people and organizations are in the chain of collaboration. These organizations include farmer groups, many of them of female farmers; they include dedicated non-governmental organizations working on improving agriculture in the tropics. ICRAF scientists work closely with scientists in national agricultural research institutions and in regional and advanced research organizations, and there is close institutional affiliation. Many farmers rely on extension services, and extension workers are active partners in disseminating agroforestry innovations to farmers. We work with universities, particularly in strengthening agroforestry education and training young agriculturists in agroforestry techniques and technologies in integrated, sustainable farming systems. More recently, we have been cultivating new partnerships in the private sector.

NEW AND STRONG PARTNERS

ICRAF has a solid record of collaborating closely with research colleagues in national systems in the 23 countries in Africa, Latin America and Southeast Asia where we conduct research and training activities. At last count, we have substantive, ongoing collaboration with 400 institutions worldwide.

We recognize that research and development are a continuum of activities, and research is incomplete until its results are adopted or not by



Children certainly are users of agroforestry products. They love the sweet and delicious fruits that trees provide. Fruits such as these from the indigenous marula (Sclerocarya birrea) *in southern Africa provide both nutrients and food security. For thousands of years, farmers have been growing trees and crops together. Trees fill border niches in this agricultural system of terraced and irrigated rice, in Solok, Southeast Asia.*

We work with extension people and development groups so that agroforestry can provide farmers with worthwhile and relevant choices as to the agroforestry technologies they may wish to use. The farmers looking over a peach palm plantation in Peru and the village elder in Indonesia talking with a researcher are both involved in the field experimentation under way in their respective areas.

farmers. We also recognize that the adoption and impact of agroforestry innovations developed by ICRAF and its partners should be closely monitored and measured to ensure that they are meeting farmers' needs and protecting the environment. For this reason, we are presently extending our reach further afield, branching out to link up with increasing numbers of development and extension groups, with industry, traders, the media and policymakers.

Through this branching out, we aim to provide farmers with *choices*— a whole range of technologies and improved agroforestry tree species to choose from. We are working with a range of partners to catalyse and accelerate dissemination, adoption and impact of these technologies and species.

By branching out, ICRAF is able to fulfil its obligations—of helping to bring agroforestry into the mainstream of sustainable development efforts, worldwide. All our partners have important roles in the promotion and development of improved agroforestry systems—from the smallest self-help group in Zambia, to the man on the bicycle peddling leaves of a fodder tree in Mali—to the auto giant Daimler Benz.

At the same time we work on understanding and developing policies and markets that will make these agroforestry options attractive and profitable. We are now linking with the private sector to explore opportunities for developing high-value products and getting them onto the market. This way we keep sight of our goals to ease pressure on tropical forests, generate income for cash-poor farmers in the tropics, and safeguard natural resources today and on into the next millennium.

We have an open research approach across the 6 ecoregions in which we work. It emphasizes partnership with farmers. To begin with, researchers and extension workers meet with NGOs, farmer groups and village chiefs, who identify their problems, and together they assess what role agroforestry can play in finding solutions. Researchers translate this assessment into strategic research hypotheses, which are tested on station, on farm and together with policy research.

Out of the possibilities, individual farmers pick and choose the technologies they think are suited to their particular needs and interests and thus want to try—nothing is 'laid on' from outside. At these meetings, farmers and researchers are on equal footing, and the mood is open and frank. Farmers learn about new technologies and what they potentially can do; researchers learn if they are on the right track in their research and how their agroforestry technologies are faring in the farm field. And some of our most insightful perspectives as to farmers' perceptions and problems come about when we bring different groups of farmers together in one of their fields.

These informal but effective adaptive research and dissemination groups help all partners evaluate promising new agroforestry practices; they catalyse dissemination of these practices; and they provide feedback, not only on successes but also on farmer adaptations, and cases of non-adoption. In Zimbabwe, for example, such a group is testing technologies to improve fodder production and soil fertility. A Philippines group is looking at better terrace management and ways to control erosion. In Mexico, a group is concerned with soil fertility and how to increase farmer income.

We feel that the diversity of our partnerships is one of our greatest strengths. And the best way to tell the story of how ICRAF is now further reaching out to the world is through a few stories about the diverse people, groups and organizations with whom we are working. Different types of partnerships, with farmers and with the private sector, feature in the following stories.

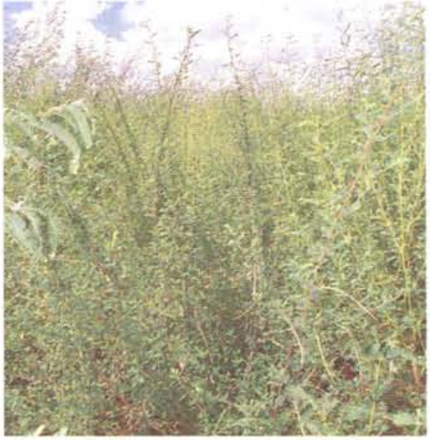
Researchers and extensionists meet with farmers and the village chief, here in Gobery-Goubay, Niger, to assess what role agroforestry can play in finding solutions to agricultural problems.

RESTORING SOIL FERTILITY IN KENYA

In western Kenya, farmers are now able to choose from a basket of agroforestry options designed specifically to combat the crucial problem of soil infertility in the region and throughout much of Africa. Trees do a lot for soils—and they can do more than is generally realized. They can restore nitrogen in depleted soils through improved fallows that are able to grow during the dry seasons or during the risky short rains. Such fallows fix nitrogen from the air and also capture leached nitrates through their roots at depths that crops cannot reach in these deep red soils. They then transfer it to the surface as leaf litter. Improved fallows with nitrogen-fixing trees and shrubs such as *Sesbania sesban*, *Crotalaria grahamiana* and *Tephrosia vogelii* are one option being tried by hundreds of farmers in the area. *Sesbania sesban* fallows also provide fuelwood; they have been found to decrease by half the seed pools of the parasitic weed *Striga hermonthica;* and they recycle enough potassium from the subsoil to prevent the need for potassium fertilization.

The phosphorus in soils of sub-Saharan Africa is being depleted at a rapid rate, and phosphorus is crucial for crop production. Because the amount of phosphorus in the biomass of most trees is small, agroforestry alone cannot provide the amount needed in most farming systems. Mineral sources of phosphorus must be applied to soils where this mineral is depleted—but commercial

Plentiful and pretty, Tithonia diversifolia, *commonly known as Mexican sunflower, can help dramatically increase crop yields when it is applied as biomass to phosphorus-depleted soils.*



A bounty of fertility replenishment options in western Kenya: Farmer Agneta Akeyo (top) stands amidst her improved fallow of the nitrogen-fixing shrub Tephrosia vogelii, *which will give her increased grain yields at her next crop harvest; (above) 14-month-old* Sesbania sesban *fallow ready for cutting in Vihiga District, Western Province; (opposite from top): tall grows the maize at the back after 1 year of* Sesbania sesban *fallows, in contrast to the control crop in the foreground, in Leuro village, Siaya District; farmer Charles Ngolo applies tithonia to his sukuma wiki field . . . and Mrs Ngolo reaps the results.*

fertilizers are beyond the means of most small-scale farmers on the continent.

Many of them face this problem acutely in western Kenya. Their farms are very small—frequently only a half hectare to 1 hectare. Because the soils are deficient in both nitrogen and phosphorus, maize yields are very low, even when rainfall is adequate. This means that the farm family—often headed by a woman—is not self-sufficient in maize, the staple food, and someone in the family must go off the farm to seek work for added income.

To solve the problem, researchers have been working closely with individual farmers and entire villages in western Kenya. The research partners come from KEFRI, the Kenya Forestry Research Institute; from KARI, the Kenya Agricultural Research Institute; from TSBF, the Tropical Soil Biology and Fertility Programme; and of course from ICRAF. They also come from the district extension services and several NGOs, including CARE-Kenya; KWAP, the Kenya Woodfuel and Agroforestry Project; and OMMN, the Organic Matter Management Network. The farmer partners number some 1200 from over 20 villages in Western and Nyanza provinces.

This year researchers have come up with what they believe is a winning combination. It involves combining the organic inputs from trees and shrubs with indigenous phosphate rock to replenish phosphorus in the soil. When phosphate rock is added to fields together with the biomass of the common shrub tithonia *(Tithonia diversifolia),* which grows abundantly on field boundaries, crop yields improve—dramatically. On-station research has shown that maize yields increased 5 times (from 0.8 to 4.5 tonnes per hectare) with phosphate rock and tithonia. Some 70% of the participating farmers said that the plots on which they had used tithonia yielded more than did their plots without it. The average increase was about 60% when tithonia was applied without phosphate fertilizers. Farmers using this practice on 'sukuma wiki', or kale *(Brassica oleracea* var. *acephala)*, a local, popular—and very marketable—leafy green vegetable, gained even more in net profit.

Enthusiasm for recapitalizing soils is high in western Kenya—and the momentum of this research is ensured by the participation of farmers and of extension and development agents as research partners. The Kenyan government is now developing a pilot project for the area, under the leadership of the Kenya Agricultural Research Institute.

The Kenyan government is an enthusiastic partner in the work to recapitalize western Kenyan soils. Finance Minister Musalia Mudavadi (standing) pledges support to the Kenya Agricultural Research Institute, whose director Cyrus Ndiritu is at the left; ICRAF Director General Pedro Sanchez is at the right. And adorning the table is a bright bouquet of tithonia flowers.

PARTNERS IN PERUVIAN AGROFORESTRY

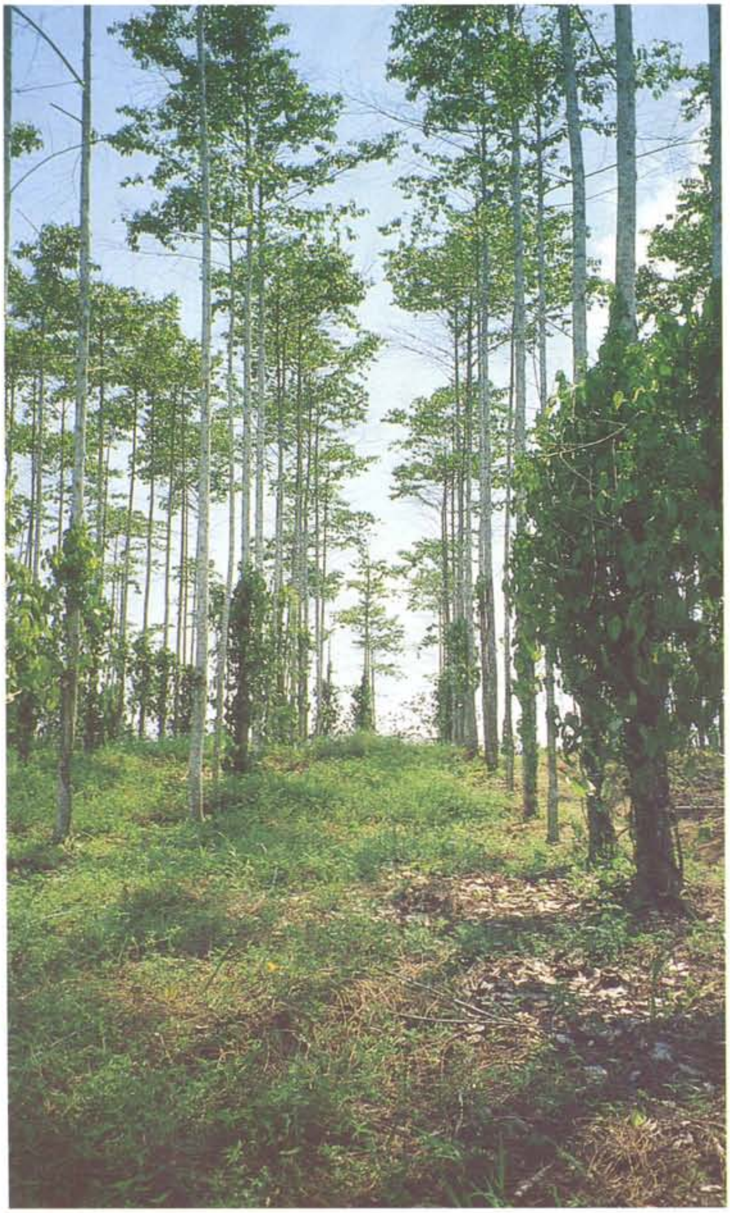
The improvement of agroforestry trees is as much a social and political challenge as a biological one. This means that farmers are research partners from the beginning, when priority trees for improvement are identified, right through to the end, when the improved germplasm is produced on farm. This is precisely how ICRAF's tree domestication work in Peru is being done. Farmers have provided researchers with a list ranked by priority of 23 tree species that they would like to improve and have specified what it is they want in an 'improved' tree. And in this process of working together, researchers have also helped increase farmer awareness of the value of genetic resources and genetic diversity on their farms.

Of course, the farmer–researcher partnership doesn't stop there. This year, farmers in the Peruvian Amazon Basin worked with researchers to start collecting germplasm of 3 of the 23 priority species: capirona *(Calycophyllum spruceanum),* bolaina blanca *(Guazuma crinita)* and pijuayo *(Bactris gasipaes).* Researchers and farmers will establish on-farm trials to evaluate genetic variation within these species, and after 3 years they will transform these trials into production systems for wood and seed orchards.

Capirona and bolaina blanca were selected as priority trees because they are both fast-growing species that can be used for light construction and carpentry and for firewood. They also provide fallow enrichment in on-farm niches.

The germplasm collection of *Bactris gasipaes* was particularly interesting. Farmers showed researchers their best peach palm, explained why they viewed it as the best and also specified the source of the germplasm they used to plant it. Despite the fact that peach palm had been greatly

Researchers worked with farmers in Peru to collect germplasm of Bactris gasipaes, *the peach palm, locally known as 'pijuayo'. Farmers identified which trees they considered superior and researchers now will work to domesticate this tree, bringing out its full potential and economic worth.*



One of the products for which bolaina blanca (Guazuma crinita) *(above) and capirona* (Calycophyllum spruceanum) *(opposite) are valued is their poles. These 2 trees and peach palm are being given priority for research by a partnership of local and international researchers and farmers.*

appreciated, and even semi-domesticated, by pre-Columbian Amerindian communities throughout much of the Amazon Basin, parts of the western Andean region and Central America, its full potential has not yet been realized.

The current work to domesticate peach palm is designed to make full use of its genetic and economic potential for acid, infertile soils of the Amazon. Its fruits are used to prepare several nutritious foods, with important implications for the food security of resource-poor farming families, and the species also provides a wide range of useful materials for construction. As if that weren't enough, there is also the enormous economic potential from the production of the gourmet delicacy 'heart of palm'.

The market for peach palm seed is growing rapidly in Brazil, especially for spineless landraces like the Pampa Hermosa that comes from the Huallaga River Basin. It is likely many farmers will dedicate production areas to seed orchards and generate income for themselves—not just from the palm's products but also from selling its seed.

Our strategy of 'conservation through use' can improve and conserve agroforestry tree genetic resources. All of the priority trees are geared for agroforestry systems that farmers are already using, such as sequentially enriched secondary forests, short-rotation tree fallows and homegardens. By working with and helping to organize farmers in a watershed into an informal production network, we can multiply, distribute and exchange improved germplasm of preferred agroforestry trees, actually increasing valuable genetic diversity within and among species on the farm and in the watershed. And networks in different watersheds can help increase the valuable genetic diversity regionally.

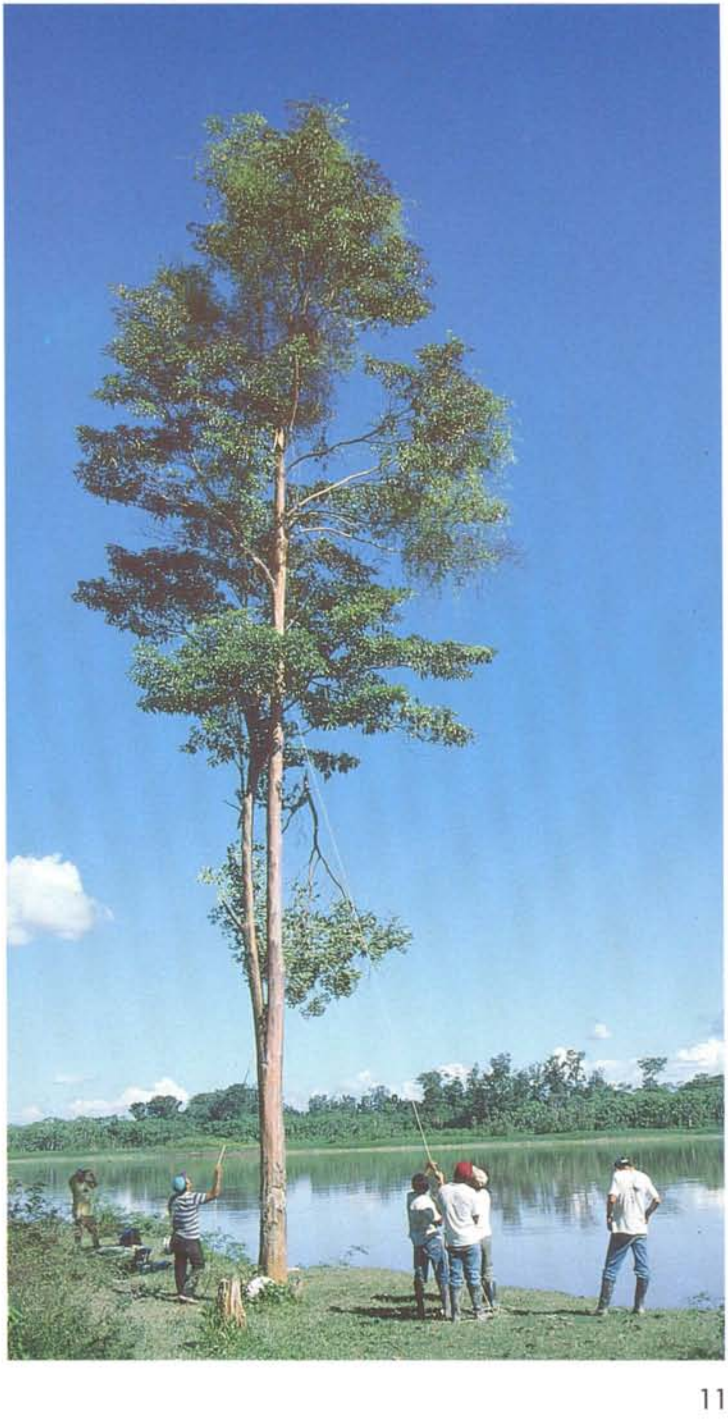
In addition to their farmer partners, ICRAF researchers in Peru are also communicating their results in Peru's agroforestry journal, *Tahauri.* There are strong links with local radio programmes in Spanish for non-indigenous farmers and also in local languages for indigenous farmers. So it is more than just improved germplasm that researchers are disseminating in Peru—it is also crucial information!

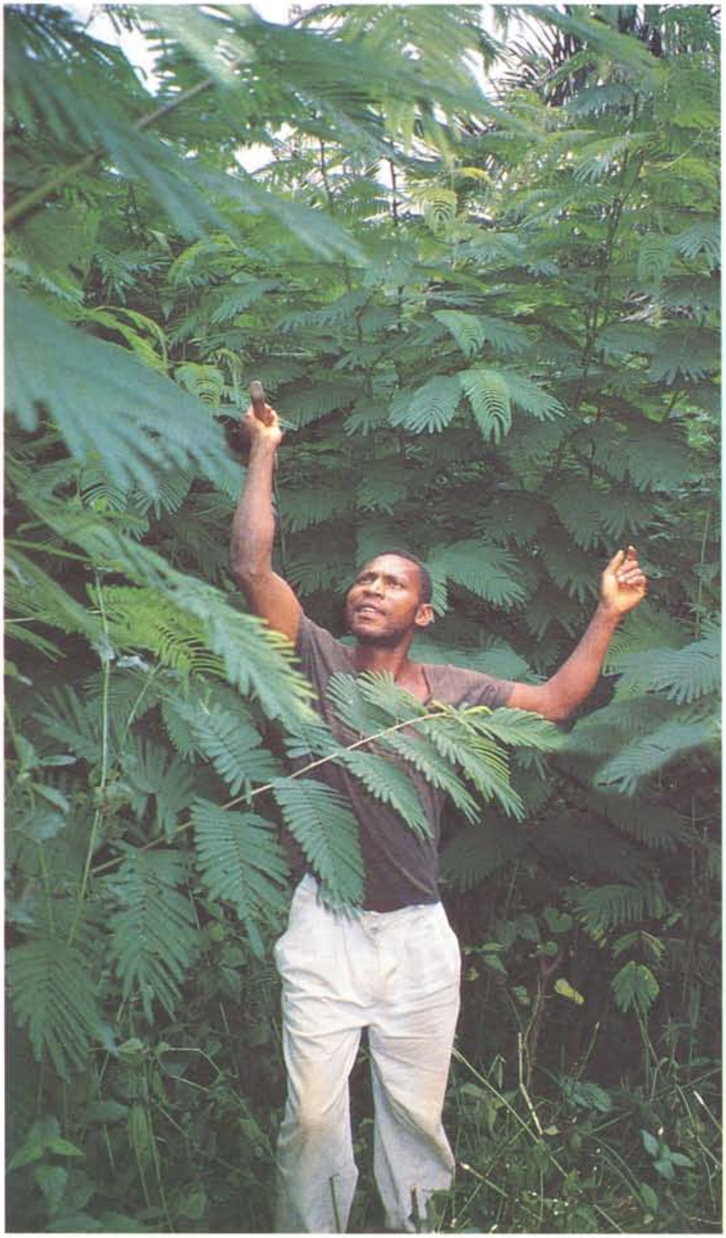
MORE PEOPLE, MORE TREES

For a number of years, the gloomy predictions have been that in the very near future, the number of trees left in the world will have declined below the level needed to sustain the human population. Everyone knows that the world's population is growing, deforestation continues, and the natural forestland is decreasing, so the inevitable treeless world is only a matter of time. But wait! Now researchers, using remote sensing and ground surveys, are showing that, at least in some corners of the world, the number of trees is actually *increasing* along with the increasing number of people. How can this be so?

In some of the most densely populated agricultural areas in eastern Africa, it is happening because farmers are caring for and using their land wisely. In much of Kenya, farmers are practising agroforestry systems, growing trees along with their crops and with their livestock. Almost everywhere in this intensely cultivated land, trees and crops are found together. In central Uganda, too, although the amount of land under cultivation is expanding, the amount of tree cover on agricultural land is increasing, too.

The amazing—and heartening—fact that researchers have discovered is that the overall number of trees in many areas is increasing. Farmers are planting and growing more trees than the number that are being felled in the forests. Moreover, as these trees grown on farms are well





Calliandra rotational fallows are one option out of a number of agroforestry technologies that farmers in Cameroon can elect to experiment with. Farmers can analyse how effective a technology is for their particular situation, how well it answers their particular needs.

cared for, they generally produce well. Planting trees and shrubs on farmland has long been a widescale activity in many countries—Bangladesh, China, Costa Rica, India, Indonesia, Kenya, Nepal and Vietnam.

Nevertheless, farms can never replace some of the ecological functions of forests, such as encouraging biodiversity, so maintaining adequate tree cover in forest ecosystems will always be important.

A major factor in this cultivating of trees is the matter of land tenure. When land is owned privately and individually by those living on it and working it, the owners plant and nurture trees; when the tenure is not theirs—when the land belongs to either the state or to absentee owners—farmers fail to see it to their personal advantage to make the long-term investment of time and effort in tree planting and protection. Thus ICRAF works with farmers and policymakers alike toward resolving ownership issues—in the best interests of the people and the environment.

Currently, ICRAF is collaborating with IFPRI and national partners in 3 countries—the Forestry Research Institute in Uganda, Bunda College of Agriculture and the Ministry of Agriculture in Malawi, and Jambi University in Indonesia—to bring these issues to the attention of policymakers.

A BASKETFUL OF OPTIONS IN CAMEROON

In Cameroon, researchers from ICRAF and the Institut de recherche agronomique pour le développement, NGO staff and farmers conducted workshops to discuss farmer problems and to assess the potential of agroforestry practices to solve them. Farmers chose from a 'basketful' of agroforestry technologies, including fodder banks with *Leucaena leucocephala*, *Calliandra calothyrsus* and napier grass *(Pennisetum purpureum);* improved calliandra rotational fallows; short-term improved fallows with *Sesbania pachycarpa* and *Cajanus cajan* (pigeonpea); hedgerows for soil erosion control; calliandra windbreaks; and calliandra woodlots with honey production.

This approach has several advantages over the conventional approach of simply asking farmers if they want to test a 'best-bet' technology. First, with this basket approach, farmers get to analyse the potential of each technology and to choose the one most suited to their real needs and interests. Farmers' choices were highly specific to each of the 3 sites and to the NGOs involved. Hedgerow intercropping in bananas was extremely popular in 2 lowland communities, while pigeonpea fallows were the preference in the highlands of Northwest Province, where interest in agroforestry is particularly high because of the prevalent problems of low soil fertility and soil erosion.

Second, the approach recognizes that even in the same area, farmers have different needs and preferences. For example, 2 farmers in the same vicinity, faced with the same problem, opted for different technologies depending on how much capital they had. A household with a shortage of land chose the short-cycle pigeonpea fallow while the neighbour with adequate land requested the long-term improved calliandra fallow and also a calliandra woodlot for honey production.

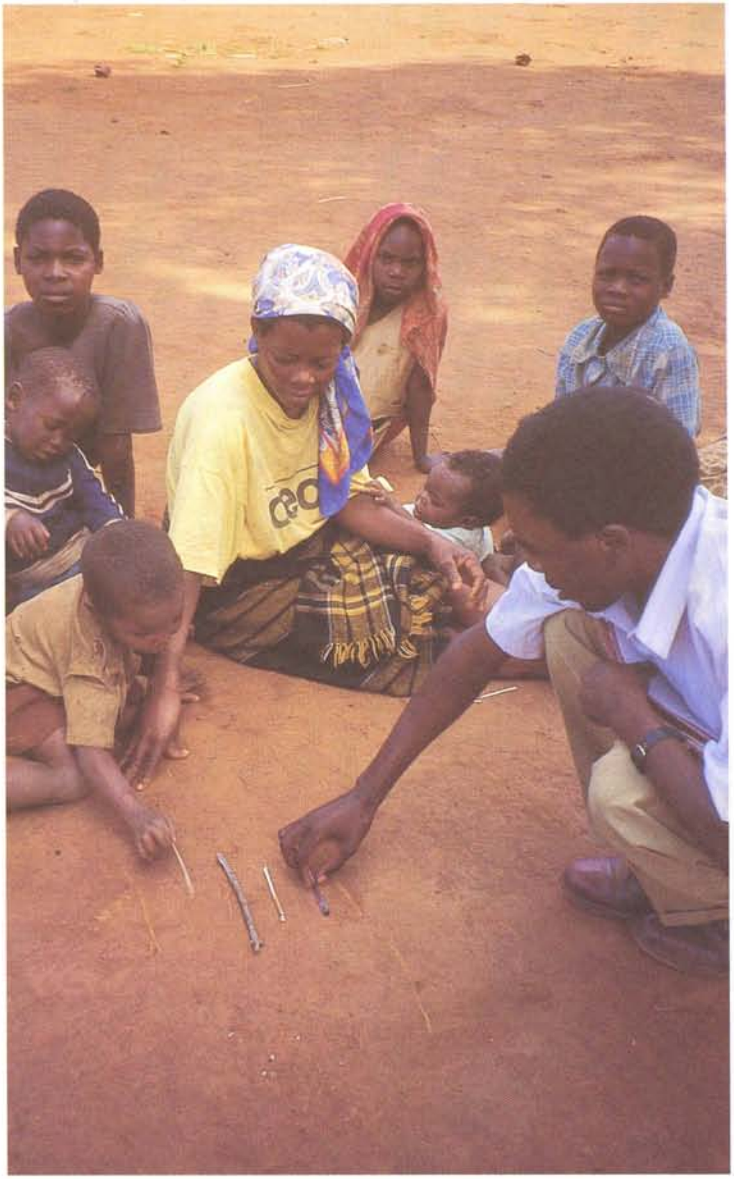
The approach of giving farmers their choice involves important NGOs that are already firmly on the ground and working with the very farmers for which ICRAF research is geared. A form has been jointly developed by researchers, NGO leaders and farmers for assessing which data are to be collected for each technology in on-farm trials.

MAKING AN IMPACT WITH IMPROVED FALLOWS IN ZAMBIA

Working with farmer groups is only part of the story. Researchers also spend time with individual farmers to find out how the technology is faring in their fields, such as those of Zelina Mwanza, a small-scale farmer of Kalichero Camp, near Chipata. This area is nestled away in Zambia's Eastern Province where declining soil fertility has led to steadily decreasing maize yields. It is not surprising that farmers around Chipata are so enthusiastic over agroforestry technologies that can increase yields—particularly short-rotation improved fallows with *Sesbania sesban.*

The informal research and development network in Zambia is already a powerful vehicle for agroforestry development in the region. The partners are studying farmer expectations from the fallows and identifying how to assess impact of the technology in the field, on the farm and in the community. Participating farmers develop their own plans for experimentation and indicate what other agroforestry techniques and systems they would like to try out in the future. Mwanza is just one of about 4000 farmers in the region who are now working with the fallows.

Mwanza says that she came to know about improved fallows through her camp officer in the 1993–94 season, shortly after the officer had attended a field day at Msekera Research Station in Chipata. In January 1994, project staff planted a researcher-designed and -managed trial in Kalichero and Mwanza was able to collect 620 bare-rooted sesbania seedlings. She carried these in a washbasin on her head to her field, 6 km away. It took her 2 trips to complete the task. She then used the seedlings to establish a trial she designed and managed herself, with an improved fallow of 528 square



Farmer Zelina Mwanza describes graphically the yields she got on different plots of her improved fallow trials. She is but 1 of the many in Zambia who are enthusiastic about how maize yields have improved since they started short-rotation improved fallows with Sesbania sesban. *Some 4000 cooperating farmers in the area are now using this agroforestry technology.*

metres. Shortly thereafter, Mwanza herself attended a field day at Msekera and visited other farmers who had planted improved fallows.

At the start of the 1994–95 season, she used naturally regenerated seedlings to fill gaps in her field and to establish a 2nd, smaller improved fallow. In late 1995, Zelina Mwanza cut down her 2-year-old sesbania trees and incorporated the leafy biomass into the soil. She used the firewood for cooking meals in the field—firewood that she says she would have had to collect from about 5 km away had she not had the sesbania firewood. She planted maize, and during the course of the season, she noted that land preparation required about 25% less time, weeding 50% less time than it did on adjacent fields that had been continuously cropped or planted after a bush fallow. She was very pleased with her maize yield following the fallow—she harvested about 3 bags (270 kg or roughly 3 tonnes per hectare). She estimates that without fertilizer or fallows she would probably have had less than 1 bag from her field.

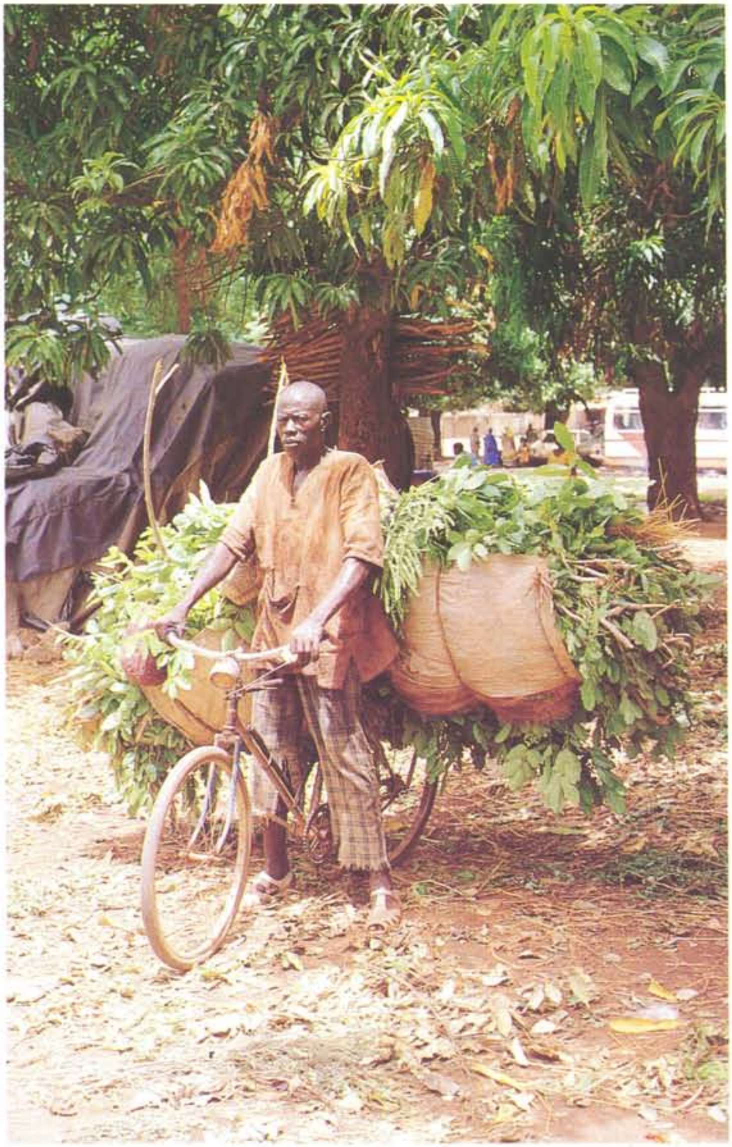
Asked what she sees as the biggest problem associated with the fallows, she says that this is the work involved in cutting the trees. She is a household head and her oldest child is only 14 years old, but she and her eldest worked together to cut the trees using axes. Still, Mwanza isn't going to let this stand in her way of using improved fallows. During the 1996–97 cropping season, she established a nursery and planted a sesbania improved fallow of 400 square metres—and distributed seedlings to several other farmers!

THE GODS' DISAPPEARING TREES

Mamadou Diallo is 50 years old, and these days he spends a good part of his life on a single-speed bicycle, pedalling across the parched countryside in the scorching heat of his native Mali. His mission? To earn enough money to feed his 4 children. He does this by finding stands of the trees known locally as 'gueni' *(Pterocarpus erinaceus)* and 'djagoboulou' *(Pterocarpus lucens),* hacking off a few leafy branches with his machete, stringing them together and getting them back to Bamako, the nation's capital—where he tries to sell them.

These pterocarpus leaves are *the* most important source of fodder for livestock—goats, sheep and cattle—during the long dry season in the Sahel, when almost all other sources of forage have dried up completely. Diallo rides his bicycle up to 80 kilometres and by dusk has gone far enough into the bush that he can find a few patchy stands of natural woodland containing pterocarpus trees—ones that have not been hacked almost bare. The next morning at dawn he cuts the branches he needs and heads back to the city. On the third day he is able to rest, in the deep shade of a large neem tree beside one of the busiest streets in the bustling centre of Bamako. There he sits and waits for buyers—people who need a few leafstalks of pterocarpus to feed their animals, which are so important to the economy and social landscape of his country.

Diallo has been doing this arduous work for 5 years, having given up on farming because, as he says, this looked like a better way to earn money for paying school fees for his children than did farming. What he didn't foresee was the rapid and devastating effect of overexploitation on pterocarpus trees in this parched Sahelian region. He says that trees with lots of foliage are now hard to find. Whereas he once found good trees about 30 kilometres from the city, now he has to travel up to 80 kilometres to harvest a bundle of leaves. And yet the price of the fodder leaves has stayed the same, with a large bundle fetching somewhere between CFA 1000 and 5000 (USD 2–10),



Mamadou Diallo bicycles into town a load of Pterocarpus erinaceus, *which he will sell in the city market. These leaves are important fodder for livestock in Mali, but the trees are becoming scarce, and Diallo must ride up to 80 km to find branches that can be lopped off trees. If farmers plant and cultivate these pterocarpus trees—and researchers are working to make them easier to propagate—fodder will be more abundant and easier to obtain.*

depending on the season and on amount of bargaining.

It used to be, when land was abundant and the population low, that people 'waited for the gods to do the tree planting'. After all, as Diallo says, the trees that grew there were the gods' and the gods knew best how to sow and nurture their own creations, put there to be used with care and appreciation by human beings. Times, however, have changed in the Sahel. Populations have been growing by almost 3% a year, and desertification has taken its toll on what was already a difficult environment. Indigenous farming systems, known as the parklands agroforestry system, in which farmers protected and kept trees on the land they cleared and then grew crops around those trees, are breaking down.

One of the parkland trees is pterocarpus, which helps to prevent widespread starvation of livestock during the annual dry season in the Sahel. Now farmers and vendors like Diallo say that the pterocarpus trees are being lopped so heavily that they are no longer producing seeds.

But agroforestry researchers are working on a solution that they think may just provide an answer—for farmers, for vendors and for the trees of the region. Their idea is to domesticate the trees, make them easier to propagate and grow, and then plant them in fodder banks on their farms.

In Mali, ICRAF researchers together with their partners in the Institut d'économie rurale have been working with *Pterocarpus erinaceus* and *P. lucens* grown in fodder banks on research plots and on farms. Early results show promise, particularly for *P. erinaceus.* In on-farm fodder bank trials, the tree produced 4.5 tonnes per hectare of fresh fodder during the long dry season. Nutrient analyses have also shown that pterocarpus foliage contains 16% crude proteins and 12% digestible proteins, making it a high-quality fodder. Researchers are also studying the genetic variability in *P. erinaceus,* and once this work is finished, they will be able to select, from their nurseries and seed orchards, genetic varieties that do well as fodder banks—on farms.

This work goes hand in hand with a market study that was done in Bamako to find out details on the current demand, prices and availability of pterocarpus in the city, with vendors like Mamadou Diallo. This study shows that vendors can earn 3–5 times as much a day from the sale of this fodder as can a casual labourer in the region. It also shows that the demand for pterocarpus fodder during the dry season is 6 times the actual supply. These results vividly illustrate the economic importance of the tree and the potential for expanding that market, particularly through cultivation of pterocarpus on farms.

Selected pterocarpus planting material is already being propagated in ICRAF nurseries in Mali for this purpose. And once the trees are being planted and grown by farmers on their land, Diallo's concerns about 'the gods' disappearing trees' in natural stands may well become a worry of the past.

KUDOS FOR INDONESIA'S FOREST GARDENS

It is this simple and also this complex—all the economic and environmental benefits in the world are not going to secure the future of any agroforestry system if the right policies are not there to promote it. Take, for example, the damar agroforests around Krui, on the Indonesian island of Sumatra. For many years, agroforestry researchers and their partners in a wide range of institutions and disciplines have been documenting the small economic miracles of these 'forest gardens', or *kabun,* as they are known by the villagers who have developed and planted them over the past century. The forest gardens produce a regular supply of damar resin that is tapped from the *Shorea javanica* trees grown in agroforests. The resin is exported internationally for use in glues and paints.

There are also windfall harvests of fruit from many of the 39 species of trees grown in the kabun. In 1995, a bumper crop of duku fruit *(Lansium domesticum)* in the agroforests around Krui resulted in a veritable economic boom in the region—allowing many villagers to afford electrification in their homes. Shortly after the duku harvest, 7 homes in 1 village suddenly sported satellite receiver dishes!

But studying the economic and environmental pluses of these complex agroforestry systems is certainly not all the researchers have been doing. They have also been working intensely with the Krui forest farmers and with the policymakers in the Department of Forestry to ensure that the future of the agroforests is secured by sound policies. This dialogue led the Department of Forestry to ask the researchers and the Krui forest farmers to make policy recommendations that would help conserve the agroforests and even increase their profitability. These recommendations have to do with security of tenure for the farmers of their land and their trees, which will save their forest gardens from threatened invasion by logging enterprises and private plantations.

This year, these close links between farmers, researchers and policymakers have paid off—and in a very big way. A group of researchers from ICRAF, the Centre for International Forestry Research (CIFOR), ORSTOM (Institut français de recherche scientifique pour le développement et coopération), the Indonesian Tropical Institute and WATALA (Society of Nature Lovers), with the support of the Department of Forestry and the local government, nominated the proprietors of the forest gardens, the Krui forest farmers, for the

Resin from Shorea javanica *trees raised in Indonesian agroforests is exported internationally—and brings profit to the farmers cultivating the forest gardens in which they are grown.*

prestigious National Environment Award in Indonesia. And their bid was successful! In 1997, Indonesian President Suharto himself is awarding the prize, known as Kalpataru, to the forest farmers of Krui Pesisir. This high-level and official recognition of the environmental value of the agroforests is a major breakthrough and a feather in the cap for all involved in the work to ensure the future of these remarkable agroforests.

AGROFORESTRY TREES AND LUXURY CARS?

The question is: what on earth can ICRAF and Daimler Benz have in common? At first glance, nothing. But there *is* a common interest—and that meeting point is tree products that farmers in the tropics can supply. Daimler Benz is interested in finding more natural products to use in manufacturing its vehicles. ICRAF is interested in the markets—local, national, regional and international—for high-value products that come from agroforestry trees. Industry generally waits until products are already developed and there is a regular supply of high-quality produce before they are interested in any product. But from ICRAF's point of view, there is little point in domesticating a tree until the market for its product is assured, at least regionally.

It is this catch-22 situation that led ICRAF to begin dialogue with the private sector, leading up to future joint endeavours that involve industry, agroforestry researchers and the small-scale farmers throughout the tropics, whose survival in the next century hinges on farming systems that include trees—particularly those with economic potential.

ICRAF is working to domesticate a wide range of agroforestry trees in a daunting and diverse range of conditions. Most of these are trees that farmers themselves have identified as their priority species and said they would like improved for planting on their farms. But this does not preclude the improvement of other species, trees that can produce high-value products such as fibres, resins or pharmaceuticals, trees with economic importance in international markets that until now have been harvested almost entirely in natural stands. The natural stands are under threat, and by domesticating the trees that could vanish with the forests—by bringing them out of the forest and onto farms—ICRAF sees real opportunities to expand farming options and income possibilities for rural people.

There is a double advantage to this approach. Domesticating trees and making use of the genetic variation within natural populations can ensure the world's supply of such products—and at the same time ease pressure on forest trees and the biodiversity they harbour.

Daimler Benz is testing auto components made from tree products, and researchers and farmers are working with the industry to help bring the products out of the forest and onto the farm, where they can be grown and harvested for a ready market.

Hence the intriguing and novel partnership between ICRAF and Daimler Benz. For the past 5 years, Daimler-Benz, together with the Universidade do Pará in Belém, Brazil, have been looking at ways of using agroforestry products such as fibres, dyes and latex in making Mercedes cars and trucks. In 1996, ICRAF was invited to share its expertise at a conference on this project, and this has led to more dialogue with Daimler Benz in Germany about the potential of other tree products—from the miombo woodlands in southern Africa, for example, that could be used in their vehicles and that could generate income for impoverished farmers there.

THE POTENT POTENTIAL OF AGROFORESTRY TREES

In 1996 ICRAF hosted an international conference on non-timber tree products in Nairobi, at which representatives from the private sector and the research community met to discuss potential tree products and markets. One family of non-wood products—perhaps the most potentially lucrative of all—is pharmaceuticals derived from tropical trees, which can be domesticated to become agroforestry trees.

At the moment, the mutual interest between ICRAF and pharmaceutical companies is the domestication of 2 trees that ICRAF sees as potential income earners for the farmers in the humid lowlands of West Africa. One of these, *Prunus africana,* provides medicine from its bark that is used to treat disorders of the prostate gland in men. And while the incidence of prostatitis is rising—already affecting half the men in the world who are over 60—this montane tree itself has been exploited almost to the brink of extinction, to the extent that certain populations of the species have been classified as endangered by CITES, the Convention on International Trade in Endangered Species of wild fauna and flora.

The interest of the pharmaceutical companies—in ensuring a good supply of the medicines in future—coincides with ICRAF's aim to domesticate this tree and make it part of agroforestry systems in Africa. The global market value of the tree product is USD 220 million a year, and the sole source of the bark is still the natural populations of montane tropical Africa, particularly in Cameroon, Kenya and Madagascar.

ICRAF, working with national partners in those countries, is now involved in a project to domesticate the species and to spread information on its

The bark of Prunus africana *is harvested for the pharmaceutical industry. Forest supplies of this bark, used for treating prostatitis, are rapidly dwindling, but the market is not. Domesticated trees grown on smallholder farms would maintain a supply of the bark for the industry—and be an economic boon for the farmers.*

sustainable use. The project will provide local communities with a source of income, and by taking pressure off the natural forests, it will help conserve the rich biodiversity of the African forests.

But tree bark can cure a lot more than prostatitis. The bark of another threatened African tree, *Pausinystalia johimbe*, is the source of the only clinically proven cure for impotence and has long been used as a traditional stimulant in Africa. In the past few decades it has made a name for itself on the international market as well. Yohimbe, as this aphrodisiac is known, is an alpha-adrenoreceptor blocker—that is, it reduces the effect of hormones that constrict blood vessels. ICRAF scientists are coordinating a resource survey of this West African tree in the rainforests of Nigeria, Cameroon and Gabon, where deforestation and overexploitation could threaten the future of this valuable genetic and natural resource. Because *P. johimbe* is a middle-storey tree, researchers at ICRAF view it as an ideal species for farmers to grow in their fields in agroforestry systems. Investigations are ongoing to determine the remaining populations of the tree, its basic biology, and the amount of genetic variation in its populations, with an eye to domesticating the tree and selecting genotypes with high concentrations of the active ingredients in its bark. With this information, domestication of the tree—improving both the quality and the quantity of the product—can proceed and provide a source of income for rural people, who can plant and grow it on their land. Not to forget the benefits of this work for the 1 in 10 men on the planet who suffer from impotence!

NEW FRONTIERS IN CYBERSPACE

This year ICRAF played a key role in helping to bring its African agricultural research partners closer to the information superhighway. Many NARS researchers are hindered in their communication with their peers and in their access to current information because they lack what the computer people call 'connectivity'—with electronic mail and Internet facilities.

This year, at the request of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA), ICRAF took the lead in implementing the AfricaLink project. This

ation: http://www.cgiar.org/icraf/

Welcome to ICRAF Online

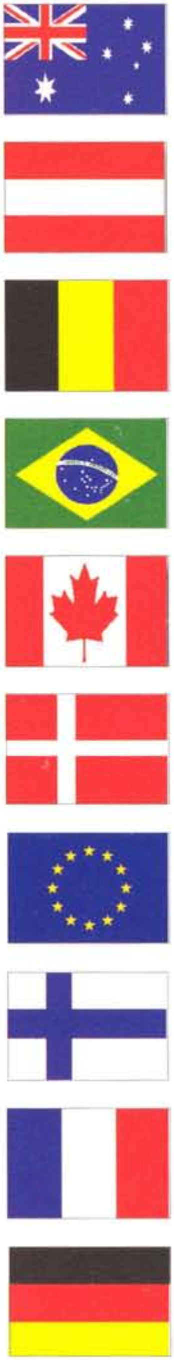
The official website of the International Centre for Research in Agroforestry

ICRAF has its own home page on the World Wide Web, where Internet browsers can glean different types of agroforestry information.

project aims to improve the connectivity of NARS and their staff who participate in research networks for agricultural and natural resources management. With funding from the Africa Bureau of the United States Agency for International Development (USAID), ICRAF began implementing the project by identifying key regional research networks and their members.

The guiding principle behind AfricaLink is to rely and build on local and national capacity, where it exists, to provide electronic connectivity, with an eye to sustainability and the promotion of local entrepreneurship. Already AfricaLink has provided email links to over 150 NARS institutions and researchers in Ethiopia, Kenya, Madagascar, Tanzania and Uganda. Arrangements have been made with local Internet service providers in Eritrea and Rwanda to provide connectivity to AfricaLink–ICRAF partners in these countries.

But that is not all we have done to expand our frontiers into cyberspace. ICRAF has also carved out a niche for itself with its own home page on the World Wide Web. We have had thousands of visitors to our site and fielded hundreds of questions in headquarters in Nairobi—about agroforestry, about ICRAF and about links with others around the world who have an interest in agroforestry. Our information offices have become the centre of what has turned out to be an informal network for the exchange of information. And given that our 1st home page was only a preliminary effort—displaying only some newsy stories about agroforestry and not the detail that has been added since then about the centre and its work—we have been delighted at the interest shown among agroforestry browsers on the Internet. It is now onwards—and outwards—as ICRAF continues to expand and develop its home page on this global medium for disseminating and exchanging agroforestry information.

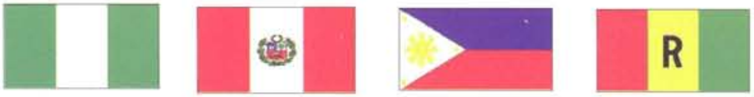


OUR DONORS

ICRAF and its global research and dissemination programmes are made possible by generous funding from many donors. In 1996, they were (in alphabetical order): Australia, Austria, Belgium, Brazil, Canada, the Centre Technique de Coopération Agricole et Rurale (CTA), Denmark, the European Union, Finland, the Ford Foundation, France, Germany, the Interamerican Development Bank (IDB), the International Development Research Centre (IDRC), the International Fund for Agricultural Development (IFAD), Ireland, Japan, the Netherlands, Norway, the Rockefeller Foundation, Spain, Sweden, Switzerland, the United Kingdom, the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the United States of America, the University of Georgia (in USA), the World Bank. Generous assistance also comes from many other governments, national institutions, centres and agencies with which ICRAF collaborates around the world.

ICRAF in the tropics

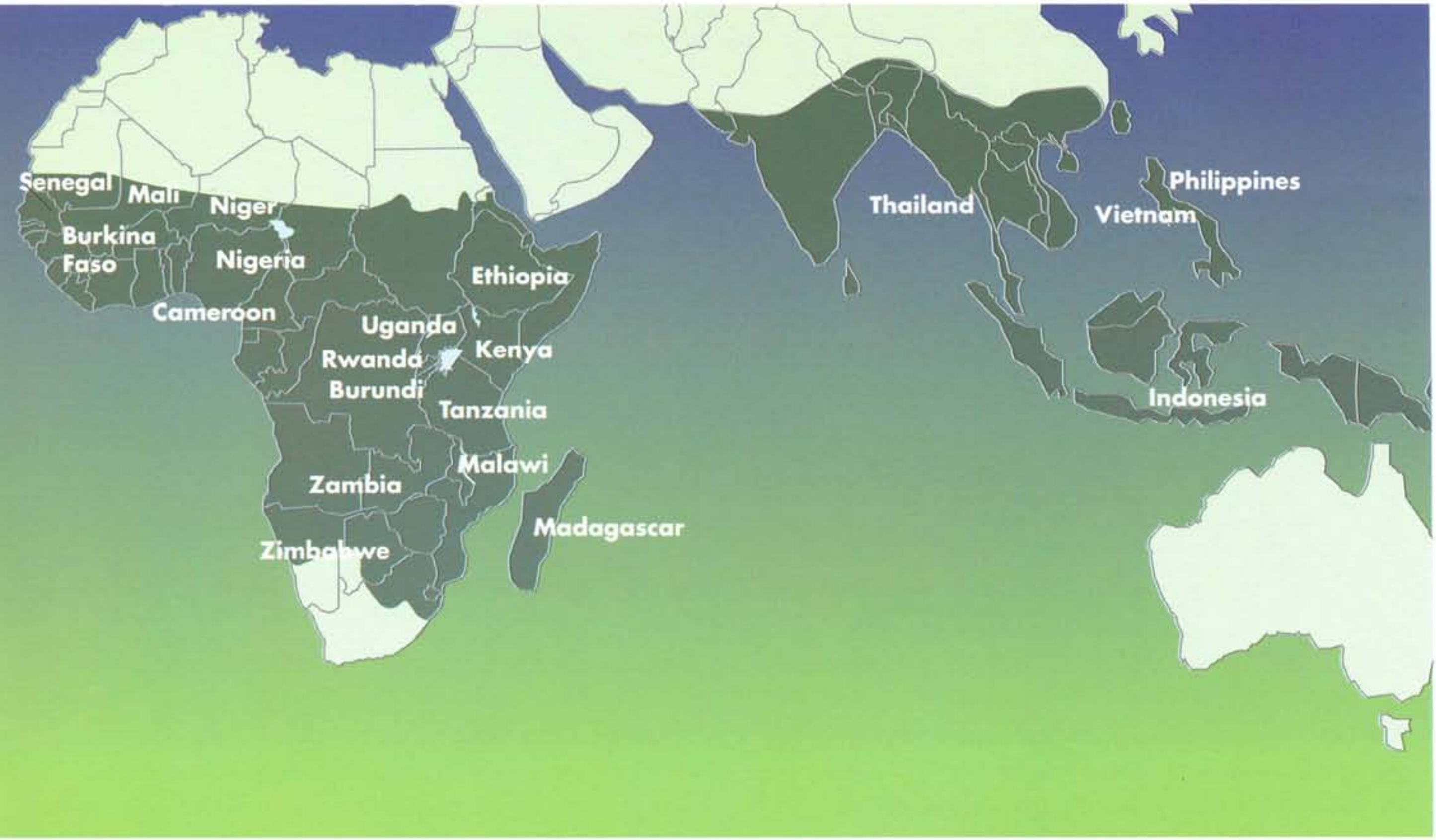
ICRAF activities are carried out by programme and project: 22 projects operating within 5 programmes. We carry out these activities with our partners at sites and stations in 23 countries—locations chosen within our 6 ecoregions: the humid tropics of Latin America and of Southeast Asia, the humid lowlands of West Africa, the highlands of eastern and central Africa, the subhumid plateau of southern Africa, and the semi-arid lowlands of West Africa. These sites represent a range of biophysical, environmental and socioeconomic conditions broad enough to provide us with the global perspective we need to produce international public goods from agroforestry research. ICRAF has only 1 research station of its own, located at Machakos in Kenya. Therefore, our on-station experimental work is done almost entirely in the research stations of national agricultural research systems (NARS). As a result, collaboration with NARS provides a critical link between ICRAF and farmers, especially in assisting with the adaptation of research results for a wider clientele.










Senegal
Mali
Niger
Burkina Faso
Nigeria
Cameroon
Ethiopia
Uganda
Rwanda
Kenya
Burundi
Tanzania
Malawi
Zambia
Madagascar
Zimbabwe
Thailand
Philippines
Vietnam
Indonesia







Consultative Group on International Agricultural Research

CIAT	Centro Internacional de Agricultura Tropical
CIFOR	Centre for International Forestry Research
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICLARM	International Centre for Living Aquatic Resources Management
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IIMI	International Irrigation Management Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IPGRI	International Plant Genetic Resources Institute
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
WARDA	West Africa Rice Development Association

The Consultative Group on International Agricultural Research (CGIAR), established in 1971, is an informal association of 53 governments, international organizations and private foundations working together to support a network of 16 agricultural research centres around the world. The mission of the CGIAR is to contribute, through its research, to promoting sustainable agriculture for food sescurity in developing countries.

The philosophy 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 to initiate research on managing natural resources and protecting the environment.

ICRAF joined the CGIAR in 1991, when donors decided that the system should expand to encompass agroforestry, forestry, fisheries and irrigation management. CIFOR was created, and ICLARM and IIMI joined at about the same time to work on those areas.

ICRAF's medium-term plan of action, 1998–2000

At ICRAF, our vision of agroforestry is evolving. As it does so, our plans for 1998–2000 focus on producing agroforestry research results that contribute to human welfare and environmental resilience, through improved agroforestry systems in the tropics. Our medium-term plan for 1998–2000 was developed together with our partners and approved by our Board of Trustees, TAC (the Technical Advisory Committee of the CGIAR) and the CGIAR. Its salient features follow.

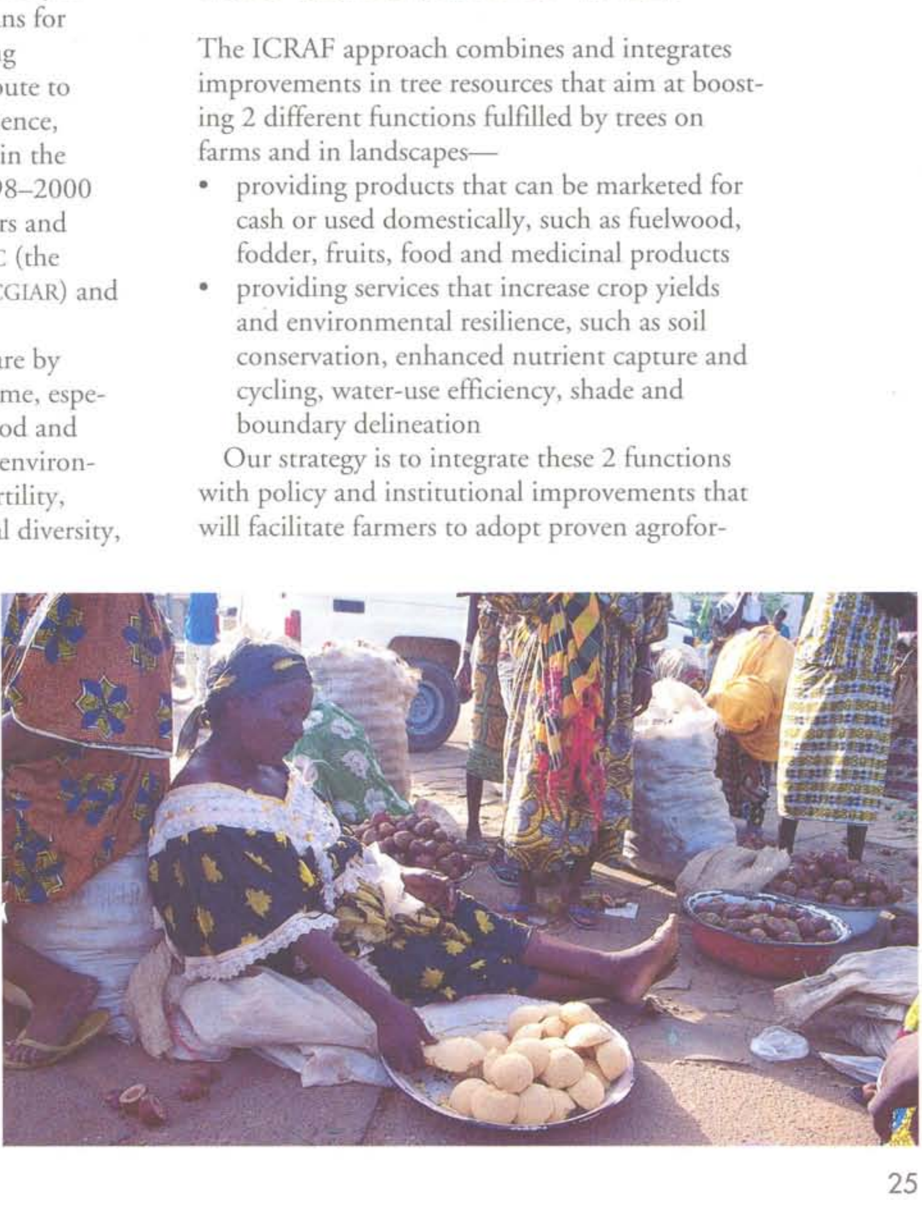
ICRAF aims to improve human welfare by alleviating poverty, increasing cash income, especially among women, and improving food and nutritional security. It aims to enhance environmental resilience by replenishing soil fertility, conserving the soil, enhancing biological diversity, sequestering carbon and reducing emissions of greenhouse gases.

TWO FUNCTIONS OF TREES

The ICRAF approach combines and integrates improvements in tree resources that aim at boosting 2 different functions fulfilled by trees on farms and in landscapes—

- providing products that can be marketed for cash or used domestically, such as fuelwood, fodder, fruits, food and medicinal products
- providing services that increase crop yields and environmental resilience, such as soil conservation, enhanced nutrient capture and cycling, water-use efficiency, shade and boundary delineation

Our strategy is to integrate these 2 functions with policy and institutional improvements that will facilitate farmers to adopt proven agrofor-



Alleviating poverty

At a Sahelian morning market, women sell néré cakes, made from the yellow powder contained in the pods of Parkia biglobosa. *The powder is made into a tangy paste that is used as a spice in stews and sauces. Marketing such tree products helps alleviate rural poverty.*

Increasing food security

The yellowed and spindly maize grown on unfallowed land stands in vivid contrast to the luxuriant, healthy growth of the maize produced after a 2-year improved fallow.

estry systems on a wide scale. This approach also represents a natural evolution of agroforestry into an applied ecological science.

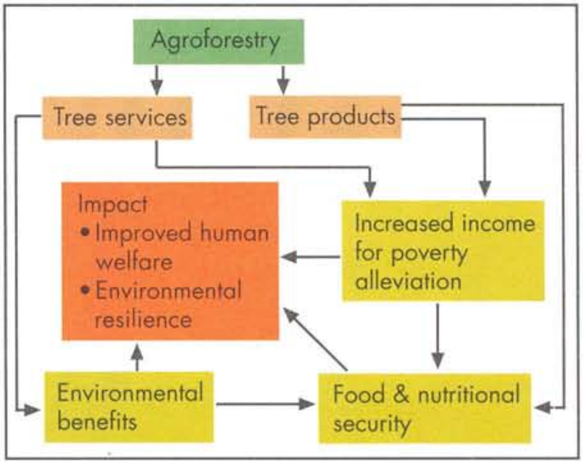
ICRAF'S 4 GOALS FOR AGROFORESTRY

To transform our vision statement into practical goals for the medium term, ICRAF sets 4 goals—

- alleviating poverty
- increasing food security
- increasing nutritional security
- enhancing environmental resilience

The relationship between the functions of trees and our goals and vision statement is shown in the figure below.

This approach also signals a natural evolution of agroforestry into an applied ecological science. It builds upon concepts drawn principally from ecology and economics, as well as the fundamentals of forestry and agronomy. Our scientists now view agroforestry as successional phases in the



The relationship between 2 principal functions of trees, the 4 goals of ICRAF's research, and the impact required to mitigate 2 global challenges.

development of agroecosystems akin to those of natural ecosystems. Thus agroforestry is rapidly becoming a multidisciplinary science—international scientists at ICRAF are trained in about 25 disciplines in the social and biophysical sciences.

SETTING OUR PRIORITIES

Priority setting in ICRAF is a consultative and iterative process. It intensively involves staff and management and takes into account the overarching goals of the CGIAR. In setting these priorities, the criteria are:

- relevance to poverty alleviation
- relevance to gender
- relevance to the environment and marginal lands
- delivery of international public goods
- new developments in science
- alternative sources of supply
- collaboration, partnerships and outsourcing
- consolidation and disengagement
- activities devolved or discontinued
- congruence with TAC priorities
- probability of success

Increasing nutritional security

Improved fruit trees help provide children with better nutrition. Here, a girl in Brazil enjoys fruit—rich in vitamins and micronutrients—from the family homegarden.

Enhancing environmental resilience

Upland rice grows in alleys between hedgerows of Senna spectabilis *in the Philippines. Such farming systems nurture the land and enhance environmental resilience.*

What is agroforestry? Agroforestry is a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.

ICRAF's working principles—

- Carrying our research across a continuum from strategic to adaptive
- Ensuring that research is strongly oriented towards development
- Facilitating interdisciplinary links
- Focusing on systems thinking
- Focusing on scaling up to watershed, community, national and global scales
- Ensuring that all ICRAF activities lie within the agreed agenda of the CGIAR

FOCUS ON GENDER

ICRAF highlights gender issues as a priority for a number of reasons—

- rural women play a crucial role in agricultural production in the developing world—and women are largely responsible for feeding the family and for fetching wood and water
- women and men often play distinctly different roles in communities
- women also often have less access to resources
- changes in household and community structures are changing women's roles—for example, the number of female-headed households in Africa has increased dramatically
- in developing countries as a whole, rural women constitute 60% of the poorest of the poor

Rural women in Africa traditionally carry a heavy load—they must farm, feed the family, tote the fuelwood and water for the home—often with little access to outside resources.

- the burden of nutritional security often falls on women—and family nutrition improves when rural women have domesticated indigenous fruit trees that provide vitamins and micronutrients

BUILDING WITH PILLARS

The ICRAF research agenda is determined by a process that starts with priority setting in the regions where it operates. As a result, we have identified 5 common themes—the pillars that give global coherence and perspective to our work. Together they constitute our strategy. Three are pillars of research and 2 of development:

- diversification and intensification of land use through *domestication* of agroforestry trees
- *soil fertility replenishment* in nutrient-depleted lands with agroforestry and other nutrient inputs
- socioeconomic and policy research leading to enabling *policy* environments that benefit smallholder farmers
- *acceleration of impact* on farm by ensuring research results are utilized
- *capacity and institutional strengthening* through training and the dissemination of information

We have incorporated these 5 pillars into our operating plan as 5 programmes, which cut across and reflect the priorities of the 6 ecoregions in which ICRAF operates:

- humid tropics of Latin America
- humid tropics of western and central Africa
- humid tropics of Southeast Asia
- subhumid highlands of eastern Africa
- semi-arid Sahel
- subhumid unimodal plateau of southern Africa

Throughout these regions, we are simultaneously tackling major poverty and environmental problems that can be particularly addressed by agroforestry. The 1st 3 regions focus on the search for alternatives to slash-and-burn agriculture at the margins of the world's tropical moist forests, where major global environmental damage is occurring in the midst of rural poverty. In the last 3 regions, all in Africa, the issue is how to overcome exacerbated land degradation accompanied by rapidly decreasing per-capita food production.

ABOUT THE PILLARS . . .

DOMESTICATION OF AGROFORESTRY TREES

Farmers throughout the tropics rely on products and services from trees for much of their livelihood. Human-induced improvement of high-valued trees can increase those products and services.

Domesticating a tree means taking it from the wild and developing the characteristics that make it more desirable. Development can start at any point along the continuum from the wild to the genetically transformed state.

ICRAF scientists and their national collaborators in these regions are now assessing the variations in the products these trees provide. Their domestication will result in high-value products for sale locally, regionally or internationally.

Which trees to domesticate is a decision that the farmers themselves make in a priority-setting exercise with ICRAF. During a rangewide survey in the Sahel, farmers identified tree species that they valued the most—those that provide food security such as baobab *(Adansonia digitata)* leaves, or high-value products such as karité or sheanut from *Vitellaria paradoxa.*

Similar surveys in the humid lowlands of West Africa and in southern Africa have identified valuable trees that provide useful products and

Much variability occurs in native, 'wild' trees, such as here (left) in the peach palm (Bactris gasipaes) *in Peru. Researchers start with trees preferred most by local farmers and select to bring out their best traits while ensuring genetic variability. The right policies can facilitate farmers in many ways; below, government policies enable these farmers in Uganda to start and operate small-scale nurseries.*

services to the local people—the bush mango *(Irvingia gabonensis)* in Cameroon and Nigeria for fruits and kernels, and 'marula' *(Sclerocarya birrea)* and 'masuku' *(Uapaca kirkiana)* in the miombo woodlands of southern Africa for fruit and beverages. Likewise, Amazonian farmers have identified peach palm *(Bactris gasipaes)* for fruit, heart-of-palm and parquet wood and *Inga edulis* for fruit and charcoal.

SOIL FERTILITY REPLENISHMENT

Much of sub-Saharan Africa has seen a fall in per-capita food production in the last 30 years. A major reason for this is declining soil fertility, caused in large part by nutrient mining and soil erosion.

The key soil fertility problems arise from the depletion of phosphorus and nitrogen. Earlier agroforestry research focused on restoring soil fertility through biological nitrogen fixation. In addition to fixation by legumes, some leached nitrates can be recovered by deep-rooted trees and shrubs. One or 2 years of leguminous tree fallows of *Sesbania sesban* and *Tephrosia vogelii* have replenished nitrogen fertility in situ, and subsequent maize crops have benefited tremendously.

But phosphorus cannot be replenished by biological means alone. However, ICRAF and its partners may have hit upon a winning combination. They are now looking at combining the organic inputs from trees and shrubs with indigenous rock phosphates to replenish soil phosphorus. When high-quality rock phosphate is added to the land along with the biomass of a common shrub, *Tithonia diversifolia*, crop yields improve—sometimes dramatically.

POLICY RESEARCH

About 1.2 billion people—24% of the world's population—both rural and urban, in developing countries of Asia, Africa and Latin America will depend largely on agroforestry products and services for their livelihood by the year 2000.

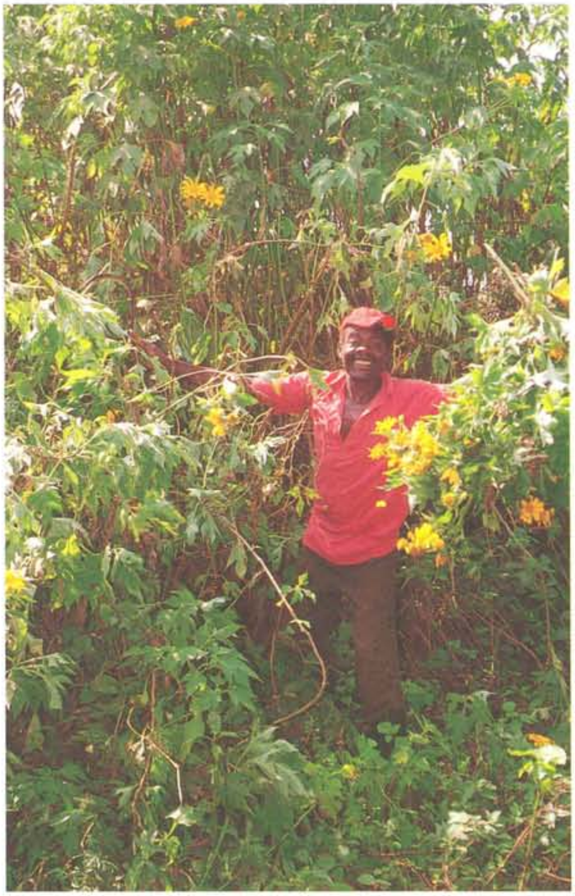
However, many of the agroforestry options that they rely on will work only when appropriate policies are in place. Policy issues are critical for enlisting the support of the many farmers practising agroforestry. Key policy issues—

- supplying and delivering tree germplasm
- clarifying land and tree tenure
- overcoming time lag before trees produce
- financing soil fertility replenishment
- improving transportation and markets of agroforestry products

Working on these policy issues is at the heart of our major research activities in Southeast Asia and Africa, and increasingly in Latin America. And we conduct both technology and policy research on the same problems at the same time.

ACCELERATION OF IMPACT

We are now working with government research and extension services, farmer groups, non-governmental organizations, and universities to disseminate the most promising agroforestry technologies. Applied research activities in the 6 ecoregions where we work focus on testing the myriad of promising technologies such as fodder banks for periurban dairy, live fences, rotational woodlots, silvopastoral systems, vegetative filter strips, improved fallows, biomass transfers, and agroforests. For example, in eastern Zambia, more than 4000 farmers are collaborating with many partners who are evaluating short-duration fallows to restore nitrogen fertility to the soils.



Farmers and researchers are working together to replenish soil nutrients, using the common shrub Tithonia diversifolia . . .

. . . along with locally available phosphate rock.

We need to understand the processes that lead farmers to adopt or reject a new technology. And we need feedback from policymakers and users. This will facilitate wider scale dissemination and enable our researchers to improve the design of agroforestry research.

CAPACITY AND INSTITUTIONAL STRENGTHENING

Non-governmental organizations, women's organizations, farmer groups and individual farmers are keen on agroforestry practices. But many lack the information, technology and skills to apply these practices effectively. Central to our development plans is the strengthening of local human resources and institutions everywhere we work. This means helping local, national and regional institutions equip their staff with the necessary multidisciplinary knowledge and skills to conduct agroforestry research and development.

By facilitating the capacity of universities to incorporate recent advances in agroforestry into training curricula, teaching materials and information dissemination processes, we hope to endow tropical countries with a lasting capability to undertake agroforestry research and development—even long after ICRAF researchers are gone.

Our aims are also to ensure that research results are available to policymakers, development projects, donors and the scientific community, and to facilitate a global exchange of information on advances in agroforestry research, with the increasing use of modern information technologies.

FROM PILLARS TO GLOBAL PROGRAMMES

To realize our vision, we have translated our pillars into 5 programmes. Each of these programmes functions in all 6 ecoregions in which we work, forming a matrix of region and pillar. The programmes, involving both research and development are—

If research is going to have any impact, it must involve the farmer at all stages. Farmer, researcher, and NGO and extension workers work together to improve agricultural conditions and yields.

- Natural resources strategies and policy
- Domestication of agroforestry trees
- Ecosystem rehabilitation
- Systems evaluation and dissemination
- Capacity and institutional strengthening

THE ECOREGIONS IN WHICH WE WORK

ICRAF undertakes collaborative research and development activities based on our 5 pillars at 59 research sites in 23 countries in the tropics—locations chosen within our 6 ecoregions. Overall, they represent a wide range of biophysical, environmental and socioeconomic conditions to provide us with the global perspective we need to produce international public goods from agroforestry research.

ICRAF's activities in the humid tropics of Latin America are located in the Amazon of Peru and Brazil and in southeastern Mexico, areas facing rapid deforestation amidst the poverty of indigenous people and migrants alike. Regional headquarters are in Pucallpa, Peru. Our work focuses on best-bet alternatives to slash-and-burn agriculture at the forest margins. We are domesticating high-priority trees for use in multistrata systems, improved fallows and silvopastoral systems. All work in this region, and in the following 2, is part of the Alternatives to Slash-and-Burn programme, where we and our partners measure the effects of the best-bet alternatives on global environmental benefits such as biodiversity conservation, enhanced carbon sequestration and decreased emissions of greenhouse gases.

In the humid tropics of western and central Africa, headquartered in Yaoundé, Cameroon, we are promoting high-value agroforestry tree products for fruit and pharmaceuticals, working to create favourable policies on marketing and land tenure, and developing improved fallows and multistrata agroforestry systems.

In the humid tropics of Southeast Asia, ICRAF, with regional headquarters in Bogor, Indonesia, works in Indonesia, the Philippines, Thailand and

Practical, hands-on training courses are a strong way to build local capacity. Here such a course takes to the field in West Sumatra.

Vietnam, focusing on rehabilitating the imperata grasslands, hilly farmlands and complete watersheds. We assist governments to frame policies that make it attractive for farmers to adopt appropriate agroforestry technologies in these degraded uplands with complex agroforests and biological control systems for soil erosion.

The subhumid highlands of eastern and central Africa include high-potential agricultural zones in Burundi, Ethiopia, Kenya, Madagascar, Rwanda and Uganda. ICRAF's work in this region centres on how to improve soil productivity. It also contributes to the African Highlands Initiative, under the umbrella of ASARECA, the Association for Strengthening Agricultural Research in East and Central Africa. The headquarters for this region is at ICRAF's main headquarters in Nairobi, Kenya.

Our programme in the semi-arid Sahel covers 4 countries: Burkina Faso, Mali, Niger and Senegal. It is headquartered in Samanko, Mali. Our job is to make Sahelian farming systems more robust. To strengthen them, we are working with our partners on live fences of trees or shrubs, tree fodder banks, soil fertility replenishment, the domestication of high-priority indigenous trees, and policy research.

The subhumid plateau of southern Africa includes Malawi, Tanzania, Zambia and Zimbabwe and encompasses the Zambezi Basin and the miombo forest ecosystem. Headquarters are in Makoka, Malawi. Here, we work in partnership with national organizations on problems of declining soil fertility, shortage of fodder and fuelwood, and environmental degradation. We are particularly promoting the improvement of indigenous fruit trees.

GLOBAL AND ECOREGIONAL PROGRAMMES

ICRAF serves as the convening centre for 2 programmes within the CGIAR system: Alternatives to Slash-and-Burn and the African Highlands Initiative, both of which are research consortia that

In Peru, the land in the foreground has been slashed and burned to clear it for agriculture. The Alternatives to Slash-and-Burn Programme is promoting multistrata agroforests as one of the best-bet alternatives to this type of agriculture. Rich in biodiversity, they produce valuable, reliable materials for the farmers who grow and nurture them.

include a number of international and national institutions, NGOs, universities, advanced research institutes and farmer groups.

Alternatives to Slash-and-Burn Programme

This programme is fully integrated into ICRAF's work in Latin America, Southeast Asia and the humid lowlands of West Africa. Currently it is working in 8 countries: Brazil, Cameroon, Indonesia, Mexico, Peru, the Philippines, Thailand, and Vietnam.

Focusing on reducing deforestation and greenhouse gas emissions and on maintaining biodiversity while addressing poverty, the programme has identified 5 best-bet alternatives to slash-and-burn: complex multistrata agroforests, simple agroforests, improved fallows, agropastoral systems, and natural forest management. They are being evaluated jointly with IITA, CIAT, CIFOR, IFPRI, TSBF and over 30 other national and international partners.

African Highlands Initiative

In eastern and central Africa, ICRAF's work is part of the African Highlands Initiative, which ICRAF also convenes. Coming under the aegis of ASARECA, it is an ecoregional programme on natural resource management, and a part of the Global Mountains Initiative convened by CIP.

The programme involves about 20 partners working in Ethiopia, Kenya, Madagascar, Tanzania and Uganda. It focuses on restoring soil fertility in the highlands, particularly in high-potential areas that have been seriously degraded over time. ICRAF contributes a perspective on natural resource management and agroforestry.

PARTNERSHIPS

ICRAF works in active, substantive collaboration with over 400 institutions. These include 19 international research institutes; 13 regional organizations; 59 agricultural, forestry, natural resources and

The African Highlands Initiative focuses on restoring soil fertility in steep but high-potential areas such as these lakeshore hillsides in Uganda.

policy-related NARS in 23 developing countries; 120 universities in developing countries; 112 non-governmental organizations and farmer groups; 94 advanced research institutes, mainly located in donor countries; and 4 private sector research organizations. The impact of ICRAF's research has been greatly strengthened by such partnerships.

LOOKING AHEAD . . .

Our medium-term plan of action is designed to help us achieve our vision of contributing to the improvement of human welfare and environmental resilience through improved agroforestry practices. It directly addresses our 4 goals:

- alleviating poverty
- increasing food security
- increasing nutritional security
- enhancing environmental resilience

. . . and our 5 pillars:

- domestication of agroforestry trees
- soil fertility replenishment
- policy research
- acceleration of impact
- capacity and institutional strengthening

We are moving toward stronger, more autonomous regional teams. This move will be complemented by the global coherence—and perspective—that ICRAF headquarters will provide, including global synthesis of research carried out on the priority research and development pillars.

ICRAF is currently funded by 33 donor agencies and partners. We see modest growth in the period from now until the year 2000, during which time we will increase the depth of our activities without expanding geographically. Our resource requirements for the period represent an increase of 2.7% a year in real terms over our 1997 budget.

These resources will enable us to address, through international research on agroforestry, a set of the central issues of our times: how to alleviate poverty, increase food and nutritional security, and increase environmental resilience, in win–win situations throughout the tropics.

Through its research and development activities, ICRAF aims to contribute to alleviating poverty, increasing food and nutritional security, and improving the environment across the tropics for this and future generations.

CONTENTS

Contents

Latin America

ICRAF's work in the humid tropics of Latin America, Southeast Asia and West Africa constitutes our institutional contribution to the systemwide Alternatives to Slash-and-Burn (ASB) Programme. Our team in Latin America is now headquartered in Pucallpa, Peru, with research and development activities in the Amazon of Peru and Brazil as well as in southeastern Mexico. ICRAF scientists are located in Pucallpa and Yurimaguas, Peru, and in Chetumal, Quintana Roo, Mexico. We collaborate closely with EMBRAPA and other ASB partners at 2 ASB sites in Brazil: Pedro Peixoto (Acre) and Theobroma (Rondonia). Work is conducted in close collaboration with INIA–Peru and INIFAP–Mexico, with several other NARS, NGOs, universities and local organizations in the 3 countries, as well as with other international research organizations: CIAT, TSBF, IFPRI, CIFOR and CIP. Major funding comes from our unrestricted core donors and from the Interamerican Development Bank, the Ford Foundation, the European Union, IDRC and in 1996, the Agencia Española de Cooperación Internacional. Additional funds are provided by DFID, DANIDA and IPGRI.

This year we report on species prioritization, germplasm collection, comparative nutrient dynamics in some best-bet alternatives to slash-and-burn, and advances in silvopastoral and multistrata systems and in capacity building.

FARMERS' PRIORITY TREES: THE ECONOMIC TEST IN PERU

Economic valuation of agroforestry tree species is an essential step in the process of selecting priority species for domestication research. Through participatory ethnobotanical surveys, we identified 5 priority agroforestry tree species for domestication research in the Peruvian Amazon

Basin in 1995 (ICRAF annual report 1995 p 124–125, 130–132). During 1996, we started an economic valuation of these species to determine their economic potential for small-scale farmers, considering both marketable products such as fruit and construction material and the intangible services such as soil fertility improvement and shade, which farmers obtain from these tree species. The tangible products are easier to quantify and have been calculated; valuation of intangible services is continuing in 1997. At this stage we are not so concerned about the exact rank of each species; rather, we are using this information to devise an appropriate domestication strategy for each one. Although much of the information we obtained did not come as a surprise, it is extremely important to actually quantify production and value. For instance, whether a tree produces a cash income in year 4 after planting or not until year 6 can have a great effect on its popularity and rate of adoption.

The 5 species provide a range of products for on-farm use or for sale. Peach palm—*Bactris gasipaes* (Palmae)—yields 2 food crops: the starchy fruit, a traditional staple food, and heart-of-palm, a delicacy sold on the international market. Fruits are consumed fresh or used to prepare flour, cooking oil and animal ration. Fruits develop 3–5 years after the tree is planted and are harvested annually, although fruit yields fluctuate tremendously from year to year (ICRAF annual report 1995 p 132–133). *B. gasipaes* is one of the few species of palm that will resprout when cut. Heart-of-palm comes from the terminal shoot and is composed of immature leaves and petiole sheaths from basal offshoots. It is relished throughout the world. Production begins 2 years after planting, with 2 to 4 harvests a year. The stems are also used on farms or sold for construction poles, fabrication of parquet floors and carving material.

Capirona—*Calycophyllum spruceanum* (Rubiaceae)—and bolaina blanca—*Guazuma crinita* (Sterculiaceae)—are fast-growing species used for firewood, light-construction poles and wall panels. Capirona is also highly valued for parquet floors and for charcoal, and the bark is used to treat skin infections. Stems of both species can be coppiced every 3–10 years, depending on the desired use, and resprouts can be managed for the subsequent harvest.

Guaba—*Inga edulis* (Leguminosae)—is a fast-growing, nitrogen-fixing tree. Its major products are fruit and firewood, and its major service functions are shade and soil improvement. Fruit production begins in the 2nd year. Trees are typically managed for fruit production for 6–10 years, after which they are cut for firewood. Some farmers coppice for firewood in a 2-year rotation. The seeds are also valued as a natural purgative for humans and cattle. Tornillo—*Cedrelinga catenaeformis* (Mimosoideae)—is a high-value timber species (25–40 year rotation) that fixes nitrogen.

The study is being done in 3 cities—Pucallpa, Yurimaguas and Iquitos—and in small farming communities near these cities (fig.1). Pucallpa is the centre of the forest products industry and the fastest growing city in the Peruvian Amazon Basin. A road links Pucallpa with the Andean highlands and the Pacific coast, and the Ucayali River allows access to markets in Iquitos and Brazil.

Figure 1. Location of research sites and major rivers in the Peruvian Amazon Basin.

Yurimaguas is a relatively small city, but it also has transport links with the Andean highlands, the Pacific coast and Iquitos. The largest city in Peru's Amazon Basin, Iquitos, depends almost entirely on the Amazon River and its tributaries for transport.

Sixteen farming communities were selected to sample the agroecological and socioeconomic conditions of smallholder farmers: 7 near Pucallpa, 4 near Yurimaguas and 5 near Iquitos. The farming communities are all located within 50 km of the city, and each has a population of 20–40 families. In each community, we interviewed male and female farmers from 10 families to obtain economic information about the 5 agroforestry species and the other crop species cultivated by the farmers. This included use, scale and cost of production, selling prices at the farmer's gate and in the market, transport costs to the market, and problems associated with production and marketing.

In each of the 3 cities, we interviewed intermediaries and merchants directly involved in the commercialization of these agroforestry products to obtain basic information about market volume, prices and problems with commercialization. Interviews were conducted in 85 markets and business enterprises: 35 in Pucallpa, 20 in Yurimaguas and 30 in Iquitos.

Currently, the 5 priority agroforestry tree species are not being managed and marketed to their commercial potential. Most farmers plant the 2 fruit-producing species at low density, and simply manage natural regeneration of the other species. Most fruit and wood products from the 5 species are destined for on-farm use. Many farmers sell surplus production to intermediaries at the farm gate or trade it with neighbouring farmers for other products and services. High transport costs, especially for wood products, prevent many farmers from directly marketing more of their surplus production. Farmers prefer to invest their resources in the production of short-rotation, marketable food crops (rice, maize, plantain and cassava) and cattle. Lack of credit for producing agroforestry tree products prevents farmers from considering larger scale production of these species.

The exception is found where farmers have access to large markets. In such locations they currently receive greater economic return by producing and marketing fruits of *B. gasipaes* and *I. edulis* and firewood and construction poles from *C. spruceanum* than they do from traditional food crops. During the peak of fruit production, however, the fresh-fruit markets soon become saturated, reducing the farmers' economic return. Commercial processing facilities have still not been developed sufficiently to create significant demand for these fruits. This situation presents an opportunity for growing fruit varieties with off-season yields.

Among the 5 agroforestry tree species, *B. gasipaes* has the greatest commercial potential for resource-poor farmers, especially in the Yurimaguas and Iquitos regions, where about 80% of the farmers interviewed cultivate peach palm on a small scale (typically 20–50 palms in a 30-ha farm). Currently, farmers are more interested in the fruit and seed than in heart-of-palm. Seeds of cultivated peach palm are sold to dealers to establish *B. gasipaes* plantations in Peru and neighbouring countries, as some local races in Peru are spineless—a greatly desired characteristic—unlike most races in the palm's extensive range (from central Bolivia to northeastern Honduras and to the mouth of the Amazon River and northern Guayana). Heart-of-palm is primarily for on-farm consumption. In the future, heart-of-palm may have greater commercial potential than the fruit, since national and international gourmet markets for this delicacy are expanding. Heart-of-palm production, however, is more labour intensive than fruit production.

Most farmers also cultivate *I. edulis* for fruit production, especially in the Yurimaguas and Iquitos regions. As with *B. gasipaes,* farmers generally do not plant many trees (10–40 per farm). The firewood market for *I. edulis* is growing in Iquitos and Yurimaguas, and some farmers are establishing small woodlots. Amazingly, the economic return on these woodlots, if close to the markets, would be greater than the return from cultivating rice, maize or other short-rotation food crops.

Markets for firewood and construction material from *C. spruceanum* are expanding, especially in the Pucallpa and Iquitos regions, but farmers are not yet cultivating the species for these markets. Many farmers near the markets recognize that economic returns from production of *C. spruceanum* are greater than those from the food crops, but they do not have the financial resources to establish the woodlots.

The market for wood products of *G. crinita* is also growing in the Pucallpa region.

At the moment, *C. catenaeformis* is of little economic importance to farmers. On most farms, nearly all trees of commercial size have been logged. Farmers would like to have more *C. catenaeformis* in their farming systems, but very few are inclined to plant long-rotation timber trees. The market demand for this tree is large, especially in the Pucallpa region, because it is becoming increasingly rare. However, basing our assessment on our economic analysis, we feel that this species should no longer be included at this time as a priority for agroforestry systems in the Peruvian Amazon, but the other 4 remain priority species for domestication research.

GERMPLASM COLLECTIONS OF PRIORITY SPECIES

Farmers value *Calycophyllum spruceanum* and *Guazuma crinita* because they are fast growing, easy to manage, and satisfy some basic needs—construction material, fuelwood and charcoal. As mentioned in the section on economic valuation, both species, but especially *Calycophyllum spruceanum,* have enormous commercial potential for resource-poor farmers.

Both species are pioneers with a wide ecological amplitude in the Peruvian Amazon. The most extensive natural stands occur on fertile, alluvial soils along the riverbanks, but they are also found on infertile, acid soils in upland areas. The natural distribution of both species also spans a wide range in rainfall—from 1800 to over 4000 mm per year.

We expect that some natural stands have greater genetic potential than others for sustained production in improved agroforestry systems. We cannot determine this genetic potential directly by evaluating the natural stands themselves; for example, some stands may grow on more fertile soils. We must evaluate performance under the same management and environmental conditions; this is the objective of a provenance trial. Seeds are collected from a group of trees representing the species in a given geographic area (provenance). A group of seedlings is raised for each provenance, and these groups are compared experimentally under expected management and environmental conditions. Ideally, provenance trials for agroforestry are established on farm, and with farmer participation in the design, management and evaluation for a specific production system (for example, production of construction poles of *Calycophyllum spruceanum* in a long-rotation fallow).

To date, there have been no provenance trials of these tree species from the Peruvian Amazon. In collaboration with national research and development institutes and several local communities, we collected seed of both *Calycophyllum spruceanum* and *G. crinita* from 11 provenances with 35 trees per provenance for each species (fig. 2). Seedlots will be used to establish on-farm provenance trials to identify superior provenances, on-farm progeny tests for estimation of trait heritability and other genetic parameters, and community-level seed orchards to meet the growing demand for improved seed.

Seeds of both *Calycophyllum spruceanum* and *G. crinita* are dispersed by water and wind, so water-dispersed seed is found primarily downstream. We hypothesized that a provenance below the confluence of 2 rivers would contain greater genetic diversity than a provenance above the confluence (for instance, Marañon and Huallaga rivers in fig. 2). We are testing this

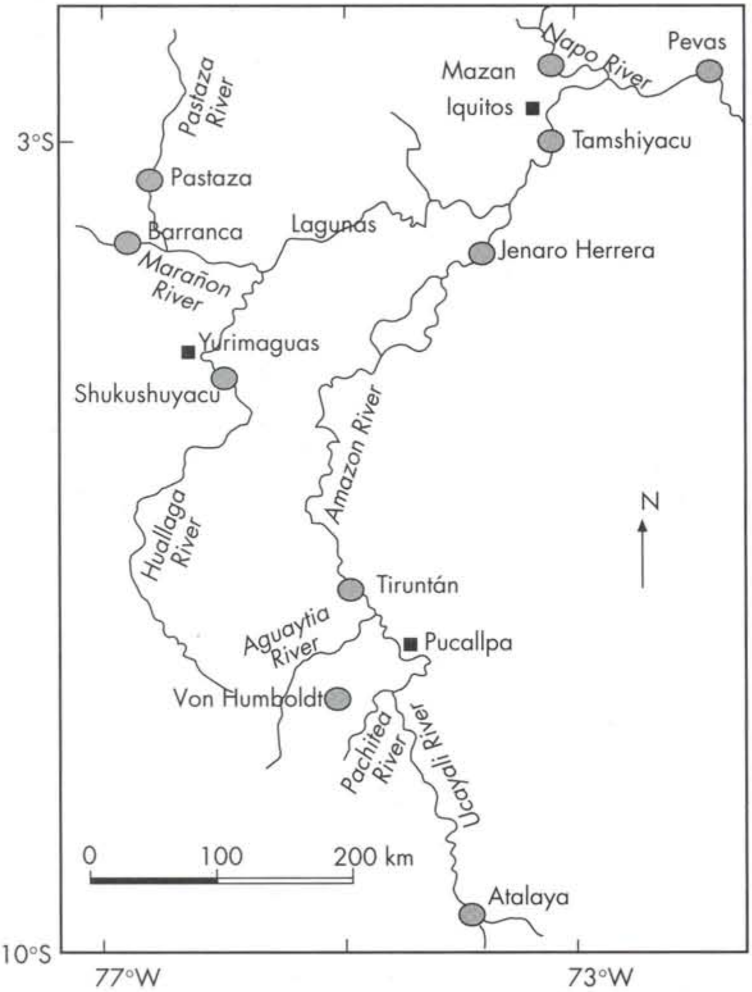


Figure 2. The seed collection sites for capirona (Calycophyllum spruceanum) *and bolaina blanca* (Guazuma crinita) *in Peru. Collections were made of 11 provenances, with 35 trees in each.*

hypothesis using molecular genetic techniques. The results will provide basic information to help manage, develop and conserve the genetic resources of these species.

USE AND MANAGEMENT OF TREE GERMPLASM IN THE PERUVIAN AMAZON BASIN

ICRAF scientists believe that improved tree germplasm will enhance productivity and sustainability of agroforestry systems, and accelerate adoption of these systems. These assertions, although plausible, remain as hypotheses to be tested and are themselves based on several underlying assumptions. For example, we assume that farmers are using primarily wild or largely unimproved tree germplasm on their farms, that there is a demand for improved tree germplasm, and that the lack of improved tree germplasm is a major constraint to adoption of agroforestry.

We started to investigate these assumptions in a case study of farming communities in Ucayali Department of Peru, in collaboration with DFID of the UK. The case study posed the following basic questions: Is the supply of tree germplasm a constraint to tree planting and management on farms in the Ucayali region? If so, how can we alleviate the constraint? If not, what *are* the major constraints or limitations, and how can a domestication programme overcome them? The objectives of the case study were to determine 1) why farmers consider it useful to have trees on their farms, 2) if farmers want additional trees, 3) if the lack of available germplasm or of quality germplasm is a major constraint to tree establishment, and 4) if farmers' lack of knowledge about the tree—its reproductive biology or its management—is a constraint to tree establishment. A brief description of the methodology and some preliminary analyses follow.

CASE STUDY METHODOLOGY

Four farming communities were selected based on cultural differences, access to the major market (Pucallpa), years since establishment and other factors. Shambo Porvenir is a 25-year-old indigenous community located along the Aguaytia River, with poor access to Pucallpa (1 day travel). The other communities are populated by non-indigenous, immigrant farmers. Porvenir is 25 years old, located 25 km from Pucallpa, and with good access by road to its markets (1 hour). San Martin is 7 years old, located 60 km by road from Pucallpa, with fair but seasonal access to Pucallpa (2–3 hours). Yanamayo is 22 years old, downstream from Pucallpa along the Ucayali River, with good access to Pucallpa (1 hour).

The 4 communities practise traditional slash-and-burn agriculture, primarily in areas that are not flooded annually. In immigrant communities, average farm size is 26 ha (1–70 ha), with 2 ha a year under cultivation (0.5–10 ha year^{-1}) and 13.3 ha of high forest (0.5–39 ha). The remainder includes different stages of natural forest fallows that are left to develop after cultivation (collectively referred to as 'crop fields'), home-gardens, orchards, boundary areas and pasture. A typical production cycle starts with slashing and burning a forest fallow 5 to 20 years old. Rice, maize, bean, cowpea, squash and cassava are cultivated for 1–3 years. Then the crops are replaced with plantain and fruit trees (mainly *Citrus* spp, *I. edulis, B. gasipaes, Matisia cordata, Spondias dulcis, Poraqueiba sericea* and *Ananas comosus*) or allowed to develop into a natural forest fallow. In addition to farming, the indigenous community spends considerable time fishing, hunting, gathering native fruits and medicinal plants, and producing handicrafts for the Pucallpa market.

Using rapid rural appraisal, we organized group discussions and semi-structured interviews to obtain information on farmers' socioeconomic conditions and on how they used and managed tree germplasm on farm. The community as a whole classified each family into 3 'well-being' categories, which the communities defined themselves. In general, classifications in the immigrant communities reflected wealth, landholding, production, time in residence, family size and members' ages, knowledge and skills. Since private property is not a traditional concept in the indigenous community, their 'well-being' categories did not reflect farm size or personal wealth. We then grouped the farmers in each community by well-being and gender and randomly sampled 5 farmers within each well-being stratum in each community. A total of 59 farmers were interviewed in the 4 communities (18 women, 41 men).

Each farmer showed us specific trees on the farm, describing each tree's primary function, and indicating the source and form of its germplasm. Germplasm sources included natural regeneration, selected trees on farm or in a neighbour's field, local market and farmers' relatives. Germplasm forms include seed or fruit, transplanted wildlings and nursery-grown seedlings. If the farmer had planted the tree on farm, we asked if it was known where the original germplasm came from (selected mother tree on farm, neighbour's fields and so on). In total, we obtained information about 205 individual trees (referred to here as the sampled trees), representing 33 species and 15 families. In addition, the farmers provided information about the number of trees of the same species at different locations on their farms, positive and negative aspects of the species in relation to crops, intraspecific variation, species' reproductive biology, management practices for the species, selection criteria used when collecting germplasm of the species, and the entire farming system.

TREE FUNCTIONS AND GERMPLASM SOURCES

According to the farmers, the sampled trees had 8 primary functions. Through a pairwise exercise, farmers ranked these functions in order of preference. Considering all communities together, the order of importance was for fruit, construction poles, firewood, medicines, sawn timber, fencing (live and dead), canoe building, and soil improvement (green manure and soil protection). Nearly 50% of the 205 trees were fruit trees: mainly exotic *Citrus* spp and mango *(Mangifera indica)* and 4 native species *(B. gasipaes, I. edulis, Poraqueiba sericea, Pouteria caimito).* The other trees were native species used primarily for poles, firewood and sawn timber (about 15% for each function): mainly *Calycophyllum spruceanum* (poles, firewood, sawn timber), *G. crinita* (poles, sawn timber), *Inga* spp (firewood) and *Cedrela odorata* (sawn timber). Farmers cultivated about 65% of the trees, mainly for fruit (49%) and sawn timber (10%); the cultivation was essentially limited to weed control during establishment. Farmers used but did not cultivate 35% of the trees, mainly for poles (15%), firewood (12%) and sawn timber (6%). The indigenous community also cultivated a few trees for canoe building *(Cedrela odorata)* and soil improvement *(I. edulis).* Trees for fruit, sawn timber and firewood were located primarily in 'crop fields' (fallows) and secondarily in boundary plantings and homegardens, while trees for poles were mainly located in the high forest.

The sampled trees came from a variety of germplasm sources but primarily from natural regeneration of existing trees and farmers' collections on farm (fig. 3). Nearly all the trees used for poles and firewood, and about half the trees for sawn timber, came from natural regeneration. For sawn timber, farmers allowed the most vigourous looking seedlings in the regeneration cohort to develop in preferred areas and rogued out the others. Farmers planted 99% of the fruit trees: 60% from selected on-farm germplasm and the remainder from off-farm sources that were relatively close to the farm. Their selection criteria for fruit trees focused on marketable characteristics of the fruit (size, sweetness, texture, taste, skin thickness) and in some cases the seed (size, colour), but not on actual yield. Farmers

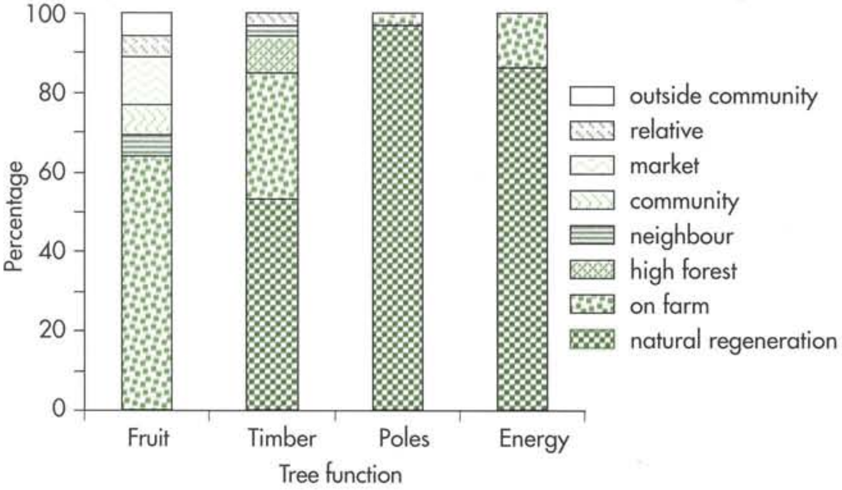


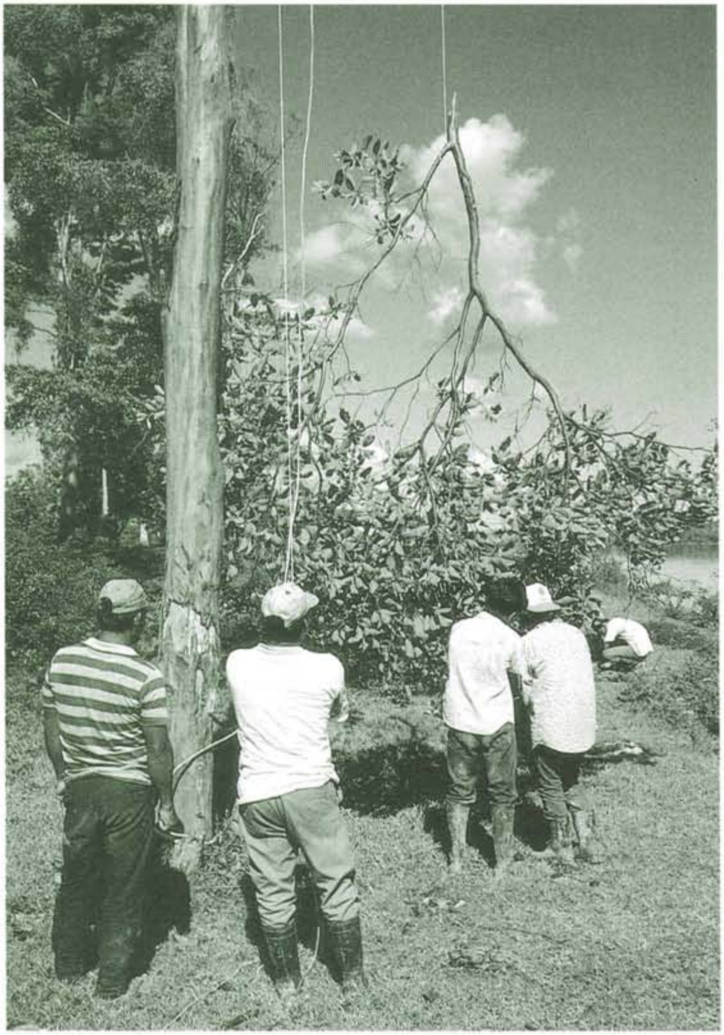
Figure 3. Sources of germplasm for trees used by farmers in the Ucayali region of Peru. Trees are grouped by primary functions: fruit, sawn timber, construction poles, and energy, including firewood and charcoal (n =101, 34, 31, and 28, respectively).

planted about 50% of the trees for sawn timber, and about 35% of the germplasm they used was collected on farm (primarily from fallows) or in their high forests.

Farmers preferred different forms of germplasm for fruit trees and sawn-timber trees. Most of the fruit trees in the sample (87%) were sown by farmers using seed or fruit (included on-farm and off-farm sources). Farmers planted the remaining fruit trees using primarily nursery-grown seedlings and transplanted wildlings. In contrast, they established about 40% of the trees for sawn timber from transplanted wildlings, and the remainder mainly from seed (included on-farm and off-farm sources).

Farmers are clearly selecting fruit and timber-tree germplasm on farm and multiplying the material, and this has important implications for on-farm management of genetic diversity. As mentioned, farmers established a 2nd generation of fruit and timber trees (about 60% of the fruit trees and 35% of the timber trees) from selected on-farm germplasm. What was the original germplasm source for these selected trees, that is, the origin of the 1st generation? According to farmers' recollections, they established most fruit trees in the 1st generation using germplasm obtained from neighbours, the local market, and on-farm collections (about 30, 20 and 20%, respectively), and most of the remaining germplasm from relatives and sources outside the community.

They planted timber trees in the 1st generation mainly with germplasm collected in their high forests and other locations on farm (together about 75%), and most of the others developed from natural regeneration (about 20%). For both fruit and timber trees, the sources of germplasm for establishment of the 1st generation were primarily local and probably contained relatively little genetic diversity. On-farm selection and establishment of the 2nd generation (and subsequent generations) from this original genetic base will reduce on-farm genetic diversity and may lead to reduced production because of



ICRAF is working with farmers to select promising germplasm of priority agroforestry tree species in Peru. This is the first step in our strategy for on-farm domestication of these species. Here, researchers and farmers are collecting seeds from a selected capirona tree (Calycophyllum spruceanum)*, a priority species for construction poles, firewood, charcoal and medicine.*

the effects of inbreeding depression or pest epidemics.

TREE-MANAGEMENT STRATEGIES

Farmers typically enriched their 'crop fields' (fallows) in a sequential manner, establishing additional trees each year in niches corresponding to the species' ecological requirements. Four commonly used tree species for fallow enrichment are *I. edulis*, *B. gasipaes*, *G. crinita* and *Calycophyllum spruceanum*. These results confirmed the species choice from priority-setting exercises carried out in 1995 in other locations. Interestingly, the indigenous community developed more diverse-enriched fallows than the immigrant communities, reflecting their greater knowledge about species use, ecology and management, and their more flexible communal land-use system.

Farmers rarely maintained trees in areas under cultivation because of perceived negative tree–crop interactions. They were not inclined to adopt multistrata agroforestry systems involving simultaneous crop and tree production. They preferred to maintain spatially or temporally distinct crop and tree-production areas, planting species according to their ecological requirements.

Farmers planted fruit trees because they provide economic return in a relatively short period of time, and their labour input is low relative to the return. The most limiting factors for fruit cultivation were related to production and marketing characteristics rather than yield characteristics. The most notable limiting factors were heavy production during a short period rather than the same production spread over several months, the high perishability of the fruits, the shortage of labour during harvest and processing, limited knowledge among the farmers about processing fruits into marketable products with longer shelflife, and the pest problems of some species (primarily *Citrus* spp, *Pouteria caimito* and *Poraqueiba sericea*).

Farmers in the highest well-being group were more inclined than other farmers to plant long-rotation trees for sawn timber (such as *Cedrela odorata* and *Swietenia macrophylla*). In general, however, farmers preferred to plant trees with shorter rotations for this purpose (such as *G. crinita*). Some farmers are establishing on-farm germplasm production areas for *Cedrela odorata*, *S. macrophylla* and *G. crinita*. These are located in their enriched fallow system or in boundary areas. The farmers will use the germplasm (seeds and wildlings) to expand their production on farm and to sell in the market. The seeds or wildlings used to establish these germplasm production areas typically come from 1 or 2 trees (especially for *S. macrophylla*), so the germplasm produced will have low genetic diversity.

Farmers used many trees for poles and firewood but did not cultivate trees primarily for this purpose. The cultivated fruit trees, especially *I. edulis*, are cut for firewood when their fruit production declines. Farmers do not perceive the need to plant trees for poles and firewood, even though the preferred species for these purposes are becoming increasingly rare (such as *Calycophyllum spruceanum*). They rely instead on existing trees in their crop lands and high forests, and salvageable trees from the annual slash-and-burn operation.

Most farmers did not express a desire to have more trees on farm, nor did they express any concern about limited supplies or access to quality tree germplasm. Some farmers did want more high-value fruit trees (for example, spineless *B. gasipaes*) and timber trees (especially *S. macrophylla*) but in general, they felt that their needs could be satisfied with the existing trees on their farms and in neighbouring farms and forests. Farmers, particularly in the immigrant communities, did not express much appreciation of intraspecific variation in tree germplasm, except for fruit trees, and did not seem to know much about the reproductive biology of the trees.

CONCLUSIONS AND RECOMMENDATIONS

- ICRAF should conduct studies on the use and management of tree germplasm as part of the site characterization exercise in all regions.
- There is a lack of quality tree germplasm for some species on farm. Farmers may not perceive this, but their perception is short term, and they do not recognize the potential value of intraspecific variation in germplasm.
- We should work with farmers to develop sustainable methods to 1) produce quality germplasm of priority agroforestry species on farm and 2) manage genetic diversity within

and among agroforestry tree species on farm, in the community and in the region.

- We should conduct market studies for agroforestry tree products, and economic analyses of tree cultivation practices.
- We should strengthen on-farm research on sequential enrichment of fallows using priority agroforestry tree species, such as *B. gasipaes*, *I. edulis*, *G. crinita* and *Calycophyllum spruceanum*.

TEN-YEAR SOIL DYNAMICS IN BEST-BET ALTERNATIVES TO SLASH-AND-BURN

Most previous efforts to find solutions to the problems caused by slash-and-burn agriculture in the humid tropics have explored high-input annual crop systems, with the expectation that they would lead to sustained production without affecting the otherwise marginal ecosystems. Although high-input systems combined with improved acid-tolerant germplasm have indicated considerable agronomic potential, the required high-input management has not been adopted widely by small-scale farmers because the farmers needed either cash inputs or more labour, resulting in lower economic returns. Thus slash-and-burn systems in disequilibrium continue to dominate smallholder agriculture in the humid tropics of Latin America. However, a major change that has happened in the past few decades is a shift from the itinerant mode of slash-and-burn to the practice of this system on sedentary farms, especially in countries that promoted organized settlements. With access to fresh land diminishing as a result of the ever-increasing population pressure, fallow periods have decreased, and increasingly farmers are practising unsustainable slash-and-burn agriculture.

Earlier research did not place a great deal of emphasis on tree crops, but many are well adapted to acid soils that are low in fertility, and their products have cash value. Tree-based systems are more attractive to farmers because they need lower external inputs than do annual crop systems, provide greater returns to labour, and reduce risks. Furthermore, complex multistrata systems involving different species that occupy different strata, besides fulfilling production functions, have the potential to offer environmental benefits similar to those of natural forests. There is, however, limited quantitative information based on long-term evaluation as to the agronomic, economic and ecological performance of systems that are potential alternatives to the slash-and-burn system.

Since August 1985, a long-term experiment has been conducted at Yurimaguas, Peru, with the objectives of 1) quantifying the biological and economic performance and 2) monitoring the long-term soil changes and implications for sustainable production of prototype systems that show promise as alternatives to the traditional slashing and burning. This study was initiated under the leadership of North Carolina State University through the TropSoils Programme in collaboration with the Instituto Nacional de Investigación Agraria (INIA), but after the closure of the TropSoils Programme in 1991 ICRAF assumed the leadership in collaboration with INIA and IIAP (Instituto de Investigaciones de la Amazonía Peruana). The study involved the following 6 systems·

Peach palm (Bactris gasipaes) *is 1 of the management systems that have been undergoing testing at Yurimaguas, Peru, since 1985 in a long-term experiment. The peach palm is planted with an understorey of* Centrosema macrocarpum.

- shifting agriculture: 1-year cropping alternated with 10-year fallow
- high-input cropping: mechanized maize–soybean continuous rotational cropping with high nutrient input from fertilizers and lime
- low-input cropping: 2-year rotational cycle of annual crops with fallow of kudzu *(Pueraria phaseoloides)*
- multistrata agroforestry: a diversified production system with timber, pole and fruit trees *(Cedrelinga catenaeformis, Coffea arabica, Colubrina glandulosa, Bactris gasipaes, Eugenia stipitata* and *Inga edulis)*, annual crops in the first 2 years, followed by a *Centrosema macrocarpum* understorey, forming different strata in the system
- peach palm plantation: peach palm planted at 5 x 5 m with a *Centrosema macrocarpum* understorey
- secondary forest fallow: maintenance of a secondary forest fallow, 10 years old in 1985

The above treatments were replicated 3 times in a randomized block design, in plots measuring 81 x 31 m. The soil under the study site is classified as loamy, siliceous Typic Paleudults. A detailed description of treatments, the soil chemical and physical changes in the topsoil (0–15 cm) over an 8-year period, and a preliminary economic analysis were reported earlier (ICRAF annual report 1994 p 109–114 and p 152–153).

Organic inputs and mineralization potential in different systems have been described in the annual report of 1995 (p 135–137). Soil nutrient changes in the 1-m deep profile over a 10-year period of the experiment, soil macrofauna and extent of mycorrhizal infection of plant species in different systems are presented in this report.

PHOSPHORUS

The initial level of bicarbonate-EDTA extractable phosphorus in the top 15 cm of soil was below the critical level of 12 µg ml^{-1} required for good growth of many annual crops, such as maize and soybean; soil P in the deeper layers was even lower (fig. 4). The soil-extractable P measured 3 months after land clearing increased by 8 to 36% in most systems as a result of burning and the addition of ash. Phosphorus levels decreased gradually over years at a soil depth of 1 m because of the accumulation of P in the standing biomass of both the agroforestry and the fallow systems. The P status in the high-input system increased over the initial level in the 50-cm profile because of the continuous addition of P fertilizers. At the end of 10 years, extractable P was 30% higher than the initial level in the 0–30-cm soil layer of the low-input system and 2 to 3 times higher than the initial level in the 0–50-cm soil layer of the high-input system.

Three important points emerge from long-term observations of extractable P: 1) phosphorus can become a limiting factor in the long run to realizing the potential benefits of agroforestry systems on acid soils, 2) low-input agricultural and agroforestry systems are probably utilizing organic forms of P

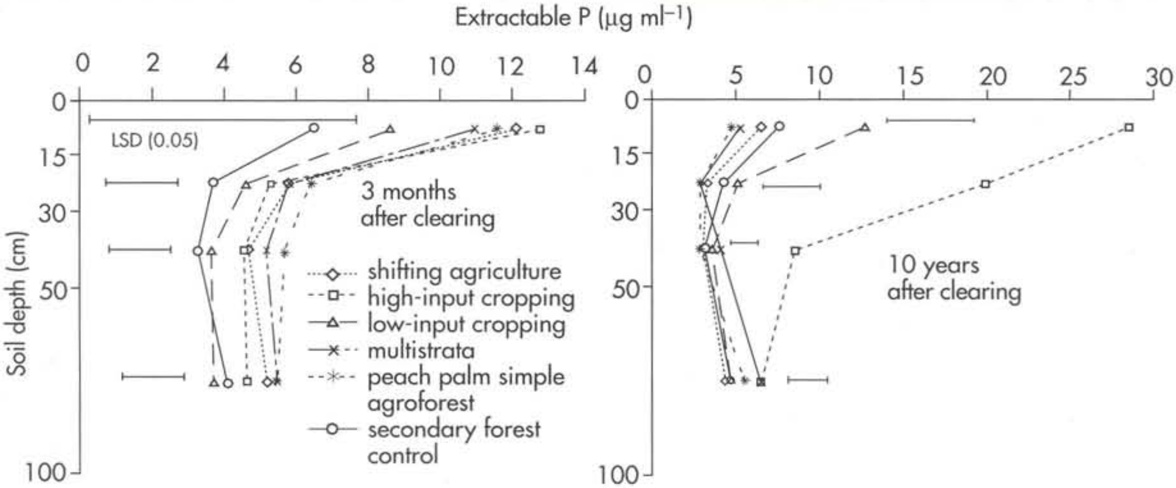


Figure 4. Extractable P in soil layers at depths of 0–15, 15–30, 30–50 and 50–100 cm, measured 3 months and 10 years after the establishment of different land-use systems at Yurimaguas, Peru.

not measured by this soil test, and 3) by regular addition of P fertilizers, at rates to meet the annual crop requirements, soil phosphorus capital can be built up in 8 to 10 years.

SOIL ACIDITY AND ALUMINIUM SATURATION

Exchangeable acidity decreased slightly in the topsoil after the land was cleared. Measurements at 3 months after clearing the secondary vegetation indicated an average acidity of 1.5 $\text{cmol}_c\ l^{-1}$ in the top 0–15-cm layer, which increased with depth to 3.3 $\text{cmol}_c\ l^{-1}$ in the 50–100-cm layer (fig. 5). Exchangeable acidity generally decreased over years throughout the profile of all systems to record values around 1 $\text{cmol}_c\ l^{-1}$ in the topsoil and a little over 2 $\text{cmol}_c\ l^{-1}$ in the 50–100-cm depth by the end of 10 years. Two notable exceptions were the conspicuous decrease of exchangeable acidity in the 50-cm soil depth under the high-input system because of regular additions of lime, and no change in soil acidity all through the experimental period under the secondary forest.

Aluminium saturation averaged 56% in the top 15-cm soil layer and close to 80% below 15 cm before the vegetation was cleared. Any changes in Al saturation were noted only in the topsoil, closely reflecting the exchangeable acidity. Following land clearing and burning of vegetation, Al saturation averaged 42% in the topsoil (fig. 6). Over the 10-

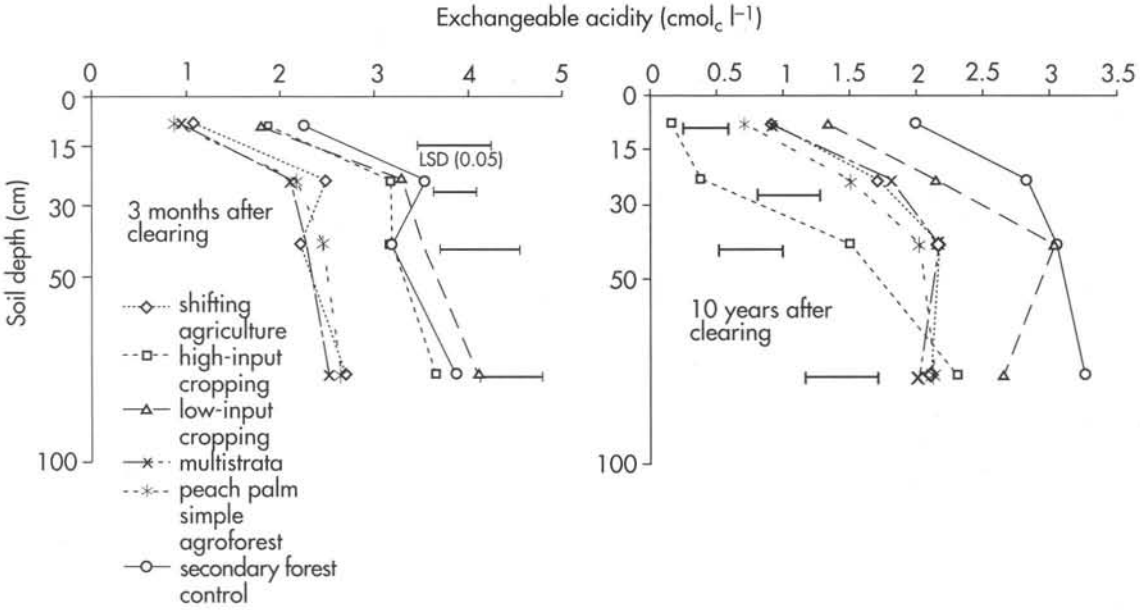


Figure 5. Exchangeable acidity in soil layers at depths of 0–15, 15–30, 30–50 and 50–100 cm, measured 3 months and 10 years after the establishment of different land-use systems at Yurimaguas, Peru.

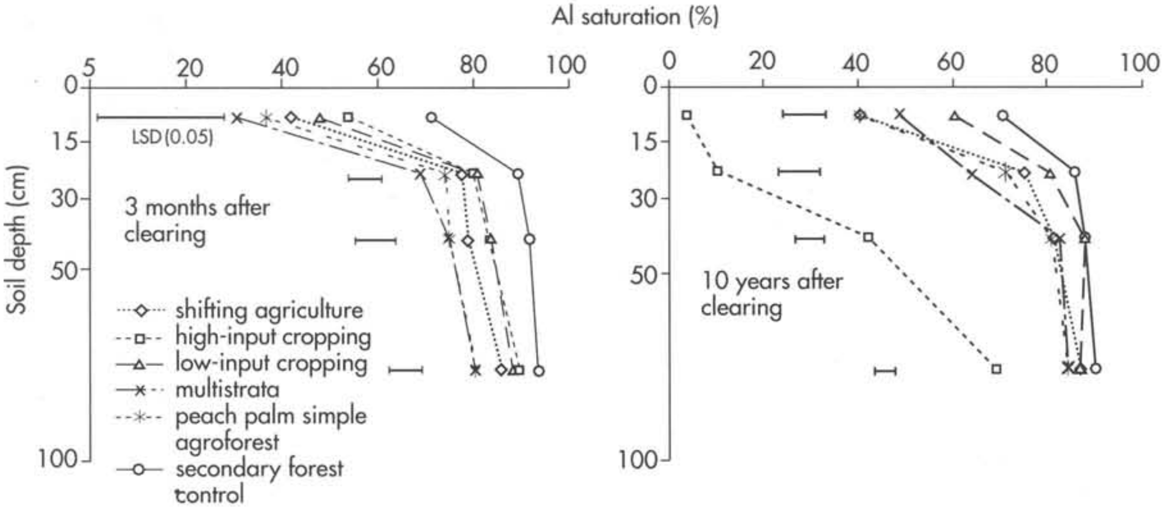


Figure 6. Al saturation in soil layers at depths of 0–15, 15–30, 30–50 and 50–100 cm, measured 3 months and 10 years after the establishment of different land-use systems at Yurimaguas, Peru.

year period, there was no change in Al sauration in the 20-year-old secondary fallow. All treatments except the high-input showed a slight increase in Al saturation, as expected, but they did not reach the level of the control or that of the soil before the experiment started. Therefore, neither the agroforestry systems nor the low-input system is degrading the natural resource base even though nutrients were exported through the harvesting of products. The high-input system, which regularly received lime and fertilizers, showed a remarkable reduction in Al saturation in the 1-m profile.

EXCHANGEABLE CATIONS

The initial level of exchangeable calcium was lower than the suggested critical level of 1.2 $\text{cmol}_c\ l^{-1}$ for good growth of crops in sandy loam soils, as in this study. The slashing and burning of natural vegetation had caused slight increases in exchangeable Ca of the topsoil (fig. 7). The high-input system recorded significantly higher levels of exchangeable Ca than any of the other systems throughout the 1-m profile, with values in the 30-cm soil layer having increased to 2 $\text{cmol}_c\ l^{-1}$ by the end of 10 years, because of lime applications. All other systems recorded lower levels compared with the initial values, probably as a result of Ca uptake by plants.

Most changes of magnesium status for all systems, except the high-input system, were noted in the topsoil. Exchangeable Mg varied little among systems, and except for the high-input system, all systems, including the secondary forest control, recorded a slight decrease over time (fig. 8). The high-input system recorded an increase all through the 1-m profile because

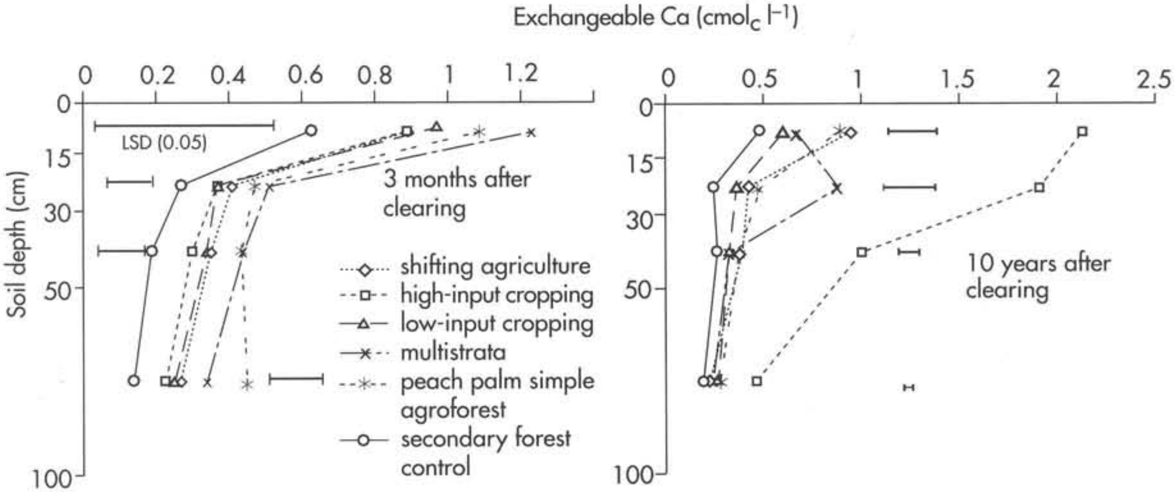


Figure 7. Exchangeable calcium in soil layers at depths of 0–15, 15–30, 30–50 and 50–100 cm, measured 3 months and 10 years after the establishment of different land-use systems at Yurimaguas, Peru.

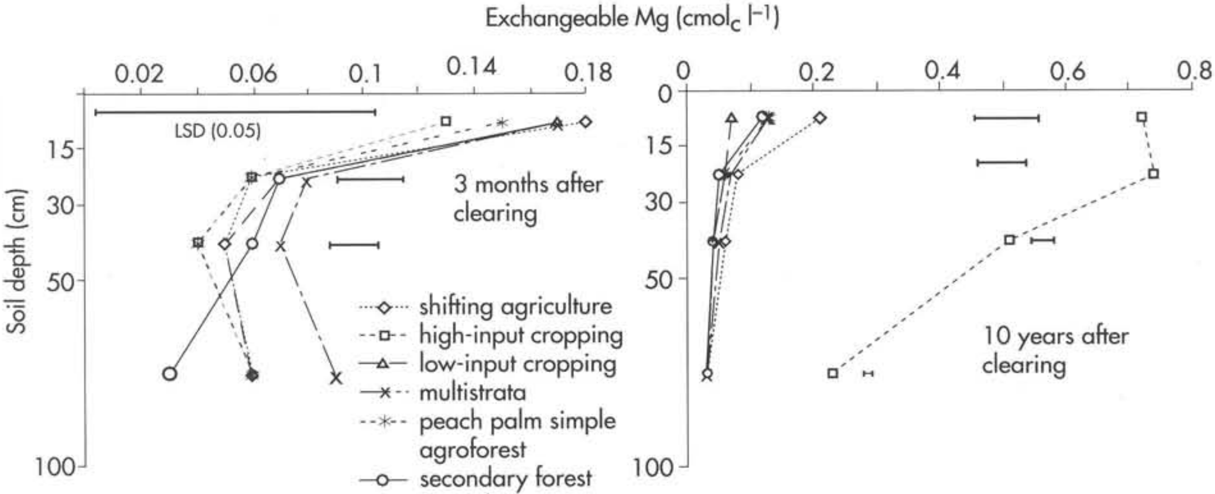


Figure 8. Exchangeable magnesium in soil layers at depths of 0–15, 15–30, 30–50 and 50–100 cm, measured 3 months and 10 years after the establishment of different land-use systems at Yurimaguas, Peru.

dolomite lime was added in the first few years. Lower Mg values in the other systems are probably caused by the accumulation of Mg in the above-ground biomass.

Exchangeable potassium increased 2- to 3-fold in the 50-cm soil profile following the slashing and burning of secondary vegetation. However, it decreased to lower than the critical level of 0.1 $\text{cmol}_c\ l^{-1}$ by the end of the 2nd year in all systems that did not receive any fertilizers (fig. 9), and this situation continued through the 10 years. The high-input system also indicated a decrease of K in the topsoil over years, but its status did not drop lower than 0.1 $\text{cmol}_c\ l^{-1}$. This decrease could be due to other factors such as plant uptake, leaching and surface losses through runoff. These results show that the recycling of basic cations is a slow process. The cations will eventually be available to subsequent crops only after the natural vegetation is slashed and burned. Their recycling could be accelerated by combining trees and herbaceous species with different litter qualities and rooting patterns.

• • • • •

Agroforestry systems have been able to maintain a level of soil fertility superior to that of the 20-year-old secondary forest fallow even after 10 years of producing various food and tree crops. The export of nutrients has not resulted in soil nutrient depletion or increased levels of soil acidity or aluminium toxicity.

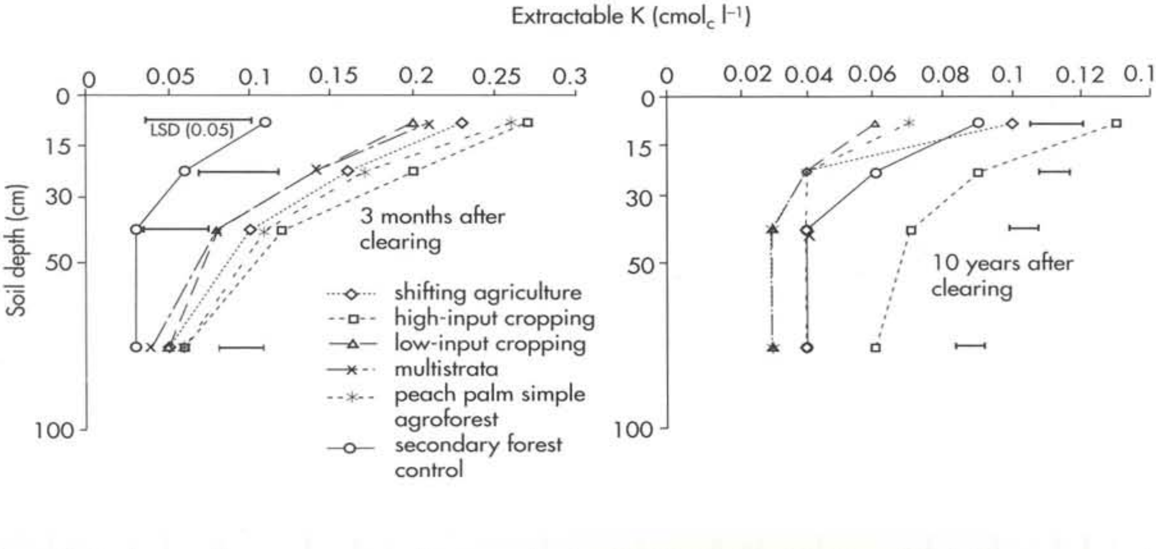


Figure 9. Exchangeable potassium in soil layers at depths of 0–15, 15–30, 30–50 and 50–100 cm, measured 3 months and 10 years after the establishment of different land-use systems at Yurimaguas, Peru.

MYCORRHIZAL ASSOCIATIONS

The extent of vesicular-arbuscular (VA) mycorrhizal infection of different plant species in multistrata and peach palm systems, 10-year-old natural fallow and 20-year-old secondary forest was assessed in August 1995, also 10 years after the beginning of this trial. Fine roots of tree and herbaceous species in each of these systems were collected and samples prepared following standard procedures for microscopic observations of mycorrhizae.

In the 20-year-old secondary forest, mycorrhizal colonization varied from 0 to 78% in the tree strata and from 0 to 57% in the herbaceous strata (table 1). Ciprana among trees and an unidentified liana among herbaceous species showed the highest infection, whereas *Maquira coriacea* (capinuri) and *Commelina diffusa* (comelina) showed no infection in the respective groups. Mycorrhizal infection was generally much higher in the younger 10-year-old fallow than the 20-year-old secondary forest. All of 18 tree and 10 herbaceous species examined in the secondary fallow were found to have VA micorrhizal association, with 42 to 100% infection among trees and 47 to 88% among herbaceous species. The tree species *Heliocarpus popayensis* ('llausaquiro') and *Oxandra* sp

Table 1. Average infection of trees and herbaceous species by vesicular–arbuscular endomycorrhizae in different systems at Yurimaguas, Peru

Scientific name	Local name	Infection (%)
SECONDARY FORESTS		
Trees		
Cecropia sp	cetico	23 (72)[†]
Cinchona officinalis	quina quina	48 (56)
Couma macrocarpa	leche caspi	36 (87)
Cynometra sp	ana caspi	46
Eschweilera sp	machinmango	53
Ficus anthelminthica	ojé	32 (76)
Ficus guianensis	renaco	31
Heliocarpus popayensis	llausaquiro	np (100)
Himatanthus platanifolia	bellaco capsi	np (47)
Inga spp	shimbillo	66 (76)[†]
Jacaranda copaia	ishtapi	np (88)
Maquira coriacea	capinuri	0
Miconia biglandulosa	caracha caspi	54
Miconia elaeagnoides	mullaca caspi	20 (46)
Miconia poeppigii	rifari	43
Ormosia coccinea	huayruro	26
Piper sp	cordoncillo	40 (87)
Pollalesta discolor	yanavara	np (93)
Pourouma cecropiaefolia	uvilla	25
Pouteria sp	caimitillo	50
Quararibea cordata	zapotillo	11 (87)
Sickingia williamsii	pucaquiro	33
Trichilia sp	cedro mullaca	29
‡	azarquiro colorado	52 (86)
‡	cedro sacha	np (80)
‡	ciprana	78
‡	fapina	np (42)
‡	liana	np (73)
‡	llaja	26 (52)

continued on next page

Table 1. (continued)

Scientific name	Local name	Infection (%)
SECONDARY FORESTS		
Trees		
‡	moena blanca	37 (97)
‡	moena negra	23
‡	yanahuasca	43
Herbaceous species		
Centrosema macrocarpum	centrosema	np (77)
Commelina diffusa	comelina	0
Cyperus sp	piripiri	np (64)
Heliconia bihai	situlli	np (70)
Myrosma stromanthoides	bijahuillo	41 (63)
Oxandra sp	espintana	np (88)
Paspalum conjugatum	torourco	np (76)
Rhynchospora sp	carrizillo	29 (47)
Tynanthus sp	clavo huasca	31 (81)
‡	liana	57 (88)
‡	sachahuiro	16 (57)
MULTISTRATA SYSTEM		
Bactris gasipaes	pijuayo	89
Cedrelinga catenaeformis	tornillo	74
Centrosema macrocarpum	centrosema	78
Coffea arabica	café	68
Colubrina glandulosa	shaina	87
Eugenia stipitata	arazá	77
Inga edulis	guaba	78
PEACH PALM/CENTROSEMA		
Bactris gasipaes	peach palm	78
Centrosema macrocarpum	centrosema	70

† Open numbers indicate percentage of infection in 20-year-old secondary forest; numbers in parentheses refer to infection in 10-year-old secondary fallow.

np = species not present in the system

‡ species not identified

('espinata') and some unidentified lianas showed 100% colonization.

In the multistrata system, *Bactris gasipaes* recorded the highest infection (89%), coffee the lowest (68%) and the herbaceous legume *Centrosema macrocarpum* had an intermediate level of infection (78%). A greater percentage of infection in the case of peach palm, *Cedrelinga catenaeformis* and *Colubrina glandulosa* ('shaina') was by arbuscular types, which are the effective mycorrhizae in this symbiotic association. In the peach palm–centrosema simple agroforest, the extent of infection was more than 70% in both species. Mycorrhizal infection in peach palm was higher when it was associated with other tree species (89%) than with centrosema (78%), signifying the role of mycorrhizae in the phosphorus nutrition of these systems. A noteworthy feature in all systems was the predominance of arbuscular mycorrhizae.

SOIL MACROFAUNA

Soil macrofauna play a significant role in the decomposition of litter, and in the process they affect nutrient availability to plants. They also play an important role in improving soil physical properties and consequently soil–water relations. Specific groups of organisms may be relatively more important than others for specific soil biological processes in low-input systems of the humid tropics. Ten years after initiation of this trial, the soil fauna populations were monitored to examine the extent of soil biological systems regulating the below-ground processes in different systems of the trial.

Soil samples were taken using a block 25 x 25 cm with a depth of 30 cm at every 5 m on a transect at a randomly selected place within each plot. The soil monolith was sampled in 4 parts (litter, 0–10, 10–20, and 20–30 cm); invertebrates were collected by careful sorting of the material and were preserved in 4% formaldehyde. The animals were separated into different taxonomic groups, their numbers counted and their fresh weights determined immediately.

Both the low- and the high-input cropping systems recorded low faunal biomass with the lowest diversity of species (table 2). This could be due to the addition of low quantities of organic residues (5.3 to 6.7 t ha^{-1} $year^{-1}$) in these systems, which are the essential source of energy for soil fauna, and probably also due to mechanical disturbance of the soil in the high-input system. Earthworms and litter arthropods disappeared and were not replaced by other adapted and beneficial species. The populations of some groups of termites (mainly humivores) that were better able to resist the disturbances of the soil actually increased.

The multistrata and peach palm systems, together with 10- and 20-year secondary forests, recorded the greatest diversity of soil macrofauna; however, the multistrata system contained the highest biomass of macrofauna (table 2). Earthworms—the most beneficial category of macrofauna—constituted the highest proportion in both number and biomass. The multistrata system conserved species of the original ecosystem, besides providing niches for exotic colonizers. An analysis of species composition indicated the dominance of exotic species in the disturbed ecosystems (multistrata and peach palm systems) compared with the undisturbed ecosystem (secondary forest). The high activity of soil

Table 2. Earthworm populations and biomass per square metre relative to total macrofauna density and biomass in different agroforestry systems 10 years after trial establishment, in Yurimaguas, Peru

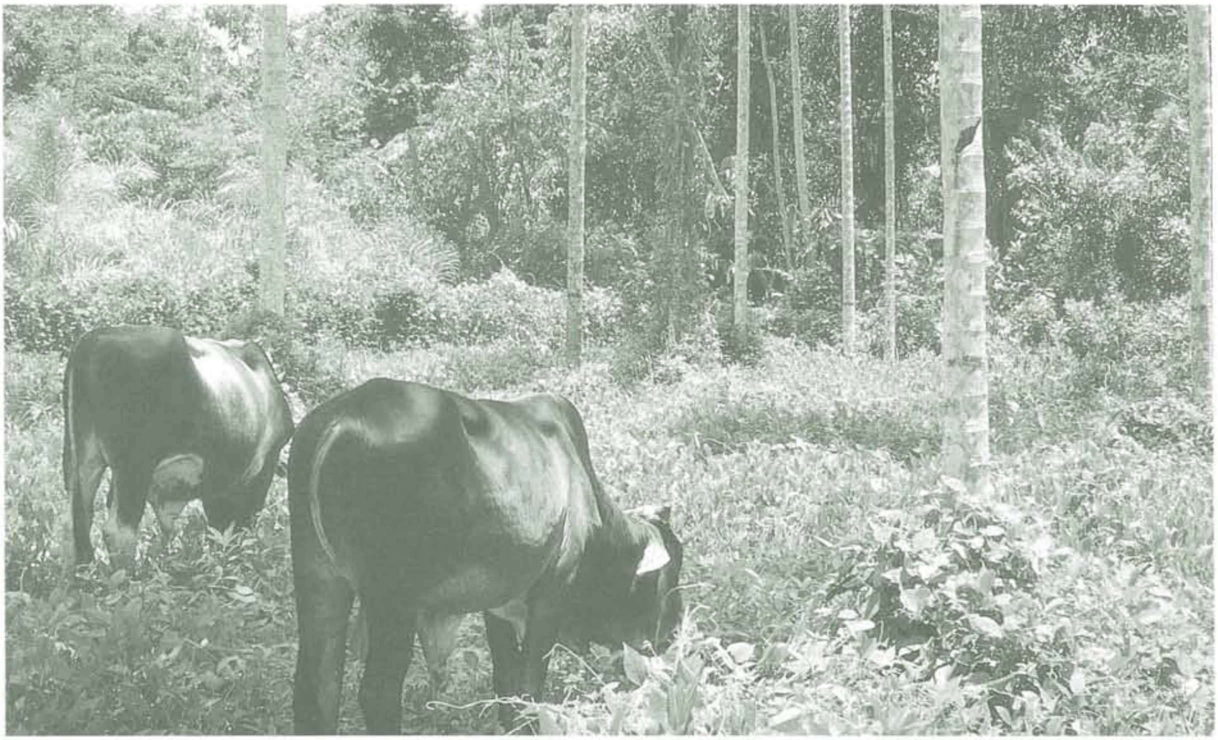
Systems	Individuals (no.)	Taxonomic groups (no.)	Earthworms (% total)	Total biomass (g m^{-2} fresh wt)	Earthworm biomass (% total)
Low-input system	169	16	21	15.4	79
High-input system	169	16	38	19.2	63
Multistrata system	144	21	69	50.8	88
Peach palm and centrosema	121	22	30	34.1	83
10-year-old forest fallow	121	22	21	20.7	73
20-year-old secondary forest	100	20	25	28.2	66

Includes ants, beetles, termites, arachnids, centipedes, millipedes and so forth, as well as earthworms

Soil macrofauna, as is well recognized, contribute significantly to improving tilth and other soil properties. At the Instituto de Investigaciones de la Amazonía Peruana in Pucallpa, earthworm humus is produced and bagged.

macrofauna in the multistrata system could be attributed to the addition of a large quantity of high-quality litter at an average of 11.5 t ha^{-1} $year^{-1}$ (see ICRAF annual report 1995 p 135–137). The heterogeneous structure of the multistrata system further contributed, as it favoured certain faunal groups. Evidence from previous studies has shown that earthworms influence the rate and timing of nutrient release to plants. On a shorter time scale (days, months), they are important in enhancing nutrient availability to plants through activation of soil microflora; on a longer time scale (season, years) their activity modifies soil physical properties (structure, porosity and water availability) and can increase SOM contents, as their casts protect the organic matter they contain from microbial decomposition.

The perennial crop-based systems have maintained the soil chemical and biological conditions very similar to those of the secondary forest, which indicates that in the long run they are sustainable with minimum external inputs. Although the low-input and shifting cultivation systems have also maintained good soil conditions, their productivity has been so low that they can no longer sustain the requirements of farm families.



Traditional silvopastoral systems can be improved by integrating economically valuable trees with high-yielding forage crops and improved livestock.

The high-input system improved soil chemical properties because of the regular addition of fertilizer, but it is unlikely to maintain long-term productivity considering the degradation of the biological and physical properties of the soil (ICRAF annual report 1994 p 114).

SILVOPASTORAL SYSTEMS

In more than 80% of the lower Peruvian Amazon Basin, cattle farming is dependent on the native pasture 'torourco', which is a mixture of *Axonopus compressus* and *Paspalum virgatum*. The low productivity of native grasses cannot sustain a stocking rate of even 1 animal ha^{-1} for more than 2 to 3 years, and the pasture degrades rapidly in its soil physical, chemical and biological characteristics. Traditional pastures rarely contain any useful trees, and the productivity of local breeds of livestock is low. Silvopastoral systems integrating economically valuable trees, high-yielding forages and improved livestock can be considered a big step forward in improving both livestock and land productivity, without affecting the soil conditions. Planting trees may help recuperate degraded pastures by microsite enrichment through nutrient cycling, particularly if the species selected are nitrogen fixing. Which species to select and how to establish trees in degraded and productive pastures are some major challenges. We have also examined the potential of developing a silvopastoral system based on peach palm.

PEACH PALM–CENTROSEMA SILVOPASTORAL SYSTEM

Peach palm or 'pijuayo' *(Bactris gasipaes),* which is planted extensively by small-scale farmers in Amazonia for its fruit, provides opportunities for an integrated livestock–tree system using an understorey of herbaceous legumes and integrating livestock. Among the different forage legumes evaluated in the region, centrosema *(Centrosema macrocarpum)* was found well adapted to serve as a cover crop in systems with upperstorey trees and in multistrata systems, and it tolerates frequent grazing. An experiment was conducted in Yurimaguas to determine the effect of livestock grazing on centrosema sown under peach palm. Under study were 1) the physical and chemical properties of the soil, 2) the regeneration and productivity of centrosema, and its nutrient cycling under grazing, 3) fruit production of peach palm, and 4) liveweight gain by the grazing animals.

Centrosema was sown in October 1988 as an understorey cover crop at a spacing of 1 m between rows and 0.5 m within rows in a 6-year-old peach palm plantation on degraded land (tree density = 600 trees ha^{-1}). The area was fertilized uniformly by broadcast application of 20 kg P and 20 kg K ha^{-1}, using Bayovar phosphate rock and muriate of potash respectively, as recommended for establishing improved pastures on degraded soils. The study involved 2 treatments—grazing of centrosema by livestock and no grazing—replicated 3 times in a randomized block design. The no-grazing plots were 600 m^2 in all blocks; the grazing plots were 2446, 2253 and 1510 m^2 in the 3 blocks. Grazing commenced 18 months after the establishment of centrosema, in April 1990, with 2 young bulls at a stocking rate of 3.3 animals ha^{-1}; it followed a rotational system of 9 to 14 days of grazing and 28 to 30 days of rest among the 3 blocks. The stocking rate was subsequently reduced to 2.3 animals ha^{-1} towards the end of the 1990 dry season, when the biomass production of centrosema decreased, which allowed the pasture to recuperate. This stocking rate was maintained for the rest of the experimental period. The cattle received additional salt and mineral supplement. The soils of the plots were monitored over a 5-year period for physical properties (bulk density, mechanical resistance, infiltration and gravimetric water content) and chemical properties (exchangeable cations, extractable P) and centrosema biomass production. The liveweight gain of the animals was also monitored.

Centrosema germinated well and developed 100% ground cover by 8 months after sowing. However, animals were not introduced until 18 months after sowing to allow the centrosema to set seed and to ensure that it would persist after it was grazed. The non-grazed plots produced twice the quantity of centrosema biomass and litter as did the grazed plots, beginning in 1991 (table 3).

Table 3. Effect of in situ grazing vs no grazing on the production of Centrosema macrocarpum *biomass, peach palm fruit and animal liveweight gain over a 4.75-year period at Yurimaguas, Peru*

System	1990	1991	1992	1993	1994
Centrosema biomass (t ha^{-1})					
Grazing	7.8	10.7	11.9	10.7	4.9
No grazing	10.6	21.1	24.2	22.2	11.1
SED ±	0.30	0.43	0.39	0.33	0.50
Peach palm fruits (t ha^{-1})					
Grazing	4.2	4.0	3.4	4.2	4.5
No grazing	3.8	4.0	3.2	3.8	4.3
SED ±	0.30	0.43	0.39	0.33	0.50
Average animal weight gain (g $animal^{-1}$ day^{-1})					
Grazing	–	426	456	440	455

Introduction of animals for in situ grazing of centrosema caused both bulk density and mechanical resistance to decrease over time; neither sorptivity nor gravimetric water content was affected by animal grazing. These observations indicate that addition of centrosema to the peach palm favourably influenced the soil physical properties, because of the regular addition of its litter and root activity.

In situ grazing by livestock plays an important role in soil nutrient dynamics, as it affects the quantity of litter production, its nutrient concentration and nutrient cycling. Addition of centrosema decreased soil acidity by 35% and Al saturation by 10% in 5.5 years, independent of animal grazing, probably because the added organic matter bound the Al in complex organic compounds. Soil nutrient status, as measured by exchangeable cations, extractable phosphorus and soil carbon, was not significantly influenced by the presence of animals in the system within the time frame of the study.

Peach palm fruit production in this study was only one-third to one-quarter of the yields observed in other trials on the station and on farms (table 3), primarily because of the poor soil conditions at the site; the soil was highly acidic, compacted and low in nutrient status. However, the grazing of animals on centrosema had no effect on peach palm production. The animals have gained weight well, 426 to 457 g $animal^{-1}$ day^{-1} over the years, which is substantially higher than weight gain in the conventional grazing system. The total liveweight of 1.12 t ha^{-1} accumulated over the 4 years in the grazing treatment provides substantial additional income. The study clearly demonstrated the scope for improving the productivity of degraded lands through a peach palm–centrosema silvopastoral system, but it also indicated that to realize potential yields of peach palm, such soils need fertilizer input.

ESTABLISHING TREES IN PASTURES

Successful tree establishment in degraded pastures as well as in those under use is dependent on choice of appropriate species, production of good quality seedlings, preparation of planting site, management of competition from pasture or weeds, and protection from animals. A series of trials was conducted jointly by the national collaborators INIA, IIAP, IVITA (Instituto Veterinario de Investigaciones Tropicales y de Altura), UNU (Universidad Nacional de Ucayali), FUNDEAGRO (Fundación para el Desarrollo del Agro) and ICRAF, the results of which are summarized here.

Effect of humus and N, P, K fertilization on tree establishment and early growth

This trial was conducted on a degraded native pasture near Pucallpa, Peru. The soil is a loamy siliceous isohyperthermic Typic Paleudult with low nutrients, high acidity and poor physical conditions (topsoil pH = 4.6, Al saturation = 60%, bulk density = 1.53 Mg m^{-3} and mechanical resistance = 4.2 kg cm^{-2}). The average annual precipitation of the site is 1800 mm, with a 3-month dry period during June–August. The mean air temperature is 26°C.

Three timber species were evaluated: *Guazuma crinita* (bolaina blanca), *Calycophyllum spruceanum* (capirona) and *Aspidosperma macrocarpum* (pucaquiro). Nine treatment combinations —2 doses of humus (2, 4 kg $tree^{-1}$) plus a control and 2 levels of inorganic fertilizers (150–22–40 and 225–33–60 kg ha^{-1} of N-P-K) plus a control —were tested on each of the 3 species, replicated 3 times in a randomized block design. Humus was prepared from brewery residues and was decomposed by the earthworm *Eisenia fetida*. The organic material and inorganic fertilizer were applied to the planting holes at the time of transplanting the tree seedlings. Treatment effects at 7 months after planting were evaluated based on an index of growth *(d^2h)*, calculated combining height *(h)* and basal diameter *(d)* of the seedlings.

Humus and fertilizer had no effect on the survival of seedlings, but both influenced the growth of the tree species to varying degrees, independent of each other (table 4). While all 3 species responded positively to increasing levels of humus, only bolaina blanca and capirona benefited from fertilizer. The effect of humus was greatest on bolaina blanca, then on pucaquiro and capirona. The dose of 4 kg $tree^{-1}$ produced 3 times the growth in bolaina blanca, 2.5 times in pucaquiro, and in capirona. Fertilizer application at 150 N–22 P–40 K kg ha^{-1} increased the growth of bolaina blanca and capirona by 50% and 37% respectively over the control. However, there was no additional benefit in applying a higher rate.

Table 4. Effect of 3 levels of humus and fertilizer (N-P-K) on the growth index (d^2h) of bolaina blanca, capirona and pucaquiro, measured at 7 months after planting in Pucallpa, Peru

Treatment	Bolaina (cm^3)	Capirona (cm^3)	Pucaquiro (cm^3)
Humus (kg $tree^{-1}$)			
0	273	489	63
2	699	750	59
4	2088	1298	154
SED	224	141	19
Fertilizer (kg ha^{-1})			
0–0–0	855	741	79
150–22–40	1285	1017	79
225–33–60	1320	771	109
SED	224	141	19

Effect of size of planting hole on survival and growth of trees

The study was conducted in 2 sites, characterized by moderately compacted soils (bulk density = 1.66 Mg m^{-3}, mechanical resistance = 10 kg cm^{-2}) and heavily compacted soils (bulk density = 1.8 Mg m^{-3}, mechanical resistance = 20 kg cm^{-2}). The soils at both sites had similar texture and chemical characteristics as those of the previous study. Different sized planting holes made with a mechanical screw mounted on a tractor were evaluated in comparison with a manually made hole (15 cm diameter by 20 cm depth) in a randomized block design. The mechanical holes were made with different combinations of diameter (20 and 40 cm) and depth (20, 40 and 60 cm). The tree species evaluated were bolaina blanca, capirona, tornillo *(Cedrelinga catenaeformis)* and cedro colorado *(Cedrela odorata)*. All treatments received 2 kg humus and 15 g of compound fertilizer (150 N–22 P–40 K) per tree.

Tornillo did not survive in the moderately compacted soil because of the lack of shade and poor drainage of the site. Initially, capirona and bolaina blanca responded better to the 20-cm diameter holes irrespective of depth, while cedro colorado required wider holes. Differences between mechanical and manual holes were not significant, which means that if no mechanical screw is available, a manual digger can be employed to make planting holes on moderately compacted soils. Bolaina blanca grew faster than the other trees and cedro was the slowest of the 3.

The rate of growth of trees was slower in heavily compacted soil than in soil only moderately compacted. Cedro colorado was replaced by caoba *(Swietenia macrophylla)* because of disease problems. The growth in height of bolaina blanca and capirona was much better in 40-cm-wide holes of any depth. The results were generally variable, but the trends indicated that holes wider than 40 cm and deeper than 20 cm favours the growth of trees on heavily compacted soils. If no mechanical equipment is available, making holes manually could be quite tedious on these soils.

FROM MAHOGANY TO MAIZE

The Selva Maya (Mayan Forest), the largest remaining area of tropical forest in Mesoamerica, extends across the borders of southeastern Mexico, northern Guatemala and Belize. People have exploited this forest for chicle (chewing gum), mahogany and slash-and-burn agriculture. Migration and agricultural development programmes have caused much of the deforestation. Today the remaining stocks of timber and the low yields of maize produced from slash-and-burn agriculture are no longer sufficient to meet the needs of the population.

ICRAF works at 2 sites in southeastern Mexico adjacent to biosphere reserves—the Zona Maya, dominated by indigenous Mayan inhabitants, and Calakmul, dominated by immigrant farmers. Most land is within 'ejidos'—communally held lands—some of which have up to 80% of the land area under secondary forest cover. Recent changes in the laws have allowed the division of land among ejido members but have prohibited the clearing of mature forest.

ICRAF has characterized how farmers use the land and what limits agricultural production. The results are being used to identify how agroforestry can help meet farmer needs without promoting deforestation. Currently, all farmers practise shifting cultivation for maize production. On average, of the 20 ha per farmer dedicated to the shifting cultivation cycle, 2–5 ha are in production at any one time. Shorter fallows are preferred by some farmers because less labour is needed to fell the younger regrowth. All farmers manage home-gardens to produce vegetables and fruits and to rear pigs and turkeys. Of the farmers surveyed, 29% had pasture (1–10 ha) and 26% fruit orchards (0.5–2 ha). These permanent features are usually added to a farm at the expense of forest cover.

The high risk of crop failure, usually caused by drought or hurricanes, strongly discourages farmers from making investments such as using agrochemicals to intensify their crop production. Spreading risk is a fundamental strategy. Local farmers say diversification is their primary aim and the reason that they are interested in planting fruit trees and timber trees and increasing the

Trial multistrata systems may combine fruit trees and timber trees, as in this on-station trial in Pucallpa, Peru.

numbers of their livestock. The main limitations to a farmer's success in working with trees are the low initial returns on a high investment, the lack of technical assistance, and pest attacks (on mahogany). When farmers were offered a range of agroforestry alternatives they gave the highest priority to homegardens, multistrata systems and improved fallows.

MULTISTRATA-SYSTEM RESEARCH ON FARM

Our strategy of on-farm research has been to evaluate with farmers the agroforestry and the non-agroforestry options for producing the same products. Joint researcher–farmer evaluations are being used to identify where the agroforestry systems can be adapted to better meet farmer needs. Workshops involving farmers, NGOs, NARS and researchers are planned to enable farmers to influence the development initiatives aimed at them and interact with the initiators.

Trial multistrata systems combining fruit and timber trees were established in collaboration with 12 farmers in 1995. It was interesting to note that many of these farmers did not plant fruit trees and timber trees in mixture. By planting them separately farmers were able to apportion the best areas of land to the fruit trees and the poorer land to the timber trees. This strategy reflected their expectation of more immediate return from the fruit trees and their desire to optimize that return. This observation led to our research agenda for 1996. Does the mixture of 2 or more tree types on the same land area reduce the capacity of the farmer to invest optimally in each component, and if so does the potentially higher production of the combined system compensate for this? In 1996, 20 farmers established multistrata systems combining fruit trees and timber trees, and also areas of pure fruit trees and pure timber trees. Each farmer's investment in each system, and tree growth and production, will be evaluated over the coming years.

ON-FARM RESEARCH FOR IMPROVED FALLOWS

Improved fallows are being evaluated for their potential to improve soil conditions and control weeds more effectively than natural short-duration fallows. Plots have been established on 20 farms to compare fields that were cropped 2–3 years and where tree stumps were allowed to resprout with fields that were cropped for longer periods and regeneration is not advanced. It is expected that improved fallows will have a greater impact in the latter situation. Farmers have established trials to compare a short-duration natural, woody fallow *(Leucaena leucocephala)* with a herbaceous fallow *(Mucuna deeringiana)*. They will be evaluated for soil changes, weed populations, and crop production at the end of the fallow. The processes of soil improvement under short-duration fallows are being studied on a degraded site in an on-station experiment.

HOMEGARDENS

To improve homegardens, or indeed any agroforestry system, quality agroforestry trees must be available. We consulted with farmers and local researchers to identify the priority species to incorporate in a tree-domestication programme. Researchers identified candidate species and key tree products in the region. Species were grouped into product categories and then offered to farmers to assess their preference for different tree products and species. Within the categories offered, farmers showed the greatest preference for quality timber trees and the least for soil-improving trees (table 5). In 1997 we will concentrate on improving nursery production practices for all agroforestry species and seed selection of the most valuable timber tree, mahogany.

THE FUTURE: TOWARDS DEVELOPMENT

In the Yucatan, we will continue to study how farmers value agroforestry systems—how they evaluate them and what they adopt. Priority areas for future research in the development of agroforestry systems are fodder production and the economic enrichment of fallows. Most importantly, we will increase participatory research by establishing community research centres within 2 ejidos. ICRAF scientists will work with the council of ejido farmers to identify their production constraints and establish experiments to tackle those that can be addressed through agronomic and silvicultural techniques.

The development of human resources is an ongoing commitment. Each year we support 2 local foresters or agronomists to attend the agroforestry course at the University of Chapingo. ICRAF also supports and supervises students from the Autonomous University of Yucatan and the College of the Southern Frontier. We are developing our overall programme by promoting the formation of adaptive research and dissemination networks that catalyse vertical integration at all levels of research, training and development (universities, NARS, NGOs and farmers) for an effective participatory development process.

Table 5. Number of farmers selecting trees of different uses (80 farmers surveyed)

Product	Species	Number of farmers
Timber	*Swietenia macrophylla* *Cedrela odorata*	49
Nectar producer	*Lippia* spp *Piscidia communis*	24
Forage	*Brosimum alicastrum* *Guazuma ulmifolia*	21
Soil improvement	*Leucaena leucocephala* *Gliricidia sepium*	11

CAPACITY BUILDING

The relocation of the regional coordinator for Latin America from ICRAF headquarters to Lima, Peru, in 1996 opened up new opportunities for capacity building. The education programme joined forces with the regional coordinator to carry out a diagnostic survey of the educational landscape in Peru. The following results emerged:

- The universities have an enormous backlog of thesis students who cannot complete their degree

programmes because they lack the funds to undertake their thesis research.
- University professors have the desire to improve their skills in agroforestry experimentation.
- Faculty who have done some agroforestry research need peer review to bring out their results for publication. They also need more research experience through contacts with ICRAF scientists.
- The National Agricultural Research Institute (INIA—Instituto Nacional de Investigación Agraria) counts on the universities to produce agroforestry research scientists to strengthen its capacity in this area.
- Universities need to strengthen the agroforestry content in their curricula.

ICRAF considers this a very attractive environment, in which results can be achieved within a relatively short time (3–5 years). The findings of the survey have been developed into a framework for strengthening the research–education nexus in Peru, with a great potential for expansion into other Latin American countries. The framework will be used to draft a project proposal for donor funding in 1997.

ICRAF continues to copublish the magazine *Agroforestería en las Américas,* issued out of CATIE (Centro Agronómico Tropical de Investigación y Enseñanza).

TO SUM UP . . .

In various disciplines, researchers in Peru are turning their attention to heart-of-palm. The principal source of this delicacy has been the Asai palm *(Euterpe oleracea)*. However, this palm does not resprout and so is becoming extinct from overharvesting. But pijuayo *(Bactris gasipaes)* does resprout, produces equally marketable heart-of-palm, and so has the potential for taking over in the ecologically aware marketplace. In addition, silvopastoral systems involving palm species are being initiated by development programmes and farmers. In one, an association of 60 farmers is growing oil palm (*Elaeis* spp) with centrosema ground cover; in the other, 500 ha of pijuayo and centrosema are being grown as an alternative to coca production. In yet another development project, the government is sponsoring the planting of 10 000 ha of pijuayo for heart-of palm. In these and similar projects, researchers are playing a role in managing the germplasm and the nutrients for the plantations. They are playing this role in development with other top-priority trees, capirona *(Calycophyllum spruceanum)* and bolaina blanca *(Guazuma crinita)*, in helping the private-sector National Forestry Commission in a 3 million dollar development project for the Aguaytia watershed around Pucallpa.

In Mexico, farmers and researchers are developing community research centres in the 'ejidos'—communally held lands. The ejidos offer a unique opportunity for future full participatory on-farm research, and researchers are exploiting the oportunity to learn how farmers value agroforestry systems and what technologies they will adopt.

Humid tropics of Southeast Asia

The Southeast Asian countries have begun to lay the foundation for sustained economic growth. Their remarkable progress has been heralded as a source of encouragement for developing countries throughout the world. This optimism is well deserved, but it should not be misinterpreted as victory achieved. Hundreds of millions of people remain in poverty, and the momentum of development has frequently accelerated the degradation of the natural resource base. These pressures are particularly acute in the uplands of the region. The rate of forest degradation and conversion has increased in recent years in those countries where significant forest resources remain, such as Indonesia. In other countries, such as the Philippines, Thailand and Vietnam, deforestation rates have declined, but this seems to be due to the fact that these nations have nearly exhausted their exploitable natural forests. The expansion of degraded imperata grasslands is often the consequence of this rapid conversion process. The human population inhabiting the uplands continues to increase, putting pressure on the fragile, sloping uplands to provide food and cash income.

Policy and technological change can assist governments and farming communities to better cope with the imperative to manage natural resources more sustainably. ICRAF's Southeast Asia Regional Research Programme is engaged in both policy and technology development with a range of collaborators. Our aim is to exploit the recognized potential of agroforestry to help mitigate deforestation and land depletion and to reduce rural poverty. The two broad issues we focus on are the development of alternatives to unsustainable slash-and-burn agriculture, and the rehabilitation of degraded or degrading upland ecosystems.

Our current work is in the context of a broader concept of agroforestry as a natural resource management system that involves the increasing integration of trees into the agricultural landscape. On the forest margins we work on systems based on smallholder agroforests for communities located in production forest environments, where forest conversion is inevitable or has already occurred. We are also developing agroforestry systems to intensify land use outside the boundaries of protected forests, in combination with enforcement and other development measures. Appropriate forms of secure land and tree tenure are a key foundation to better land use. Case studies with affected communities are building feasible options for tenure policy reform. Research on the ecology and improved productivity of complex agroforests supports the expansion of these systems to stabilize shifting cultivation and to improve the sustainability of permanent farming systems. Comparative environmental benefits of agroforests vis-à-vis natural forests and other land uses are being assessed.

In the imperata grasslands we are emphasizing the identification, refinement and extrapolation of indigenous strategies to intensify shifting cultivation. Smallholders practising slash-and-burn agriculture in natural grass fallows are beginning to integrate herbicides into their farming system to manipulate the fallow vegetation from undesirable species (such as imperata) toward more desirable ones (such as *Chromolaena odorata*). Research and development could build upon this innovation to enable many other farmers to enjoy more productive fallows that better sustain their livelihood and eliminate the need to abandon the land because of weed pressure. Leguminous tree fallow systems have been developed by some farming communities. We are investigating hedgerow fallow rotation systems for low-input grassland farming.

Contour hedgerow systems have proven potential to control soil losses in crop production even on fairly steep slopes (20–50%). A promising 'low-labour' farmer-developed solution is natural vegetative strips on the contour. As these gain widespread acceptance in the southern Philippines we are investigating ways to avoid or alleviate the decline of soil fertility in the upper alleyways—the 'scouring' effect produced as soil is redistributed within the alleyways. We are also testing farmer-to-farmer methods for rapid dissemination of simple hedgerow and agroforestry tree technologies. We have recently adapted permanent-ridge tillage to animal-power systems in Southeast Asia. This method shows great promise. The following sections review these advances in greater depth.

INDIGENOUS STRATEGIES FOR INTENSIFICATION OF SHIFTING CULTIVATION

In recent decades, mounting population densities and competing land uses in Southeast Asia have severely eroded the ecological balance of slash-and-burn systems endemic throughout the region's uplands. A growing body of literature has documented concomitant degradation of upland farming systems and noted the urgent need to identify interventions to stabilize this downward spiral and to increase the human carrying capacities of the systems. Regardless of the merits of the long-fallow forms of slash-and-burn agriculture of the past, we need to be thinking of pathways to stabilize and improve the productivity of today's declining systems—preferably finding ways to build on indigenous practices. The relevant issue is not whether shifting cultivation should be allowed or prohibited, but how to intensify it in the reality of more mouths to be fed from a dwindling land base. This is a high-priority research and development issue across many Southeast Asian countries.

Farmers have not widely adopted the technical approaches that research has put forward for stabilizing and improving the productivity of slash-and-burn systems in the sloping uplands of Southeast Asia. The fact that farmers have ignored the solutions that researchers have originated has

A farmer slashes and burns an old rubber agroforest to replant a new one—an example of managed resources—near Muara Bungo, Jambi Province, Indonesia.

made the researchers much more aware of farmer constraints such as shortage of labour, inadequate access to planting materials, uncontrolled fires and communal grazing. The researchers now realize how necessary are participatory, on-farm approaches to their work, to identify solutions that clearly take farmer circumstances into consideration.

There are also many compelling examples where slash-and-burn farmers have successfully managed local resources to solve local problems. Farmer responses to the pressures of agricultural intensification may generally be classified as innovations to achieve—

- more *effective* fallows—which improve the biological efficiency of fallow functions, where the same or greater benefits can be achieved in a shorter time
- more *productive* fallows—in which fallow lengths stay the same or actually lengthen as the farmer adds value to the fallow by introducing perennial economic species
- combinations of the 2 trends, where a degree of both biophysical and economic benefits may be accrued

The implications for land use of these 2 major pathways towards the intensification of slash-and-burn systems are profound. More effective or accelerated fallows often provide an intermediate step in the transition to permanent cultivation of annual crops. Alternatively, in more productive fallows, the phase of reopening and cultivating annuals may eventually be forgone altogether if the farmer chooses to protect perennial vegetation and allows it to develop into semipermanent or permanent agroforests.

If Southeast Asia's forest remnants and their biodiversity are to be protected, and slash-and-burn communities afforded a better standard of living, pathways towards intensification of shifting cultivation systems are urgently needed. One of the most promising approaches to identifying biophysically workable and socially acceptable technologies is to document and understand case studies of indigenous adaptations towards intensification of shifting cultivation. Unfortunately there is little documentation of such innovations to feed into the national and international research agenda or to inform policymakers. They are either unobserved or misinterpreted.

ICRAF is collaborating with local partner institutions, IDRC and Cornell University in developing a regional research initiative, 'Indigenous strategies for intensification of shifting cultivation in Southeast Asia'. It is envisaged that a coordinated team approach will enable a thorough and systematic investigation of a wide variety of improved fallow systems that have evolved in different agroecozones across Southeast Asia. The approach will showcase indigenous knowledge, and local practices will become the point of departure in the search for pragmatic and adoptable solutions to intensify and reinforce the sustainability of highly stressed slash-and-burn systems. The work will be guided by the hypothesis that isolated pockets of shifting cultivators have often successfully responded to intensification pressures by quietly evolving improved variations of land husbandry. These practices are of immense scientific and development interest for their potential or further refinement and dissemination to a range of contexts in communities

For the farmer in his carefully nurtured agroforest, security of land tenure—or lack of it—is a critical issue.

facing similar degradation problems. This is not suggested as a panacea—but it is a promising approach that builds on indigenous practices, and it should be added to our repertoire of technical responses to declining slash-and-burn systems.

Clearly there is a wide menu of components from which shifting cultivators may choose when they need to intensify their use of the land, but this research will focus sharply on indigenous innovations to manage fallow land in more productive ways. It should be stressed that our operational definition of 'managed fallows' is wide and covers the entire spectrum—from growing viny legumes as dry-season fallows lasting a few months to incremental inclusion of perennials of more economic value into the 'fallow', until it develops into a long-term complex agroforest. The salient point is that we are trying to understand the array of farmer-generated solutions that have successfully permitted an intensification of shifting cultivation in the face of increasing land-use pressures. Figure 10 categorizes indigenous strategies for fallow management that fall along this continuum. The map in figure 11 indicates roughly where we know that these strategies are practised in the region. These representative practices provide us with a firm foundation as we work across Southeast Asia to develop longer term methods and a coordinated way of stabilizing shifting cultivation.

The research thrust on improved fallow management is nested within ICRAF's broader Alternatives to Slash-and-Burn (ASB) programme—linking it directly with global efforts to mitigate the impacts of deteriorating slash-and-burn systems, providing opportunities to draw on methodologies developed by ASB and to participate in ASB events (see pages 223–238).

The strategy of the project will be to develop a collaborative team approach and network.

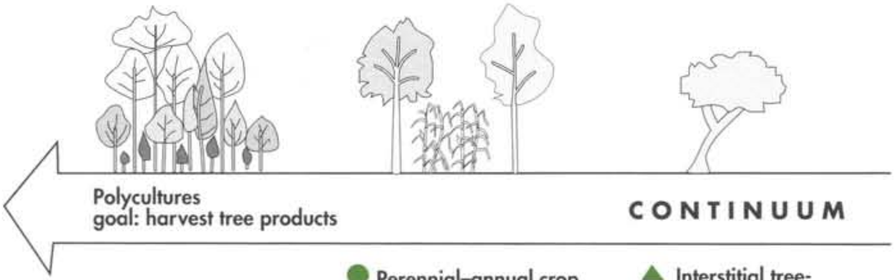
POLICY RESEARCH

Policy research in Indonesia identifies policies that must be in place before farmers will adopt the agroforestry systems that can slow down deforestation—or even reverse it—while reducing poverty among smallholders dwelling at the forest margins. A central hypothesis of this multifaceted research project is that uncertain property rights (the terms of access, use, control and transfer) over land and trees undermine incentives for sustainable natural resource management. Currently, there is strong demand by policymakers in Indonesia for workable means to address tenure insecurity. ICRAF's ongoing research work on land and tree tenure in Indonesia focuses on the policy problems and institutional challenges that distinguish 2 forest policy domains discussed below: buffer zones of protected forest areas and imperata grasslands. The concluding section on the export potential of Indonesia's rubberwood is an example of work on another policy research hypothesis: that counterproductive policies (such as trade and marketing restrictions that drive down farmgate prices) are inefficient and create inequitable conditions for smallholders to invest in agroforestry.

INDIGENOUS LAND AND TREE TENURE INSTITUTIONS

Indonesia's Kerinci Seblat National Park encompasses the largest contiguous primary forest in Sumatra, with an area of over 14 000 km^2, including forest areas near the ASB benchmark area at Rantau Pandan. The villages in it traditionally have followed a matrilineal inheritance system with joint ownership that limits the individual's rights to dispose of land and other assets. ICRAF's research in the buffer zone of the park is conducted in collaboration with IFPRI and Jambi University, with primary funding from the government of Japan and additional support from DFID. This work is part of a multicountry study led by IFPRI, and it includes ICRAF-IFPRI collaboration in Ghana, Uganda and Malawi. (Highlights of the work in Uganda are reported on pages 168–170.) Data collection in Sumatra has been undertaken in 2 phases: an extensive community survey, which is complete, and an ongoing, intensive household survey. The objective of the extensive community survey is to characterize land and tree tenure and inheritance practices for a wide range of communities in the ASB benchmark area at Rantau Pandan and in the Kerinci Valley (both sites are in Jambi Province).

Humid tropics of Southeast Asia



🟩 **Agroforests**

Latex based
Hevea brasiliensis

Resin based
Shorea javanica
Rhus vernicifera &
  Pinus yunnanensis
Styrax tonkinensis &
  S. benzoides
S. benzoin &
  S. paralleloneurus

Fruit & nut based
Durio zibethinus
Coconut palm
Commercial fruit
  orchards

Others
Amomum compactum
A. subulatum
Piper nigrum
Camellia sinensis
Coffea spp
Zanthoxylum limonella
Borassus sundaica

Mixed systems
Kenyah/Iban fallow enrichment
Ifugao woodlots

● **Perennial–annual crop rotations** (cyclical taungya system)

Timber based
Cunninghamia lanceolata
Paraserianthes falcataria
Melia sp
Tectona grandis
Gmelina arborea
Eucalyptus spp
Pinus wallichiana
Santalum sp
Cedar
Alnus nepalensis

Non-timber
Cinnamomum burmanii
Aquilaria sp
Broussonetia papyrifera
Gigantochloa levis
Other bamboo spp
Calamus caesius
Calamus sp &
  Plectocomia himalayana
Talun kebun (mixed)

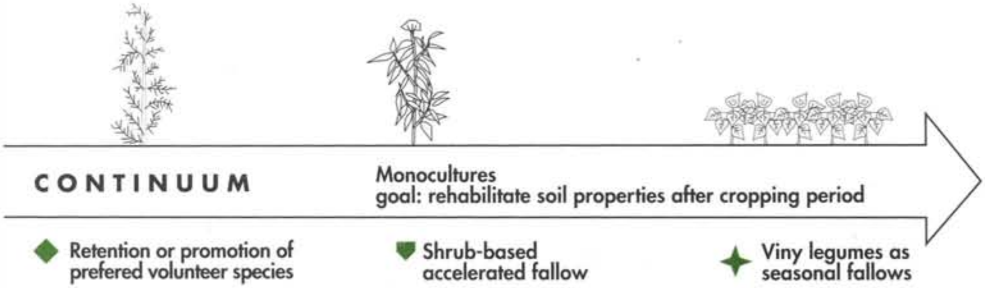
▲ **Interstitial tree-based improved fallow**

Simultaneous
Alnus nepalensis
Leucaena leucocephala
  & *Gliricidia sepium*
Leucaena leucocephala
  & *Sesbania grandiflora*
Leucaena leucocephala
Erythrina sp & *Desmodium*
  sp & *Hibiscus* sp
Albizia chinensis
Acacia villosa
Ficus spp (fodder)
Pinus kesiya

Successive
Tephrosia purpurea
Sesbania spp
Alnus nepalensis
Casuarina oligodon
Alnus japonica
Parasponia rugosa &
  Schleinitzia novo-guineensis
Hibiscus tiliaceus

Figure 10. Spectrum of indigenous approaches to modify 'fallow' vegetation in Southeast Asia.

Humid tropics of Southeast Asia



CONTINUUM

Monocultures
goal: rehabilitate soil properties after cropping period

◆ **Retention or promotion of prefered volunteer species**

♥ **Shrub-based accelerated fallow**

✦ **Viny legumes as seasonal fallows**

Economic utility

Food

bamboo shoots
native vegetables & other wild food plants

Fibre

construction material such as planting *Corypha utan* and other palm spp before abandoning swidden to provide roofing materials for field hut construction in next cropping phase
harvest of poles useful for house or hut construction
Imperata cylindrica & other spp of thatching grass for roof construction

Fodder

Imperata cylindrica & other native forages

Fuel

Medicinal herbs

Stimulants

Nicotiana tabacum
Piper betel + spp providing shade, pleasant smells, nectar for honey production, attracting wildlife for hunting, etc.

Ecological functions

selective felling to retain 'mother trees' & accelerate recovery of secondary forest
protection of existing coppices: limit cropping period, fire management & avoid tillage

Non N-fixing

Compositae spp
(N-accumulating?)
Austroeupatorium inulifolium
Tithonia diversifolia
Chromolaena odorata

Other

Mallotus barbatus
Ricinus communis
Tecoma stans

N-fixing

Mimosa invisa
Cajanus cajan

Legume rotations

Phaseolus calcaratus
Amphicarpaea linearis
Flemingia vestita
Dolichos lablab
Vigna sinensis
Calopogonium mucunoides
Pachyrhizus tuberosis

increasing integration of legume components into cropping sequence + ruminant livestock

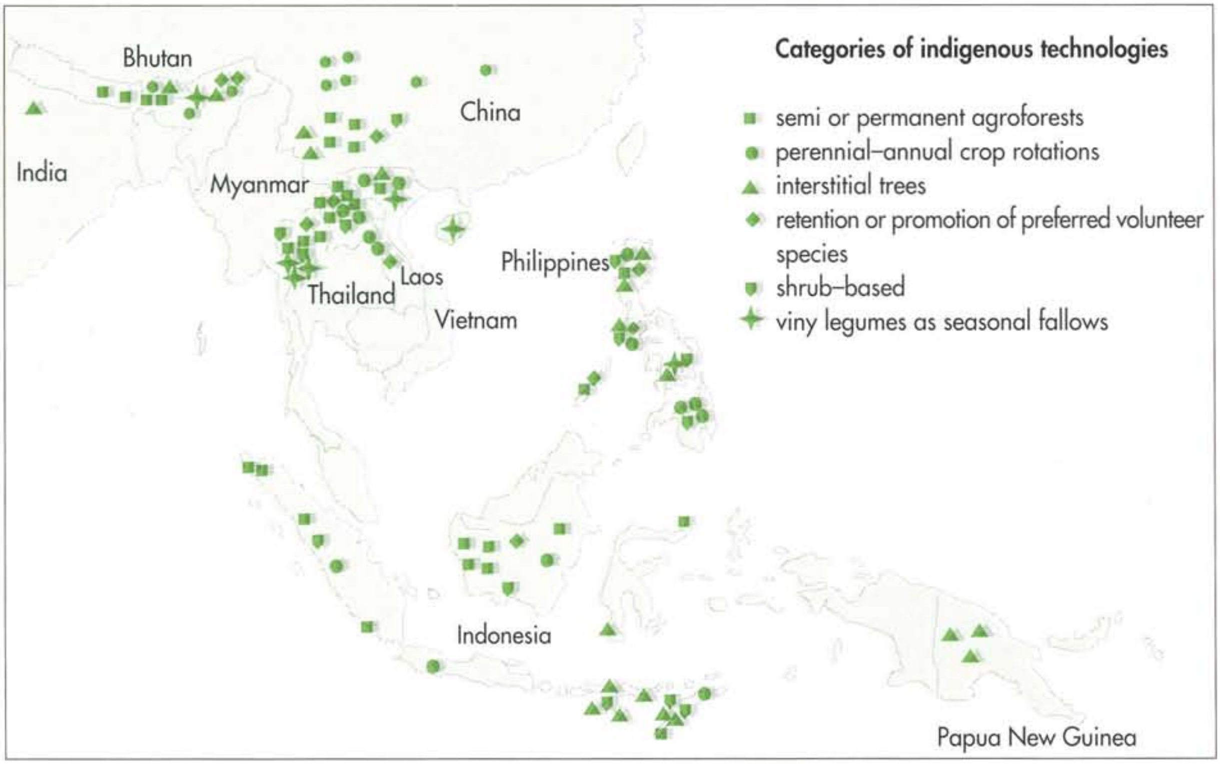


Figure 11. Spatial analysis of variations on the management of improved fallows.

An assumption, often implicit, of many so-called integrated conservation and development projects is that establishing sustainable land-use management practices in an adjacent buffer zone will reduce pressure on the protected area. More secure land tenure may stimulate farmers to adopt more efficient and more sustainable forms of land use, including agroforestry. But it has often been argued that the indigenous tenure systems in Indonesia based on customary law ('hukum adat') are breaking down because of population growth and agricultural commercialization. If there is in fact a tendency toward individualizing land tenure, this institutional shift could have a powerful influence on the intensity of land use and the development of agroforestry. Better understanding of how these institutions respond to population growth, the transition from land abundance to land scarcity, and other pressures is directly relevant to the search for workable policy options that improve smallholder welfare and enhance prospects for sustainable resource management.

Even though tenure institutions in the park buffer zone appear to be evolving toward greater individualization, traditional inheritance systems still are very much in evidence. The extensive survey found 3 sets of rules of land inheritance. First is the traditional matrilineal system, where land and crops are inherited by daughters. Second is an undifferentiated system where land and crops are inherited by sons as well as daughters. Finally, inheritance rules in the 3rd system vary by type of land and by crop. Under this system, wet rice fields are inherited by daughters, land planted with trees (rubber and cinnamon) is inherited by sons, and other upland plots (often reserved for food production) are inherited by sons and daughters.

The percentage of villages by inheritance systems and site is shown in table 6. A unique situation was found in villages in the Rantau Pandan benchmark area. Villages in the eastern part of that site have an inheritance system for upland fields that depends on the crop. Major tree species, such as rubber and cinnamon, are inherited by sons while other types of upland fields are inherited by both sons and daughters.

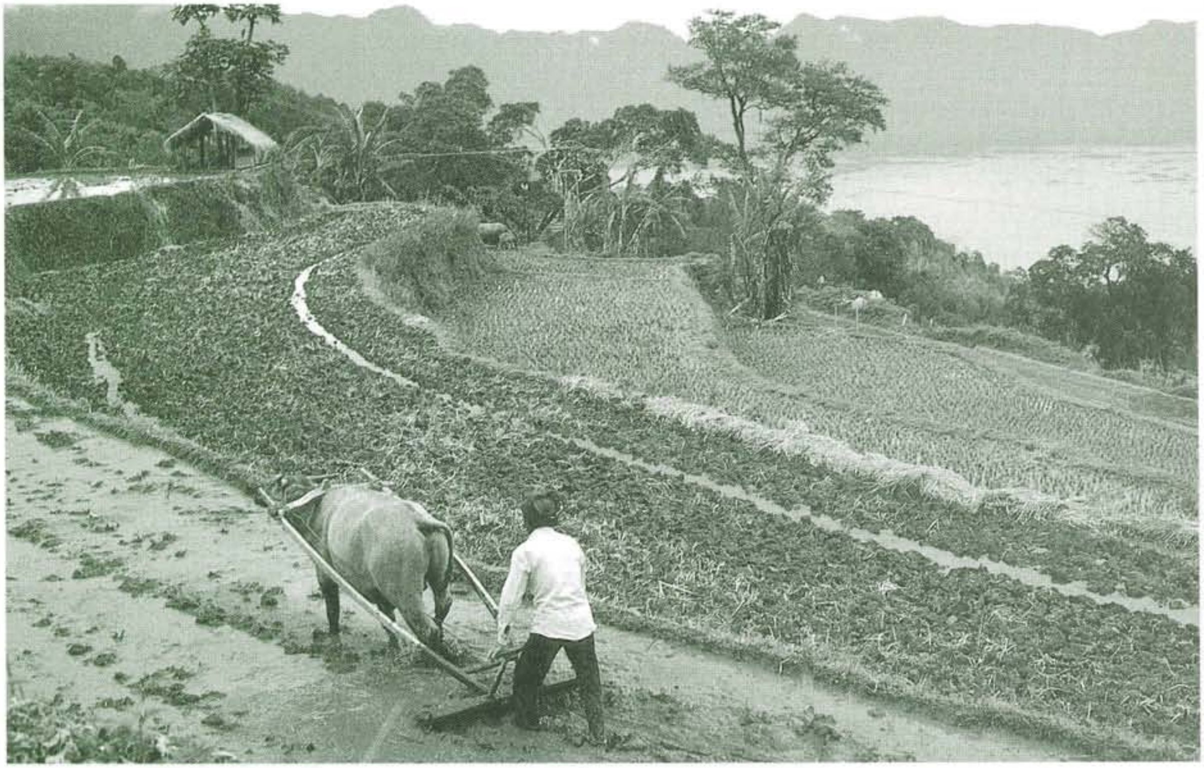
Tabulations of data from the extensive survey indicate that, as expected, shifting cultivation is more likely under land tenure that is less individualized and, in contrast, that most tree crops are planted on land with a higher degree of individual property rights. The objectives of the intensive survey are to enable a more detailed analysis of the determinants of the decision to plant trees and to compare the economic efficiency of land use under different land and tree tenure rules.

Table 6. Percentage of villages by inheritance system and land type

Inheritance systems	Wet rice fields		Dry land	
	Kerinci	Rantau Pandan	Kerinci	Rantau Pandan
Matrilineal	35	100	22	38
Undifferentiated	35	0	50	0
Matrilineal and undifferentiated	30	0	28	0
Depends on crop type	0	0	0	63

IMPERATA GRASSLANDS

Should policymakers care about tens of millions of hectares of imperata grasslands in Southeast Asia? Previous work highlighted at least 3 necessary socioeconomic conditions for the success of any effort to establish trees on imperata grasslands: secure tenure, fire control and access to markets. As discussed in ICRAF's annual report 1995 (p 159–164), a policy to establish secure property rights over all products—including timber—for smallholders who convert plots of grassland by planting and managing trees could be an important 1st step in addressing the lack of tenure security and in creating incentives for community-based fire control. But, aside from efforts to mitigate market imperfections and to reverse policy failures, are direct subsidies or other policy interventions justified in order to promote conversion of imperata grasslands to other uses? The answer depends on the balance between the costs of conversion to other uses and the net benefits produced in economic growth, poverty alleviation and



Land is being prepared in Indonesia for wetland rice. In some inheritance systems, these wet rice fields are inherited by the daughters of a family, and the land with trees is inherited by the sons.

environmental benefits. Little hard evidence is available regarding crucial parameter values, but a study by researchers from ICRAF, FINNIDA, the Australian National University and CIFOR provides a 1st step. It sets up an analytical framework to consider environmental benefits of policy issues related to grassland conversion.

Converting imperata grasslands to agroforestry would appear to offer few, if any, additional soil conservation benefits and might even increase erosion. Additional empirical research would be needed to value other regional externalities associated with imperata grasslands and alternative land uses, especially regarding agricultural pests, local climate and hydrology, and the financial and public health effects of smoke. Data on these regional externalities are not sufficient at this time to make a case for direct policy intervention to promote imperata grassland conversion. For agricultural pests, the net result of conversion from imperata grasslands to tree-based systems may be small because of offsetting effects (fewer rats but more damage from wild pigs and monkeys). The effects of grassland conversion on local climate and hydrology and on smoke in the atmosphere could be substantial, but no one has attempted to put a value on these externalities.

Fairly robust evidence is available, however, on the carbon sequestration value of conversion. Because changes in land use bring big changes in carbon stocks, compensation for carbon sequestration through investment to establish tree-based systems can significantly raise profitability of grassland conversion. Although there is no substitute for project appraisal for specific settings, significant imputed values of carbon sequestration from conversion to *Acacia mangium* and rubber agroforestry (under technologies, prices and policies prevailing in Indonesia) hold up in the economic analysis even for a conservative estimate of the marginal value of sequestered carbon. But only when the simulated investments to establish *A. mangium* were discounted at a high real rate (20% per annum) were there clear-cut results consistent with the necessary conditions for policy intervention to promote conversion: an investment is socially profitable but free markets alone fail to provide sufficient financial incentives for investment.

The estimates for simulated investments in rubber agroforestry indicate that it is neither financially nor socially profitable at a 20% discount rate. For real discount rates up to almost 15% for the simulations for rubber agroforestry and a bit above 15% for *A. mangium,* the illustrative calculations reveal no policy problem; wherever investment is socially profitable, it is financially profitable. To be sure, compensation for carbon sequestration would raise the profitability of these investments significantly. But for circumstances under which these models might apply, this compensation would simply raise profits on investments that would have been undertaken anyway.

In other words, the case has yet to be made that imperata grasslands constitute a 'problem' that merits compensating for the imputed value of carbon that could be sequestered in tree-based systems. It needs to be emphasized, however, that the 2 examples include only the effect on profitability of compensation for the imputed value of carbon sequestration and ignore other possible environmental externalities. To undertake a complete assessment of the merits of direct policy intervention, much more work would have to be done to estimate the value of other environmental externalities and public goods; we simply do not know much about these values at this time.

Until a convincing case is made for policy intervention to promote conversion, governments should focus their efforts on establishing clear, secure tenure over products of alternative land-use systems and on removing policy distortions. Financial profitability of grassland conversion can be overturned by a number of policy distortions, including macroeconomic, trade and pricing policies that depress output prices. These distortions arise from national and local policy decisions and hence should be analysed country by country as a component of the appraisal of alternatives. Eliminating current policy failures and distortions that retard grassland conversion is a prerequisite to any policy intervention to promote conversion.

EXPORT POTENTIAL OF INDONESIA'S RUBBERWOOD

The world price for rubberwood has increased since the late 1980s because of the rapid depletion of ramin wood in the natural forests of Southeast Asia. As a result, the wood of rubber trees has emerged as an important by-product of natural rubber production. Indonesia could be a big rubberwood producer because it has the world's largest stock of old rubber trees. Yet Indonesia lags behind the other 2 major natural rubber producers in utilization of this resource. In 1993, Thailand made use of over 80% of its available rubberwood (exporting it under labels like 'white teak' and 'Thai oak') and Malaysia used more than 60%, while Indonesia was using, at most, only 27% of its potential supply. Instead, most of Indonesia's rubberwood goes up in smoke when smallholders cut old rubber trees to clear land for replanting.

Rubberwood sales could generate economic benefits for smallholders, who produce 70% of Indonesia's rubber and operate an even greater proportion of the old rubber trees. Rubber typically accounts for 60% of the standing trees in the so-called jungle rubber systems that predominate in Sumatra and Kalimantan. If they can sell this rubberwood when it is time to replant, farmers can cover costs of land clearing and still net the equivalent of USD 200 or more in cash per hectare—even under current policies. It will not be feasible to market all smallholder rubberwood; much is simply too isolated. But where marketing is feasible, revenue from rubberwood sales can cover half of the costs of higher yielding planting material and other inputs that dramatically increase future income for smallholders. (Farmgate prices of rubberwood vary depending on distance to markets, transport costs, and the local levies discussed below.)

Rubberwood exports also could yield environmental benefits. Burning rubberwood releases carbon dioxide and methane, which are 'greenhouse gases' linked to global warming. Each year, burning rubberwood in Indonesia releases emissions equivalent to over 5 million tonnes of carbon dioxide. (This includes the 'greenhouse gas' effect of methane, which has 25 times the effect of carbon dioxide.) Although these emissions from burning rubberwood are insignificant compared with greenhouse gases released by deforestation, the smoke from these fires can be a highly visible nuisance.

Why this failure to exploit the potential of rubberwood? Rubberwood exports—and the opportunity they offer to increase smallholders' incomes while providing environmental benefits—continue to fall short of their potential because of local and national policies that inhibit marketing. Indonesia's export taxes on rubberwood reduce export revenues and depress smallholder incomes. The current tax of USD 500 m^{-3} puts Indonesia at a competitive disadvantage when compared with Thailand, which has no tax, or Malaysia, which has a tax of only USD 50 m^{-3}. Local levies and restrictions on purchasing rubberwood from smallholders have also proliferated. The administrative burden of these regulations combined with confusion from frequent changes in regulations results in an effective ban on purchases of smallholder rubberwood in major rubber-producing regions.

Local levies and trade restrictions that increase the costs processors face in purchasing rubberwood from smallholders are biased in favour of large-scale plantations. These policies reinforce the plantations' technical advantages over smallholders as rubberwood suppliers. The levies and restrictions stem, in part, from concern that processors will exploit smallholders, enticing them to cut their rubber trees prematurely. There is no evidence to support the anxiety that smallholders will cut young rubber trees to sell them for wood. In fact, analyses by ICRAF and others of the economics of replacing rubber trees at different ages indicate that these official fears are groundless and local trade restrictions are not needed.

TREE SPECIES PERFORMANCE BY ELEVATION

National parks and other protected ecosystems in the humid tropics are under great pressure from agricultural encroachment. They often represent remnant forests on some of the taller mountainous peaks. The buffer zones outside many of these biodiversity reserves therefore exhibit major variation in elevation. The integrated conservation–development approach to protection often involves identifying key agroforestry enterprises that will improve the livelihood of the communities in the buffer zone and at the same time enhance tree cover and biodiversity features of the landscape outside the park. A central issue, therefore, is determining the most suitable species for the range of altitudes encountered, given that the performance of agroforestry tree species is often strongly influenced by the differences in temperature regime and other aspects of the local ecology.

ICRAF and its partners in the USAID-supported Sustainable Agriculture and Natural Resources Management (SANREM) Project are working in the buffer zone of the Mt Kitanglad Range National Park in Bukidnon, Philippines (8°N), a steep volcanic range where these issues are prominent. A strong altitudinal gradient exists in forest margin villages, with elevation ranging from less than 700 m to more than 1700 m. This area has 3 key zones: intact forest at high elevations (1600 m and above), where some of the highest levels of biodiversity have been reported in the Philippines; a zone of sloping state forest land that was logged, was subsequently transformed into *Imperata cylindrica* grassland, and is currently settled increasingly by smallholder households growing food and market vegetable crops with shifting cultivation methods; and a zone of private land, which is more permanently farmed in maize and vegetables.

Farming systems are in a state of flux. Agroforestry is common at elevations below 600 m, based on mixed perennials including coffee, coconut and fruits. Recently the dramatic decline in timber supplies, brought about by overcutting and a logging ban, has driven timber prices up and stimulated great interest among smallholders throughout the area in planting timber species for profit. Our previous surveys have indicated that the 3 top choices of agroforestry enterprises among smallholders in the buffer zone were timber tree production, fruit trees and contour hedgerow systems for soil conservation.

The 1st stage in developing a research programme to guide efforts to accelerate agroforestry tree production systems was to obtain good information on the performance of the species and provenances currently being grown by households along this elevation gradient. We designed a survey that endeavoured to capture the observations of smallholders, and also tested a method that combined participatory and more conventional mensuration approaches.

After identifying the major species of perennials we searched the available literature to summarize existing information on their performance by elevation, based on other data sources. The elevation range of the major perennials grown in Lantapan as reported in the existing literature is shown in table 7. We then conducted an informal survey across the watershed to make a more accurate separation of watershed classes, estimate sample sizes needed, determine the sampling design, select the best candidate species for a more formal survey, define the parameters to be measured and develop the interview protocol. On the basis of the informal survey, the watershed was classified in 6 elevation strata (later aggregated into 4 elevation zones). The performance of the trees commonly grown by local residents is summarized in table 8.

From the original list of 38 species for which observations were recorded, those for which frequencies were impractically low were discarded. The resulting performance patterns of the remaining species (shown in table 8) were then compared with the elevational ranges as given in the existing literature (table 7). Those species exhibiting strong correlations with their reported range and whose ranges were not suitable to the midland or highland climate were also dropped from further analysis. The literature review had highlighted some species whose climatic suitability greatly depended on variety. In these cases distinctions were made on the basis of variety. Additional species were added to the remaining list at the recommendation of the local enumerators. This yielded a priority list of 9 timber and 17 fruit species for the formal survey.

In the formal survey informants were asked to rate (on the basis of other specimens of the species they had observed elsewhere) the rate of girth thickening, rate of vertical growth, and timber quality of the bole of the trees on their own farm. The enumerators measured the girth and height of each tree and noted the slope and elevation where it was planted. In cases where more than 10 trees were present, a systematic subsample was taken. A number of site and management parameters were recorded as possible influences on performance, such as planting pattern (line, block, or mixed), fertilizer application, pruning or weeding regime, and planting material used and its source. The survey revealed that farmers varied little in their practices of applying fertilizer (93% did not fertilize) or in their planting materials (100% used seedlings). A tree spacing of 2–3 m predominated (86%). The spacing variability showed no association with elevation ($p = 0.131$). The land of 73% of the sample population was on 0–3% slope.

There were no significant differences in the slope of the locations sampled between zones ($p = 0.874$). There was substantial variability in the source of the germplasm that farmers used; most

Table 7. Elevation range of perennials commonly grown in Lantapan as reported in existing literature

■ ideal; commercial plantations often found
▨ becoming critical; commercial plantations seldom found
□ poor; the species not suitable for this elevation

Local & common English name	Scientific name	Elevation (metres above sea level)													
		400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	
abaca	*Musa textilis* Nee	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
abokado (avocado)	*Persea americana* Mill	'West Indian': lowlands; 'Guatemalan': 1000 m and above; 'Mexican': 1500 m & higher													
"bamboo"[†]	*Bambusa* sp	depends on species, some of which are suitable for all elevations													
bayabas (guava)	*Psidium guajava* L.	■	■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨
cacao	*Theobroma cacao* L.	■	■	■	▨	▨	▨	▨	□	□	□	□	□	□	□
caimito (star apple)	*Chrysophyllum cainito* L.	■	■	■	■	■	■	■	■	▨	▨	▨	▨	□	□
calamansi	*Citrus madurensis* Lour.	■	■	■	■	■	■	□	□	□	□	□	□	□	□
castor	*Ricinus communis* L.	■	■	■	■	■	■	■	■	■	■	■	■	■	■
citrus (mandarin?)	*Citrus reticulata* Blanco	can be found up to 1800 m in tropics depending on sun and rainfall													
coconut	*Cocos nucifera* L.	■	■	■	■	▨	▨	▨	□	□	□	□	□	□	□
coffee arabica	*Coffea arabica* L.	□	□	□	□	□	□	□	□	□	□	■	■	■	■
coffee robusta	*Coffea canephora* var. *robusta* L.	■	■	■	■	■	■	■	■	■	■	■	■	▨	▨
	Eucalyptus camaldulensis Dehnh.	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Eucalyptus deglupta Blume	still seeking information on this species; appears suitable in wide range													
	Eucalyptus torelliana F. Muell.	still seeking information on this species; appears suitable in wide range													
"falcatta" (white)[†]	*Albizia falcataria* (L.) Fosb.	still seeking information on this species													
*red falcatta	*Albizia julibrissin* Durazz.	still seeking information on this species; appears suitable in wide range													
gmelina	*Gmelina arborea* Roxb.	■	■	■	■	■	■	▨	▨	▨	□	□	□	□	□
guyabano (soursop)	*Annona muricata* L.	■	■	■	■	■	■	■	▨	▨	□	□	□	□	□
ipil-ipil (leuceana)	*Leucaena leucocephala* (Lam.) de Wit	■	■	■	■	■	■	■	■	■	■	■	■	■	■
kasoy (cashew)	*Anacardium occidentale* L.	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	no data	
lansones	*Lansium domesticum* Corr.	▨	▨	▨	▨	▨	□	□	□	□	□	□	□	□	□

continued on next page

Table 7. continued

▓ ideal; commercial plantations often found

▒ becoming critical; commercial plantations seldom found

░ poor; the species not suitable for this elevation

Local & common English name	Scientific name	Elevation (metres above sea level)												
		400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
lomboy (duhat)	*Syzygium cumini* L.	▓	▓	▓	▓	▓	▒	▒	▒	▒	▒	▒	▒	▒
mahogany	*Swietenia macrophylla* King	▓	▓	▓	▒	▒	▒	▒	▒	▒	▒	▒	░	░
makopa	*Syzygium samarangense* (Blume)	still seeking information on this species												
manga (mango)	*Mangifera indica* Wall.	▓	▓	▓	▒	▒	▒	▒	▒	▒	░	░	░	░
mangium	*Acacia mangium* Willd.	▒	▒	▒	▒	▒	░	░	░	░	░	░	░	░
marang	*Artocarpus odoratissima* Blanco	▓	▓	▓	▒	▒	▒	▒	▒	▒	░	░	░	░
nangka (jackfruit)	*Artocarpus heterophylla* Lam.	▓	▓	▓	▓	▓	▓	▓	▒	▒	▒	▒	▒	▒
narra	*Pterocarpus indicus* Willd.	▓	▓	▓	▓	▓	▓	▓	▒	▒	▒	░	░	░
pomelo	*Citrus grandis* (L.) Osbeck	able to fruit to 1800 m but needs uniformly warm temperatures for good fruit flavour												
rambutan	*Nephelium lappaceum* L.	▓	▓	▓	░	░	░	░	░	░	░	░	░	░
rubber	*Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg.	depends on species but generally all lowland												
santol	*Sandoricum koetjape* (Burm F.) Merr.	▓	▓	▓	▓	▓	▒	▒	▒	░	░	░	░	░
'Sunkiss'[‡]	*Citrus sinensis* (L.) Osbeck	can be found up to 1800 m in tropics depending on sun and rainfall												
'V. orange'[‡]	*Citrus sinensis* (L.) Osbeck	can be found up to 1800 m in tropics depending on sun and rainfall												

[†] double quotes indicate local names that distinguish only the genus

[‡] single quotes indicate local names that distinguish a particular variety or cultivar

of it was obtained casually and locally (73%). Line planting was the dominant planting pattern (81%). Pruning and weeding practices were the strongest potential sources of performance variability. Pruning was done on 63% of the observations, weeding on 43%. Frequency of pruning was higher in the lower strata. Based on information on performance data (table 7), 6 strata in 5 elevation ranges were decided upon for the survey (fig. 12):

Table 8. Performance of trees commonly grown in Lantapan as reported by local residents (results of an informal transect survey conducted with 35 respondents, January 1996)

⬜ mostly good reports ░ mixed reports ▒ mostly average reports ▓ mostly bad reports

Local & common English name	Scientific name	Elevation (metres above sea level)													
			400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
abaca	*Musa textilis*	░	░	░	░	░	░	░	░	░	░	░	⬜	⬜	⬜
abokado (avocado)	*Persea americana*	⬜	⬜	⬜	⬜	▒	▒	▒	▒	░	░	░	▒	▒	▒
"bamboo"†	*Bambusa* sp	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
bayabas (guava)	*Psidium guajava*	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
cacao	*Theobroma cacao*	░	░	░	░	░	░	░	░	░	░	no data available			
caimito (star apple)	*Chrysophyllum cainito*	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	▓	▓	▓	▓	▓
calamansi	*Citrus madurensis*	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	░	░	░	░
castor	*Ricinus communis*	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
citrus	*Citrus reticulata*	░	░	░	░	░	░	░	░	░	░	░	░	░	░
"coconut"†	*Cocos nucifera*	⬜	⬜	⬜	⬜	⬜	⬜	░	░	░	▓	▓	▓	▓	▓
"coffee"†	*Coffea arabica*	⬜	⬜	⬜	⬜	▒	▒	▒	▒	⬜	⬜	⬜	⬜	⬜	⬜
coffee robusta	*Coffea canephora* var. *robusta*	▒	▒	▒	▒	▒	▒	▒	▒	▒	⬜	⬜	⬜	⬜	⬜
Jap bamboo		⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	Eucalyptus camaldulensis	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	Eucalyptus deglupta	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	Eucalyptus torilliana	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
"falcatta"† (white falcatta)	*Albizia falcataria*	⬜	⬜	⬜	⬜	⬜	⬜	▒	▒	▒	▒	░	░	░	░
gmelina	*Gmelina arborea*	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	▓	▓	▓	▓	▓	▓
guyabano (soursop)	*Annona muricata*	⬜	⬜	⬜	⬜	⬜	⬜	▓	▓	▓	▓	▓	▓	▓	▓
ipil-ipil (leuceana)	*Leucaena leucocephala* (Lam.) de Wit	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
kasoy (cashew)	*Anacardium occidentale*	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
lanzones	*Lansium domesticum*	⬜	⬜	⬜	⬜	⬜	▒	▒	▒	▒	▓	▓	▓	▓	▓
lomboy (duhat)	*Syzygium cumini*	░	░	░	░	▒	▒	▒	▒	▒	▒	░	░	░	░

continued on next page

Table 8. continued

□ mostly good reports ░ mixed reports ▒ mostly average reports ▓ mostly bad reports

Local & common English name	Scientific name	Elevation (metres above sea level)													
			400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
mahogany	*Swietenia macrophylla*	□	□	□	□	□	□	□	□	□	▒	▒	▒	▒	▒
makopa	*Syzygium samarangense*	□	□	□	□	□	□	□	□	□	▓	▓	▓	▓	▓
manga (mango)	*Mangifera indica*	□	□	□	□	□	▒	▒	▒	▒	▒	▓	▓	▓	▓
mangium	*Acacia mangium*	□	□	□	□	▒	▒	▒	▒	▒	▒	▒	▓	▓	▓
marang	*Artocarpus odoratissima*	□	□	□	□	□	░	░	░	░	░	▓	▓	▓	▓
nangka (jackfruit)	*Artocarpus heterophylla*	░	░	░	░	░	░	░	░	░	░	░	░	░	░
narra	*Pterocarpus indicus*	□	□	□	□	□	□	□	□	□	□	no data available			
pomelo	*Citrus grandis*	□	□	□	□	▒	▒	▒	▒	▓	▓	▓	▓	▓	▓
rambutan	*Nephelium lappaceum*	□	□	□	□	□	▒	▒	▒	▒	▒	▓	▓	▓	▓
rubber	*Hevea brasiliensis*	□	□	□	□	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
santol	*Sandoricum koetjape*	□	□	□	□	□	□	□	□	□	▓	▓	▓	▓	▓
'Sunkiss'‡	*Citrus sinensis*	no data available													
'V. orange'‡	*Citrus sinensis*	□	□	□	□	□	□	□	□	□	□	░	░	░	░

† double quotes indicate local names that distinguish only the genus
‡ single quotes indicate local names that distinguish a particular variety or cultivar

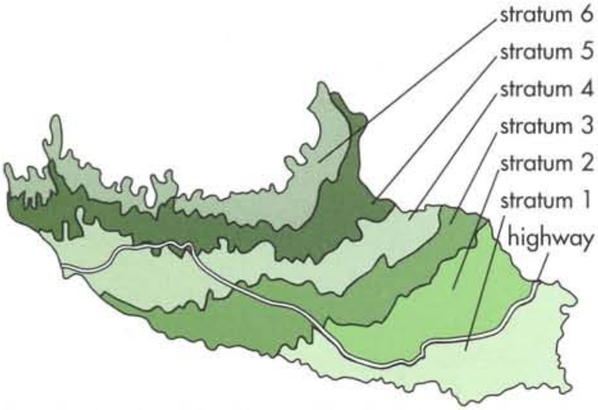


Figure 12. Map of Lantapan showing strata and quadrant sampling grid.

stratum 1	< 700 m, above highway, suitable for most species
stratum 2	< 700 m, below highway, suitable for most species
stratum 3	700–950 m critical threshold for strictly lowland species
stratum 4	950–1200 m suitable for mid-altitude species and hardy lowland species, depending on local climate
stratum 5	1200–1400 m critical threshold for mid-altitude species
stratum 6	1400–1700 suitable for very few species

Table 9. Species sampling frequencies across elevation zones

Scientific and common name	Strata				
	1/2	3	4	5/6	Total
Pterocarpus indicus (narra)	11	6	7	4	28
Swietenia macrophylla (mahogany)	20	11	22	6	59
Acacia mangium (mangium)	18	14	26	14	72
Gmelina arborea (gmelina)	19	25	29	25	98
Albizia falcataria (white falcatta)	5	14	7	5	31
Albizia julibrissin (red falcatta)	1	6	9	17	33
Eucalyptus camaldulensis	11	3	12	5	31
Eucalyptus torelliana	2	10	10	11	33
Eucalyptus deglupta	9	3	3	1	16
Total	96	92	125	88	401

Ten species growing across these elevation zones were selected for sampling. The number of reports on each species is shown in table 9. Report frequencies tended to be highest in stratum 3 (700–950 m) and stratum 4 (950–1200 m), which were critical threshold areas. A summary of the performance response data by species and elevation zone is shown in table 10. Narra *(Pterocarpus indicus),* a common reforestation species in the Philippines, has an upper threshold range of approximately 1000 m according to the literature. The survey data supported a downward trend in the rate of girth thickening and in bole quality at higher elevations. Mahogany *(Swietenia macrophylla)* is reported to thrive best at altitudes lower than 600 m. The survey trends suggest a steady decline in rate of girth thickening and bole quality beginning at the lower mid-altitude (stratum 3). *Acacia mangium* is recommended for a growing range less than 300 m, although the tree is capable of thriving at much higher altitudes. The species received predominantly good to average reports across all zones, although the ratio showed a steady shift from good reports to average reports with increasing elevation. Nearly all respondents observed that this tree breaks comparatively easily in the wind.

Eucalyptus camaldulensis is reputed to be hardy and adaptable to a wide range of climatic conditions (see table 7). In our survey the species received few responses of 'slow' or 'poor' for any performance criterion. Because of the small sample sizes, we aggregated the data into 2 elevation strata. Chi-square analysis showed no significant differences in girth or height with elevation, but there was a significant trend in reduced bole quality ($p = 0.035$).

Gmelina arborea is the most commonly grown timber tree in Lantapan. Its range for commercial production, as recommended in the literature, is less than 1000 m (table 7). Our results showed a strong negative trend between elevation and bole

Table 10. Perceived performance by elevation raw data summary: medians of response by 4 elevation zones

		Response distribution (%)												
Species (common English name in parentheses)	Altitude range	Rate of vertical growth				Rate of girth thickening				Bole quality				Sample size
		fast	avg	slow	no resp	fast	avg	slow	no resp	good	avg	poor	no resp	
Acacia mangium (mangium)	< 700	83	17	0	0	89	11	0	0	78	22	0	0	18
	701 – 950	71	29	0	0	50	50	0	0	0	50	50	0	14
	951 – 1200	42	54	4	0	54	46	0	0	35	65	0	0	26
	1201 – 1700	36	50	7	7	50	36	14	0	29	50	14	7	14
Albizia falcataria (white falcatta)	< 700	40	60	0	0	60	40	0	0	80	20	0	0	5
	701 – 950	36	21	43	0	29	36	36	0	21	50	29	0	14
	951 – 1200	43	43	0	14	43	43	0	14	0	57	29	14	7
	1201 – 1700	60	40	0	0	20	60	20	0	0	100	0	0	5
Albizia julibrissin (black wattle; red falcatta)	< 700	100	0	0	0	100	0	0	0	100	0	0	0	1
	701 – 950	50	17	17	17	33	33	17	17	17	50	17	17	6
	951 – 1200	44	33	11	11	56	33	0	11	11	56	22	11	9
	1201 – 1700	35	59	6	0	65	29	6	0	29	59	12	0	17
Eucalyptus camaldulensis	< 700	55	27	18	0	64	9	27	0	82	18	0	0	11
	701 – 950	67	33	0	0	33	67	0	0	67	33	0	0	3
	951 – 1200	58	33	0	8	50	42	0	8	33	58	0	8	12
	1201 – 1700	40	60	0	0	60	20	20	0	40	40	20	0	5
Eucalyptus deglupta (bagras)	< 700	100	0	0	0	89	11	0	0	89	11	0	0	9
	701 – 950	33	67	0	0	33	67	0	0	33	67	0	0	3
	951 – 1200	0	100	0	0	0	67	33	0	33	67	0	0	3
	1201 – 1700	100	0	0	0	100	0	0	0	100	0	0	0	1
Eucalyptus torelliana Muell.	<700	100	0	0	0	100	0	0	0	100	0	0	0	2
	701 – 950	50	50	0	0	50	50	0	0	50	50	0	0	10
	951 – 1200	40	60	0	0	40	40	20	0	30	60	10	0	10
	1201 – 1700	64	27	0	9	64	18	18	0	46	27	18	9	11
Gmelina arborea (gmelina)	< 700	53	37	11	0	95	5	0	0	89	11	0	0	19
	701 – 950	52	20	24	4	52	28	20	0	36	52	12	0	25
	951 – 1200	14	45	34	7	10	38	45	7	10	52	31	7	29
	1201 – 1700	52	44	4	0	4	44	52	0	12	40	44	4	5
Pterocarpus indicus (narra)	< 700	64	36	0	0	55	45	0	0	27	46	27	0	11
	701 – 950	33	17	50	0	33	33	33	0	33	33	33	0	6
	951 – 1200	14	29	43	14	0	14	71	14	29	29	29	14	7
	1201 – 1700	0	75	25	0	25	25	50	0	0	75	25	0	4
Swietenia macrophylla (mahogany)	< 700	90	10	0	0	85	15	0	0	85	15	0	0	20
	701 – 950	18	36	45	0	27	27	45	0	18	64	18	0	11
	951 – 1200	9	64	27	0	23	50	27	0	23	59	18	0	22
	1201 – 1700	0	33	67	0	0	50	50	0	0	83	17	0	6

quality girth thickening and height growth with strongly significant chi-square values of $p < 0.001$. Regressions for the measured relationship between *G. arborea* diameter at breast height (dbh) and age were different for the lowland and the highland zones. The regression line showed an advantage of 5 cm after 2 years. The slopes of the regressions were not significantly different, indicating that this difference did not increase substantially with age. This implies that the major difference in growth performance by elevation occurs in the first 2 years. A regression of measured dbh values by age, classified by farmer ratings of either 'good' or 'poor', may be conceived as the growth rates that farmers perceived for these categories. The regression indicates that the average rate of girth thickening for trees rated as 'poor' was about 0.4 cm per year; for those rated as 'good' it was about 2.5 cm per year.

Are farmers' opinions reliable indicators of species performance patterns? Farmer response by elevation patterns was similar to expected trends as gleaned from the literature, and at least 2 of these responses—'good' and 'poor'—appeared to reflect genuine differences in growth rates when quantitative data were plotted in response class series. Where the participatory method fell short was in conclusively identifying underlying causes for performance differences ('why do they grow poorly?'). Enumerators reported respondents as accommodating and interested. Enumerators appreciated the flexibility of the sampling design (by species quota rather than number of respondents). This enabled them to customize interview time to suit the interest level of the respondent.

It appears that the best results for reconnaissance-level research on species performance by elevation could be obtained by combining the 2 approaches—farmer perception survey and tree growth measurements. Use of perceived performance as an indicator of actual performance may be a more efficient approach at a broad scale. Note that 9 species were considered here for perceived performance patterns compared with 1 for measured observations. Calibration of the response classes to get at least a general estimation of growth rate will further strengthen the results (but slow the sampling rate). Careful sampling design and collection of at least the most rudimentary information regarding confounding performance variables would flag potential dangers of misconclusion. A perception survey could be a valuable tool in reconnaissance-level research, yielding scientifically credible results with the capacity to support technical research planning.

Site-compatibility trials based on these results have now been established for 8 timber species on 14 farms across a range of altitude, slope and aspect. This work is being complemented by an investigation to domesticate a number of local species identified and used by farmers for timber.

AGROFORESTRY INNOVATIONS TO CONVERT IMPERATA GRASSLANDS

Imperata cylindrica grasslands are a large, underutilized resource in Asia that exist as a result of deforestation. This underutilization has prompted many governments to attempt to reforest the grasslands through large-scale projects—a strategy that has seldom been successful. A recent project supported by ACIAR provided ICRAF the opportunity to develop better estimates of the area of grasslands in Asia dominated by *I. cylindrica*, and to conduct fieldwork in Indonesia to elucidate how smallholders cope with the farming challenges in these harsh environments. Based on information collected from each of the countries, we estimated that the area of huge grasslands in tropical Asia is 34.7 million hectares—about 4% of the land area.

Our analysis indicates that the countries, with the largest area of imperata grasslands are Indonesia (8.5 m ha) and India (8.0 m ha). However, the countries with the largest proportion of their surface area covered with imperata are Sri Lanka (23%), the Philippines (17%) and Vietnam (9%). Laos, Thailand, Myanmar and Bangladesh evidently all have similar proportions of their land area infested with imperata: all are in the range of 3 to 4%. The countries that evidently have quite minor areas of imperata as a proportion of their total land area are Malaysia (< 1%), Cambodia (1%), and the southern part of China (2%).

During our field surveys in 3 contrasting agroecological zones in Indonesia where huge grassland areas occur, we saw innovative farmer adaptations that have wide-ranging implications for extrapolation; 2 examples are described in the following sections. The first is that of a slash-and-burn community in Indonesia that is harnessing new conservation tillage technology through the use of herbicides.

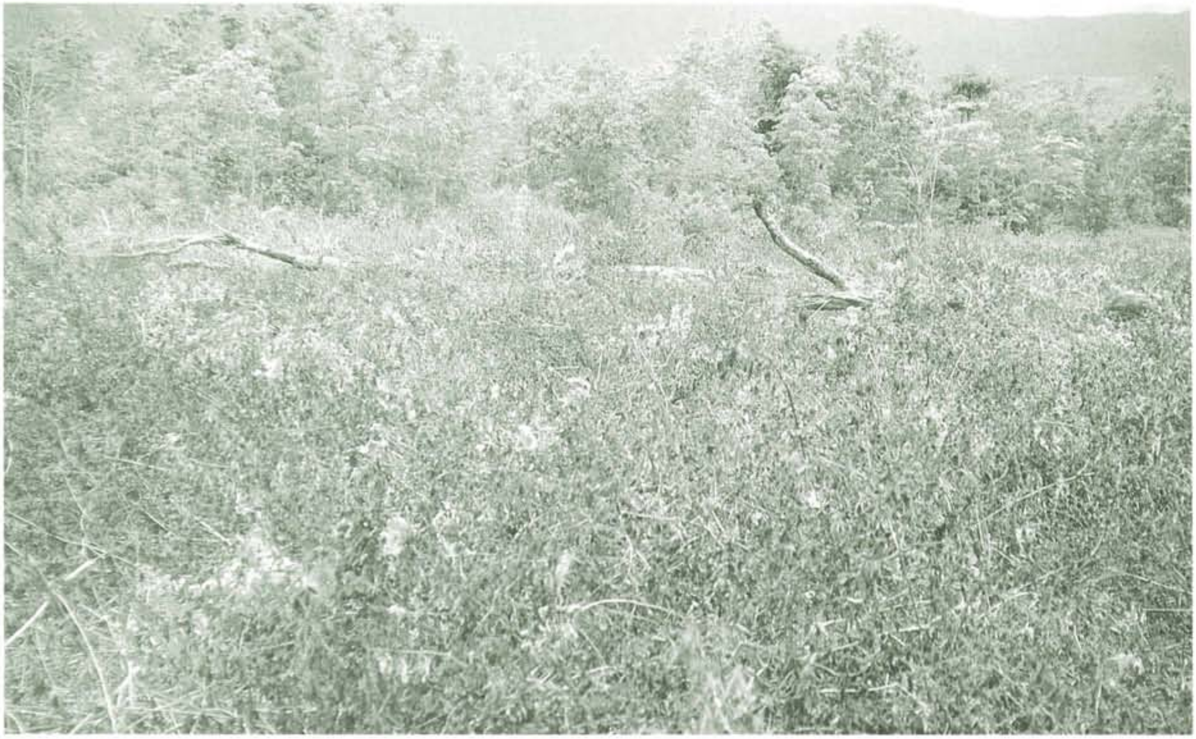
HERBICIDES TO MANIPULATE FALLOW VEGETATION

Shifting cultivation systems are by definition land abundant and labour deficient. The household's challenge is how to make best use of its limited pool of labour. Modern conservation tillage technologies can converge with shifting cultivators' objectives in minimizing labour in land preparation. A classic case in point is the village of Belangian in South Kalimantan, Indonesia.

South Kalimantan has one of the largest areas of imperata in Indonesia (623 000 ha). The grassland lies in a north–south belt on the western side of the Meratus Mountains. Farming in the village of Belangian, Riam Kanan, is based on a manual slash-and-burn system. Farmers confine their cultivation to areas dominated by chromolaena *(Chromolaena odorata)* and have tried to avoid opening imperata grasslands because of the enormous amount of work involved. But imperata has spread over most of the village lands, so every year there is progressively less secondary vegetation available for new fields. About 3 years ago the entire village started using glyphosate to control imperata when the fallow land was opened for cultivation.

Farmers first slash and burn the vegetation. When the grass grows back to a height of 20–40 cm after 2–4 weeks, they spray the grassy patches and burn the field a 2nd time. They then plant by dibbling the seed. All farmers now use glyphosate as part of their management system as it has enabled them to reopen fields with a substantial amount of imperata. They say that the use of glyphosate not only has controlled imperata, enabling zero-tillage annual cropping, but also has caused the postcropping fallow vegetation to shift back to chromolaena—and the area dominated by imperata is now declining.

Farmers had been concerned that land in chromolaena was decreasing and that it was getting



In the village of Belangian, South Kalimantan, Indonesia, slash-and-burn farmers have discovered that spraying glyphosate on imperata fields before they are cropped not only controls weeds during the crop cycle, it also causes the fallow vegetation to shift to a highly desired fallow species. The field pictured is now dominated by Chromolaena odorata. *Before cropping, it had been infested entirely by imperata grass. ICRAF is verifying this useful prospect for manipulating fallow vegetation toward useful species.*

increasingly difficult to find suitable fallow land. Imperata-dominated land had spread over most of the village. This situation would soon have necessitated a drastic change in their cultivation system. The crisis had prompted their discovery.

Farmers claim that the glyphosate system provides critical advantages:

- They will be able to maintain and increase the amount of chromolaena-dominated land, increasing the area potentially suitable for cropping.
- They are now able to utilize land that is considerably infested with imperata. Previously this land was too costly to bring back into production and was abandoned in favour of fields that were dominated by chromolaena.

Successful zero-tillage food-crop systems using herbicides are rare in the tropics. Thus, the fact that such a system was developed independently by a village of shifting cultivators is remarkable. The glyphosate system does not replace slash-and-burn farming; rather, it enhances it through more effective weed management during the cropping cycle and a favourable vegetation shift during the fallow period. Both aspects improve the sustainability of the system. The extrapolation value of this system is not trivial, because chromolaena is a widely preferred fallow species for slash-and-burn systems in Southeast Asia (including western Indonesia, the Philippines, Laos and Thailand). Other species of the Compositae family have been shown to play the same role in other environments. We are currently documenting this in more depth in the context of the indigenous strategies thrust of the global Alternatives to Slash-and-Burn programme.

CREATING AN AGROFOREST ON A CRITICAL WATERSHED

Agroforests are mixed perennial systems developed by smallholders; they occupy millions of hectares in Indonesia. They are often based on a major tree species, which is mixed with a range of other species. Examples are the rubber agroforests of Sumatra and West Kalimantan, the damar *(Shorea javanica)* agroforests of southern Sumatra, which supply commercial resins, and fruit-based agroforests (for example, those based on durian—*Durio zibethinus*). These are developed by interplanting the trees with annual food crops through slash-and-burn farming in secondary forests.

Agroforests have long been considered a highly desirable direction for the rehabilitation of degraded grasslands. However, there is scepticism about whether they are a practical possibility where the soil has been degraded and the microclimate has been changed from a conducive, humid forest environment to one that is open and intensely drought prone. Indeed, to date there have been few documented cases where smallholders have transformed whole landscapes located in the midst of a huge grassland into permanent agroforest systems of mixed perennials. The village of Tiwingan, which farms the steep hillsides on the banks of the Riam Kanan reservoir in South Kalimantan, presents such a case. The lands surrounding the reservoir were designated as watershed conservation forest lands, but they are well known in Indonesia as a problematic critical watershed. Open grasslands cover the slopes of the rolling hills of the watershed from the lakeshore to remnant forests perched on the peaks of the distant mountains. The village of Tiwingan is different: whole hillsides are clothed in mature agroforest in the midst of a landscape of surrounding grasslands. The surrounding villages also farm the grasslands but have not converted the landscape to tree-based systems. Why and how did this particular village succeed in making the conversion? What lessons might their experience have for broader efforts to revegetate imperata-infested conservation areas here and elsewhere?

The village is a new resettlement village, established in 1975, after the reservoir was filled in 1972/73. It is about 25 minutes by boat from the market port of Aranio, which is connected by road with Martapurta and other major cities of South Kalimantan. The village, with an area of 9 km^2, is inhabited by 2164 people in 524 households, giving an average population density of 240 persons per km^2. The inhabitants—almost

*Smallholders reclaim imperata grasslands in many areas by developing complex agroforests. Villagers in Tiwingan, Kalimantan, planted trees in their swiddens in the vast grasslands surrounding the Riam Kanan reservoir in South Kalimantan, Indonesia. The dominant species planted are candle nut (*Aleurites moluccana*), petai (*Parkia spp*), coconut (*Cocos nucifera*), rambutan (*Nephelium lappaceum*), mangoes (*Mangifera indica*), durian (*Durio zibethinus*), bananas, cloves and rubber (*Hevea brasiliensis*). Hundreds of hectares of agroforest exist after 2 decades of settlement.*

all Banjarese—originated from villages down river that had been inundated by the reservoir. Their previous livelihood was drawn from farming paddy rice ('sawah') and from rubber and durian agroforestry.

The villagers related that the area's uplands were covered by imperata grassland long before the Riam Kanan River Basin was inundated. When they relocated from the valley to establish a community on the shores of the new lake the entire area available for occupation was exclusively grassland. They found that they had no choice but to find ways to make a living on the steep grassy slopes. With their very limited resources, they resorted to cultivating food crops using slash-and-burn methods adapted to the grassland setting.

As new settlers joined the community, the population density increased rapidly. Open, unclaimed land became less available, and what there was of it was soon at a fair distance from the settlement. The villagers reacted by planting trees in and around their fields during the cropping cycle. The practice was a way to lay firm claim to the land and was also an investment toward future income. In their peanut and rice crops they planted many different kinds of fruit and timber trees. The dominant species planted were candle nut *(Aleurites moluccana),* petai *Parkia* spp, coconut *(Cocos nucifera),* rambutan *(Nephelium lappaceum),* mangoes *(Mangifera indica),* durian *(Durio zibethinus),* bananas, cloves, rubber *(Hevea brasiliensis),* kuini *(Mangifera odorata)* and cashew. Species that were particularly popular as boundary plantings were gliricidia *(Gliricidia sepium),* parkia, sungkai *(Peronema canescens)* and alaban *(Vitex pubescens).* Besides these planted species, several species growing naturally in the area were encouraged or propagated.

This practice launched the gradual evolution of the hundreds of hectares of agroforest that are present today, only 2 decades after the settlement was established. Each new field that was subsequently opened up and cropped presented villagers with an opportunity to continue expanding their tree gardens. Today, most families have more than 2 plots of mixed garden ('kebun campuran'), the total area of which varies from 1 to 3 ha. The quantity of products they harvest and market from the kebun are now enough to meet their cash needs. The perennial components most important for income are bananas, durian, mangos, candle nuts and petai. The villagers continue to open plots of new imperata land that are available and to plant paddy and peanut in them before developing the land into dense mixed gardens. Thus, the area of grassland is still decreasing as it is continually transformed in mixed gardens.

What are the lessons that communities elsewhere might use? Clearly, it does not take a long time for a village to make major headway towards such a conversion. Tiwingan Baru is only 20 years old. The success achieved in growing trees in opened imperata grassland on sloping soils of typically poor inherent fertility is remarkable. The villagers' motivation and the care they took with their seedlings apparently made the difference. The Tiwingan Baru villagers brought with them tree cultivation skills. Making these skills available to pioneer communities that do not possess them, as well as providing promising planting materials, are 2 key extension issues.

Communities such as Tiwingan Baru should be recognized as 'agroforest laboratories' where cross-visits and farmer-to-farmer extension could be organized to diffuse the system to a much wider farming clientele. An agroforest type suitable for a given locality depends on markets and the biophysical environment. But recognition and documentation of success stories in other grassland areas throughout the country could be an effective technique in promoting farmer-to-farmer extension efforts elsewhere.

BUILDING ON INDIGENOUS TECHNOLOGY: NATURAL VEGETATIVE STRIPS

A major ICRAF thrust in Southeast Asia is to adapt conservation farming technology derived from the practical needs of smallholders. At our Claveria research site in Mindanao, the Philippines, we observed that farmers initially exposed to the concept of contour hedgerows went on to experiment independently with natural vegetative strips (NVS) as an alternative to tree or fodder grass hedges. Some 400 farmers in the area have spontaneously adopted the NVS or grass-strip system, in many cases as a base for establishing lines of fruit and timber trees for cash. In recent years the research project has encouraged this option as the most promising alternative to previously promoted hedgerow systems to sustain crop production on sloping fields. We have found that the maintenance labour required for pruning NVS is generally much lower than for other systems, and the competition effect of natural grasses on adjacent field crops is minimal. We have observed that NVS can reduce soil loss by more than 90%, and that grass strips are apparently more effective than trees. However, NVS do not provide a large amount of biomass that could be used to maintain soil fertility in the alleys. Thus, a cropping system based on NVS depends largely on imported nutrients to maintain continuous crop production.

THE SUSTAINABILITY OF CONTOUR HEDGEROW AND NVS SYSTEMS

The deposition of eroded material from the upper parts of the interstrip areas (alleys), mainly caused by tillage operations, facilitates the often rapid formation of natural terraces. The levelling effect of terrace formation is claimed to be one of the major benefits of vegetative contour strips, because it improves water retention in the field, reduces the loss of applied nutrients and makes land preparation easier. But it also often causes a drastic depletion of the fertility of the upper parts of the alleys, a scouring–deposition effect. A more favourable crop environment occurs immediately above the grass strip or tree hedgerow, as opposed to immediately below it.

Typically, the crop yield trend across the alleyway is associated with a decline in soil organic matter, nitrogen, and phosphorus and calcium contents in the upper alley zones. This raises serious concerns about the sustainability of the contour hedgerow concept. With time, the scouring effect will dissipate as the terrace surface stabilizes and more organic matter can be retained in the surface soil in the upper zones of the alley. However, it is not known how long this process will take on different sites and under different management regimes. In the study area, contour grass strip systems that had been established 8 years before still exhibited a skewed distribution of crop yield, with lower plant height and yield on the upper part of each alley.

The overall aim of our on-farm research is to improve permanent crop production systems based on contour grass and natural vegetative strips on sloping lands, and to extrapolate our results to a wider range of management options and environments. A central focus is to identify and build upon indigenous practices that cope with the scouring of soil fertility and other potential constraints of the technology.

We are currently identifying improved soil management techniques that can avoid or reduce interstrip soil degradation or ameliorate its effect.

We are building on farmers' strategies in participatory on-farm experimentation, and we are reexamining the competition between strip species and associated crops, as well as the labour that must be invested to establish and maintain natural vegetative strips.

FARMER PERCEPTIONS OF TECHNOLOGICAL CONSTRAINTS WITH NVS AND FODDER GRASS STRIPS

An interview survey was conducted during June and September 1995 among 30 farmers who had established NVS or fodder grass strips on their farms at least 1 year previously and who have adopted the system. Neighbours of these contour farmers were also interviewed to identify why they did not adopt NVS, grass strips or similar conservation techniques. The objectives of the survey were to assess farmers' experience with grass or natural vegetative filter strips for soil conservation on sloping land. There was special focus on the effects of scouring of the soil fertility—that is, the development of a fertility gradient across alleys caused by soil erosion. The study aimed both at evaluating the importance of developing alternative soil management techniques and at identifying farmers' ideas and methods in dealing with the scouring effect. These ideas and methods were used as starting points for present and future research and for developing strategies to ameliorate or avoid the scouring effect.

The study showed that most farmers who adopted the technique valued the contour grass-strip or NVS technology as the single most effective method to conserve their soil and to ease land preparation on sloping lands. They believed the land value of contoured fields to be higher, solely because of the fact that they are protected by the soil conservation technology. More than 50% of the farmers estimated the value of land with contour strips to be 1.5 times the value it would have had without them. They felt that their investment spent on the buffer strip system, which included establishment, maintenance (pruning 2 to 3 times per cropping), and biased fertilizer application, paid off in higher (maize) crop yield and easier land preparation some years after contouring. In the case of planted grasses, the payoff was immediate through the provision of animal fodder. The main reason farmers did not extend their area or that others did not use the technique on their sloping fields was the lack of time to establish and maintain the system.

Although more than half the farmers said yes when asked if NVS or grass strips caused more weed infestation on the alleys, none claimed this was a problem, because they control weeds in maize by 2 interrow cultivations, done by animal-drawn plough 15 and 30 days after emergence.

Most contour farmers observed that upper alleyway scouring caused by water runoff and tillage operations adversely affected plant height and crop yield on the upper part of each alley. Farmers could see that 3 to 4 rows of maize below each contour strip were reduced in plant height and their grain yield was lower. Collected data confirmed that maize yield on the upper zones of a single alleyway was significantly lower than that from lower zones (see also fig. 13). Over the landscape, alleys at the upper slope proved to be less productive than those on the lower, more fertile slope positions.

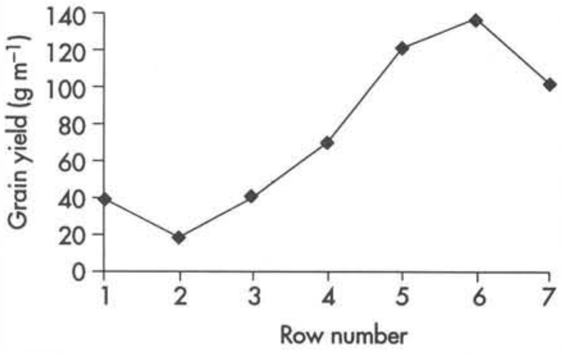


Figure 13. Typical maize grain yield per linear metre across a single alleyway under farmer management (low fertilizer inputs, that is, less than 50% of the recommended rate) on an acid upland soil (mean of 3 replications, 1st crop 1995, Claveria, Philippines).

Scouring was generally believed to be a transitory phenomenon, affecting crop performance during the first 3 to 5 years after establishment. However, scouring was not usually perceived to be a serious constraint to contour farming in the study area. Many farmers have their own strategies in dealing with the effect: application of up to 2 times more nutrient inputs (mostly mineral fertilizers) on the upper 3 to 4 rows or the upper half of the alleys. But even with scouring, farmers generally observed the overall yield on the contoured fields to increase over time. Farmers who did not adopt the technology observed scouring of the whole slope and claimed that higher fertilizer inputs were needed to improve yield on degraded upper slopes.

The study concluded that the buffer strip technology would more likely be adopted if further improvements in soil management could increase total crop yield from contoured fields. These improvements include making better use of strip cuttings (as mulch or green manure) and crop residues, and using farmers' strategies, such as biased nutrient application, bund scraping (weeding of lower bund side) and ploughing close to the strips to improve crop performance on the degraded rows directly below the strips. The promotion of grass strips or NVS as a base for planting fruit and timber trees, a frequently observed practice in the area, can help make more productive use of the NVS and further improve the adoptability of the technique. From the 2nd cropping in 1995, newly derived ideas for soil management have been used as the basis for newly established on-farm trials in Claveria to verify scientifically these farmer observations.

MAKING CONTOUR HEDGEROWS: THE COW'S BACK METHOD

The labour investment in establishing and maintaining the contour lines remains a major constraint to the adoption of hedgerow technology. The conventional approach for establishing contour lines has been by using an A-frame or a water hose.

A farmer cooperator recently shared with us a provocative alternative method—elegantly simple and eminently practical. He found that by carefully observing the backbone of the cow as he walked behind it guiding his mouldboard plough, he could maintain a reasonable trajectory in ploughing a furrow on the contour (fig. 14). As the cow walked along on the contour,

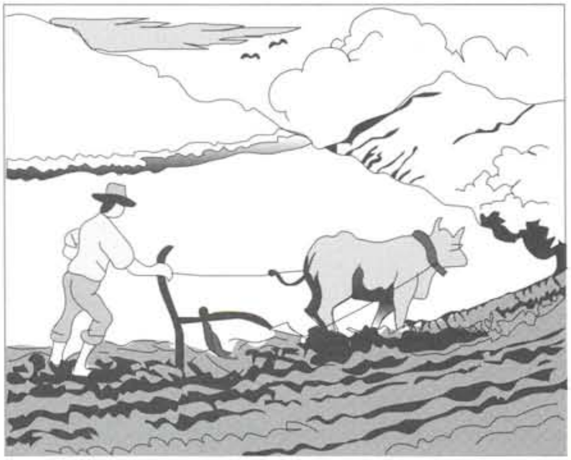


Figure 14. The 'cow's back' method for laying out contour lines promises to make this operation more convenient and lower in cost than any method has been before—a major advantage in accelerating the adoption of contour hedgerow systems in Southeast Asia.

the backbone profile remained parallel to the ground. If the cow's head was observed to be higher than the backline, the cow was moving upslope and off contour. If its tailbone was observed to be higher than the head, it was moving downslope and off the contour.

We investigated the accuracy of this farmer's practice in establishing contour lines on the slope and compared the relative labour cost of the technique against 2 other methods (the A-frame, and the hose-pipe).

A field 75 m in length with approximately 20% slope was used to establish a number of contour lines using the 3 different methods: the 'classical' A-frame technique, the supposedly more accurate hose-pipe method, and the extremely cost-effective technique of observing and maintaining level the back of the cow while laying out lines across the slope with the plough during 1st land preparation. The time taken for marking the contour lines was recorded for each of the 3 techniques, and at the end of the 75-m field the vertical distance between the lines marked with the cow's-back method and those marked with the A-frame was measured against the more accurate lines established by using the hose-pipe. Three replications of the test were made. The experiment was conducted in collaboration with scientists at the Misamis State College of Agriculture and Technology in Claveria. The cow's back method was tested twice again during farmer training sessions in Lantapan (Bukidnon) and Claveria.

The cow's back method was clearly the most time-efficient way of laying out contour lines. It did not involve any significant labour cost because passing the plough once back and forth along the contour is just part of the usual land preparation process. The hose-pipe method took the longest time to lay out the contour lines.

The A-frame and the hose-pipe methods were similar in accuracy. If the A-frame is calibrated well it is a very accurate tool. The hose-pipe proved to be tedious in levelling out the contour line, and it requires some skill and practice. All 3 contour lines established with the cow's back method went off the contour, going down at an angle of 1 to 2% (vertical interval of 1.0 to 2.5 m after 100 m length). The difference between real and marked contour lines was not visible until after the real contour had been laid out with the hose-pipe (the 'control method'). An angle of

1–2% for contour bunds is judged fully acceptable, because water infiltrates at the contour strips; it does not drain to the side of the field.

Experience with the A-frame and the cow's back method during the farmer-to-farmer training programmes conducted in Bukidnon and Claveria in March and April were very similar.

Each of the 3 tested techniques to lay out contour lines has its preferential use, depending on a farmer's need to establish contour lines either as accurately as possible, or as fast as possible with less precision. Clearly, the use of the A-frame is preferable to the hose-pipe, since it requires less skill and no purchase of materials, while maintaining a relatively high accuracy. The cow's back method is less accurate, and it also requires some practice. However, it has reasonable precision and is definitely much more exact than eyeballing the contour. Thus its use can greatly increase the adoptability of contour hedgerow and NVS techniques because contours can be established conveniently at no extra cost.

RIDGE TILLAGE SYSTEM FOR ANIMAL-DRAUGHT FARMING

We have been searching for practical ways to avoid scouring in hedgerow systems by preventing the movement of soil downslope. We examined the principle of permanent-ridge tillage as practised in the United States: maintaining alternate strips of untilled and tilled land in a row-cropped field. The untilled strip (the ridge) is where the crop is planted in exactly the same row position in each successive season; the interrow strip is tilled, controlling weeds and hilling up to rebuild the ridges (fig. 15). As adapted to animal-powered systems, the sequence of operations is to make a shallow furrow through the stubble of the previous crop and plant in the same row; cultivate the crop with the mouldboard plough, usually by burying weeds between the rows, at about 14 days after emergence, and hilling up at about 28 days after emergence to create the ridges; after harvest, replant the next crop through the stubble in the same rows as the previous one, without any ploughing or harrowing operations. If there is considerable weed growth on the ridges, band-spray a broad-spectrum systemic herbicide

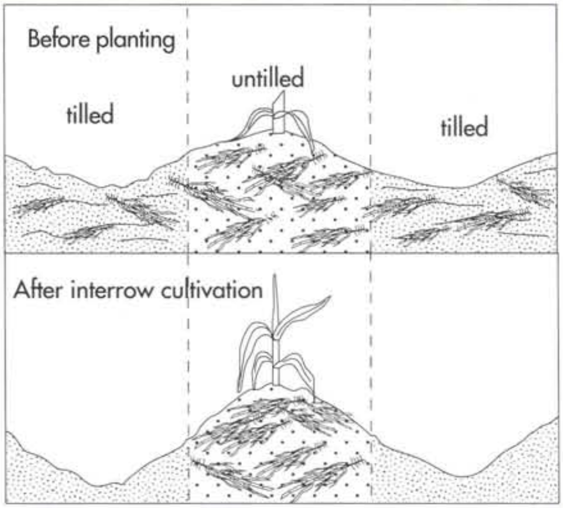


Figure 15. In ridge-till farming each successive crop is planted in the same row location as the previous one. Since the land is not ploughed, and only interrow cultivation is practised during crop growth, a zone of non-tilled soil alternates with tilled interrow spaces. This system reduces soil loss and soil creep downslope.

(usually glyphosate is preferred) on the ridges to eliminate early weed competition. Interrow cultivation controls weeds in the interrow area and rebuilds the ridges.

The ridge-till field differs little in appearance from a conventional row-crop field. The ridges are but slightly more pronounced than those in conventional hilled-up maize. They tend to slump during and between crops. At planting the ridges may be only slightly elevated above the base level of the interrow furrows.

Then, what are the hypothesized advantages of such a system? First, many studies in the US have shown that the permanent ridge system dramatically reduces soil loss. The ridges may act as a partial barrier to the surface flow of water, but their major distinction is that they act as a zone of greater infiltration. The no-tillage area tends to accumulate organic matter and macropores caused by soil biological activity and root channels. Since primary and secondary tillage operations are not practised for land preparation between crops, the land is less subject to erosion in the off season. Second, labour and expense in land preparation are eliminated. Preplanting weed control is accomplished by judicious use of a herbicide.

We recently completed a 4-year study of permanent-ridge till systems on 2 farmers' fields in Claveria Philippines. The soils were very fine kaolinitic clays classified as Lithic and Rhodic Hapludox, with strongly acidic surface soils (pH of 4.1–4.4) and organic carbon contents of 1.6%. The conventional cropping system in this area is 2 crops of maize per year. Most cropland has slopes in the range of 10 to 60%. Annual rainfall is about 2000 mm. Farmers plough and harrow twice to prepare the land for each crop using a single draught animal and a mouldboard plough. Planting is done by hand in furrows made with the plough point. Seeds, usually single-cross hybrids, are dibbled in the furrow and covered by foot. Interrow cultivation is also done with the same mouldboard plough. We used the same local equipment for the permanent-ridge till system.

In conventional maize production in Claveria, farmers generally plant more or less on the contour. We compared the conventional system with ridge tillage and with natural vegetative strips (NVS) laid out at an 8-m distance from each other, a difference of 1.5 m in vertical drop. The 4th treatment was a combination of ridge tillage in the alleyways between natural vegetative strips. Hybrid maize was produced in all treatments in rows spaced 60 cm apart.

The slopes of the on-farm experiments were 14% at Patrocinio village and 20% in Anei. Ridge tillage reduced soil loss by 49% in Patrocinio, and 58% in Anei (table11). Natural vegetative strips reduced soil loss even more: 97% in Patrocinio and 90% in Anei. When the 2 conservation tillage systems were combined, soil loss was 0.3 t ha^{-1} in Anei, 1.1 t ha^{-1} in Patrocinio. Clearly, both systems were effective in dramatically reducing erosion. When combined they proved exceedingly effective.

The permanent ridges in the ridge-till treatments had infiltration rates of 49 cm hr^{-1}, 30% higher than in the rows of the conventional treatment. Infiltration rates were also high for the zone just above the natural grass strips (59 cm hr^{-1}). The high infiltration rates reduced runoff from row to

Table 11. Water- and tillage-induced soil erosion as affected by soil-management systems in Claveria, Misamis Oriental, Philippines

Soil-management system	1993	1994	1995	Mean
	Anei site (soil loss t ha^{-1})			
Contour ploughing	26.7	26.1	17.1	23.4a
Ridge tillage	9.9	12.5	7.1	9.8b
Natural vegetative strip	2.2	1.8	2.5	2.2c
Ridge tillage + natural vegetative strip	1.2	1.0	1.2	1.1c
Bare	0.0	75.2	95.7	85.5
	Patrocinio site (soil loss t ha^{-1})			
Contour ploughing	6.0	10.0	5.7	7.2a
Ridge tillage	3.3	5.1	2.7	3.7b
Natural vegetative strip	0.3	0.3	0.1	0.2c
Ridge tillage + natural vegetative strip	0.4	0.3	0.1	0.3c

row in the ridge-till system and reduced runoff through the grass barriers in the NVS. It has been demonstrated that the infiltration rate in the vicinity of contour hedgerows is the major factor explaining the exceptional ability of contour hedgerows systems to reduce runoff and off-field soil losses.

Mean grain yields of 6 crops over the 3-year period were the same for the conventional contour ploughing and the ridge-till systems (3.9 t ha^{-1} and 3.8 t ha^{-1}, difference non-significant). The grass strips occupied 12.6% of the field area. This resulted in grain yields that were about 10% lower than those for the contour ploughing system or the ridge-till system alone (table 12). Thus, ridge tillage maintained maize yields, although it drastically reduced the amount of labour invested in tillage and weed control. It was not as effective as NVS in erosion control, but it did not cost the farmer any penalty in crop yield.

Did permanent-ridge tillage reduce downslope soil scouring from the upper alleyways to the lower alleyways? This was the issue that first prompted our interest in adapting this unique tillage system to animal-powered farming systems. Our measurements on tillage-induced soil movement within the treatments are being analysed. However, preliminary examination of the data suggests that ridge tillage did indeed dramatically slow down the downslope movement of soil across the alleyways. This would slow the rate at which topsoil is removed from the upper alleyways and deposited above the grass strip downslope. The practice, therefore, appears promising. It could be the most effective way to manage contour hedgerow systems on land with quite shallow soils, such as in areas where the topsoil is often only 20–30 cm deep over limestone rock, as in some parts of Southeast Asia. Under these conditions the scouring effect can be devastating to long-term crop production if hedgerows are installed.

Weed control is the key challenge in converting to a permanent-ridge till system. In superimposed

Table 12. Maize grain yield as affected by soil-management systems in Claveria, Philippines

Soil-management system	1993 crop season		1994 crop season		1995 crop season		Mean
	1st	2nd	1st	2nd	1st	2nd	
Anei site (grain yield t ha^{-1})							
Contour ploughing	4.4	3.0	4.4	2.1	2.8	4.0	3.8
Ridge tillage	5.5	2.8	4.5	1.6	2.8	4.0	3.5
Natural grass strip	4.4	2.7	3.8	1.9	2.6	3.6	3.4
Ridge tillage + natural grass strip	4.0	2.6	3.8	1.4	2.5	4.1	3.1
Patrocinio site (grain yield t ha^{-1})							
Contour ploughing	5.6	3.8	5.0	2.8	3.4	3.7	4.1
Ridge tillage	5.4	3.7	5.2	3.0	3.3	4.5	4.2
Natural grass strip	4.9	3.6	5.6	2.7	3.0	3.4	3.7
Ridge tillage + natural grass strip	5.2	3.4	4.4	2.8	3.1	4.1	3.8

trials we tested various methods of weed management that compared the use of glyphosate with non-herbicidal alternatives. In this humid, tropical environment the potential is profound for weeds to regrow in the period between wet-season crops and during the dry season. We found that the only practical way to plant on permanent ridges without prior tillage was to use glyphosate herbicide before planting.

In future will small-scale farmers adopt herbicides as part of their crop production system? No one knows the answer, but it is clear that many already are using them. Many farmers in Claveria now use glyphosate and other herbicides for specific applications to complement their animal-powered weed management, especially where it reduces manual labour. Our studies in Indonesia have shown that many upland farmers are using glyphosate in opening land that has been in grass fallow. As discussed above, even villages of shifting cultivators are integrating herbicides into their crop production system to expand the potential to use *Imperata cylindrica*-infested land, and to save labour in cultivation. The cost of labour relative to other production factors is expected to continue to increase. Therefore, it is quite likely that upland farmers will increase their use of herbicides in the coming decade. Such a trend would parallel the experience in wetland rice in the Philippines, where herbicide use was unknown in the early 1970s but was ubiquitous by the late 1980s.

TREE–SOIL–CROP INTERACTIONS

WANULCAS MODEL

Substantial improvements were made in the WANULCAS (water, nutrient and light capture in agroforestry systems) model developed for integrating tree–soil–crop interactions (see ICRAF 1995 annual report p 179–180). The model can now be linked to external files for input of climate data and has been expanded to cover different spatial zones of tree–crop interactions (fig. 16). The 1st zone near the trees involves above-ground as well as below-ground interactions; the other zones involve only below-ground interactions, but with different tree–root length densities. The model can now be used not only for hedgerow intercropping and improved fallow systems, but also for systems where the tree canopy and interaction zones change over time, such as in taungya or boundary planting systems with a linear geometry. On the basis of nearest-neighbour distances, the model can also be used as a 1st approximation to the tree–crop interactions in parkland systems with irregularly distributed trees.

The expanded model can now serve as a unifying framework for a wide range of agroforestry systems, as it relates below-ground competition and complementarity to growth of crop and tree for a wide range of rainfall regimes. Furthermore, recycling of nutrients through organic residues and redistribution of topsoil on sloping lands to account for erosion and sedimentation processes can now be evaluated for a wide range of systems. The model also allows for an evaluation of lateral resource capture by shallow tree roots extending horizontally a long way from the tree.

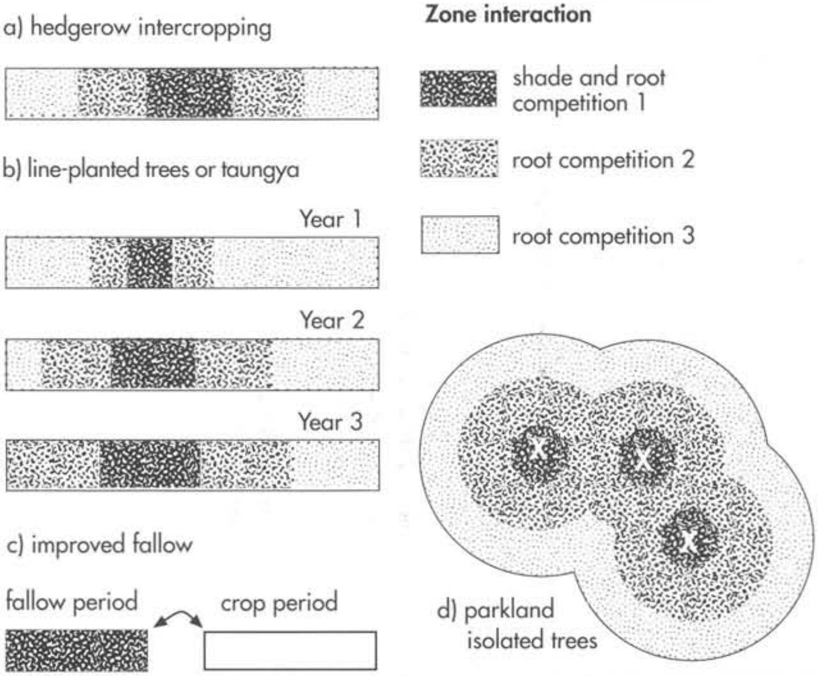


Figure 16. Tree–crop interaction zones in agroforestry systems and their representation in the WANULCAS (water, nutrient and light capture in agroforestry systems) model. The model user specifies root distribution and tree canopy size, which together determine the intensity of competition in each zone, day by day.

NITROGEN AND PHOSPHORUS MINERALIZATION

In recent years considerable progress has been made in fractionating soil organic matter (SOM) into pools with different dynamic behaviour (see

ICRAF annual report 1995 p 175–177), with relevance to crop growth (see ICRAF annual report 1995 p 83–86). A direct test of the functional role of the SOM fractions can be obtained by incubating them under standardized conditions and measuring their nutrient mineralization. Such a test is not without problems, as the medium used to fractionate the soil, or even the mere separation of organic matter from mineral particles, may have a major effect on the properties of the fractions. Despite these caveats affecting the absolute values of the results, incubating fractions obtained from a range of land-management systems can clarify whether the fractions have similar properties across the systems. Data on N mineralization revealed that the differences between the fractions were smaller than the differences between the land-management systems. Knowing the fraction size or its N content is not enough to allow the prediction of the N mineralization in the incubation study. For P, however, the SOM fractions clearly differed in their mineralization pattern; fractionation of SOM may thus contribute to a prediction of P supply to crops. The mineralization from the sand-sized light fraction (ludox-light) was clearly greatest when expressed per gram of fraction dry weight (fig. 17). This result is in agreement with results on a good correlation of light fraction pool size and P-limited maize growth in western Kenya (see ICRAF annual report 1995 p 69–70).

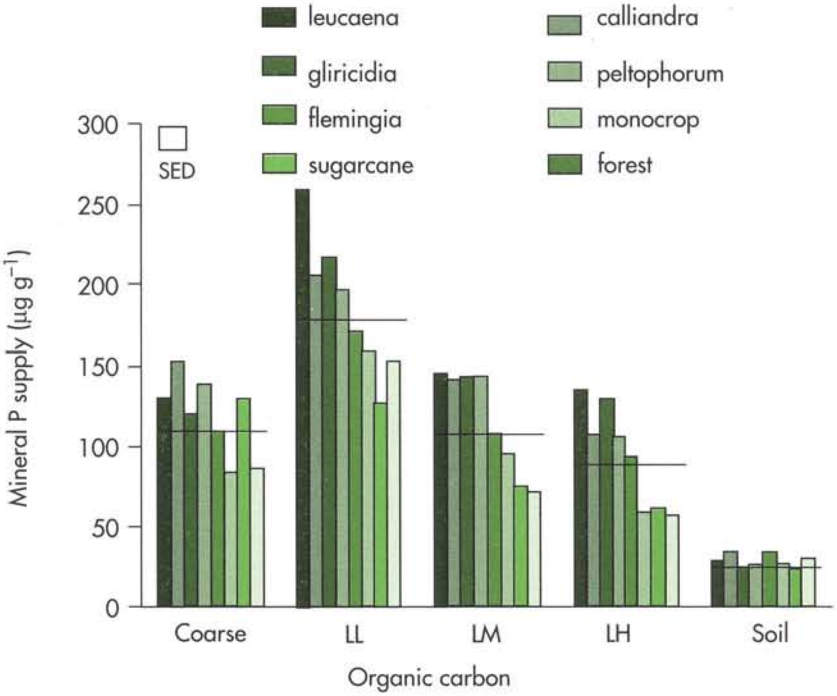


Figure 17. Release of inorganic P during a 70-day incubation period of 4 macroorganic matter fractions (coarse litter and ludox light (LL), medium (LM) and heavy (LH)) and unfractionated soil from the top 15 cm of a long-term hedgerow intercropping experiment with different tree species and neighbouring land under sugarcane or forest (data from North Lampung, Indonesia, in cooperation with Brawijaya University, Malang). The average across land-use systems for each soil macroorganic matter fraction is indicated by the horizontal line.

CARBON BALANCE OF SHIFTING CULTIVATION AND FALLOW ROTATION SYSTEMS

Two basic approaches are possible to assess the effects of changes in land use and land cover on global carbon budgets and on net emissions of specific greenhouse gases. One is based on measuring fluxes (flows) and the other on stocks (pools). In theory, the 2 approaches should give the same results, and the choice of approach may be based on convenience and availability of data. In practice, however, considerable inconsistencies are likely to exist in the current patchwork of flux- and stock-based approaches to various subsectors of the global carbon economy. The inventory methods used by the International Panel on Climate Change do not yet have a consistent approach to deal with shifting cultivation and fallow rotation systems. As a 1st approach, a method was developed that assumes a linear carbon accumulation rate during the fallow period (fig. 18).

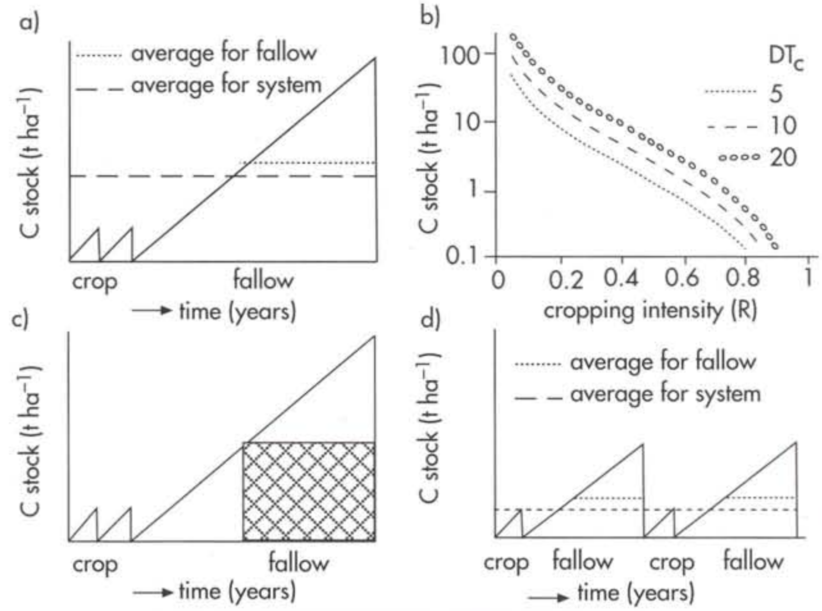


Figure 18. Schematics showing a) the development of the carbon stock per unit of land during the cropping and the fallow phases of a shifting cultivation or fallow rotation system; b) average carbon stock as a function of cropping intensity (R), based on equation 2, in which D = linear carbon accumulation rate of fallow vegetation and T_c = average duration of cropping (see text); c) carbon stock during a crop–fallow cycle; and d) carbon stock during a crop–fallow cycle with the same crop: fallow ratio as in c but a different cropping period. The hatched area in c) represents the increased average lifetime of carbon sequestered in the early part of the fallow phase, which causes the difference between c) and d) in time-averaged C stock.

Conventionally, shifting cultivation and fallow rotation systems are often characterized by a cropping intensity *(R)*:

$$R = \frac{T_c}{T_r} = \frac{A_c}{A_r} \qquad \text{[eq. 1]}$$

where

A_c = area cropped in year of observation (ha)
A_r = total area under shifting cultivation rotation = $A_c + A_f$ (ha)
T_c = average duration of cropping stage (yr)
T_r = total cycle length of fallow rotation = $T_c + T_f$ (yr)

Land-use practices with *R* values below 0.33 are conventionally classified as 'shifting cultivation',

R values between 0.33 and 0.66 as 'fallow rotations' and R values above 0.66 as 'permanent cultivation'.

If we can assume that the average carbon stock in the cropping period (C_c) is negligible, the time-averaged carbon stock (C_r) of a shifting cultivation or fallow rotation system can be expressed as a function of R, D and T_c:

$$C_r = \frac{C_f \; A_f + C_c \, A_c}{A_f + A_c} = \frac{D \, T_c \; (1 - R)}{2R} \qquad \text{[eq. 2]}$$

where

A_f = area fallowed in year of observation (ha)

C_c = carbon stock in crop, averaged over cropping period (t C ha^{-1})

C_f = carbon stock in fallow, averaged over fallow period (t C ha^{-1})

C_m = carbon stock in fallow vegetation at time of clearing (t C ha^{-1})

D = linear carbon accumulation rate of fallow vegetation (t C ha^{-1} yr^{-1})

Equation 2 shows that the carbon stock not only depends on the relative cropping intensity (R) but also on the absolute length of the cropping period (T_c). Figure 18 shows how the average carbon stock decreases, approximately with the inverse of R (note the logarithmic scale of the Y axis). The increase of the carbon stock with increasing cropping period, at constant R, may be counterintuitive, but it can be understood from figure 18. The increase can be attributed to the cross-hatched area, which represents the increased average lifetime of carbon sequestered in the early part of the fallow phase. While the carbon fluxes are the same in situations illustrated in figure 18, the average carbon stocks differ.

Improved fallow systems may reduce the fallow length by increasing the biomass accumulation rate during the fallow period. We can compare systems 1 and 2 with different carbon accumulation rates D_1 and D_2, respectively, but with an equal biomass at the time the fallow land is cleared for cultivation. An increase in D allows for a proportional increase in cropping intensity R:

$$R_2 = R_1 \, \frac{D_2}{D_1} \qquad \text{[eq. 3]}$$

From equation 2, we can now evaluate the effect of improved fallows on the average carbon stock, if the length of a cropping phase, T_c, remains constant and the possible intensification of cropping is fully used, by increments in R:

$$C_{r2} = \frac{D \;\, T_c \, (1 - R_2)^2}{2R_2} = C_{r1} \frac{(1 - R_1 \; (D_2/D_1))^2}{(1 - R_1)^2} \quad \text{[eq. 4]}$$

If $D_2 > D_1$, we can see that $C_{r2} < C_{r1}$, so the average carbon stock will decrease, despite the increased rate of carbon sequestration during the fallow phase.

This conclusion may again be counterintuitive, as it is easy to get carried away by the idea of faster carbon sequestration during the improved fallow period. But when we consider the system as a whole, the more rapid carbon sequestration during the fallow will be more than counterbalanced by a reduction in fallow length, if farmers see fallows mainly as a method of restoring soil fertility for subsequent cropping. Thus the production objective of farmers may go against that of carbon sequestration, as long as food production is the major aim of land management. If cropping intensity does not change, carbon sequestration will increase with an increase in *D,* but effects on increased food production will be small.

Where fallow systems have evolved into long-rotation and productive tree systems (such as the jungle rubber in Sumatra), carbon sequestration will increase considerably, with equal or greater financial returns to the farmer. Boundary plantings of trees are likely to be much more effective in increasing carbon sequestration than improved fallows.

PEST MANAGEMENT

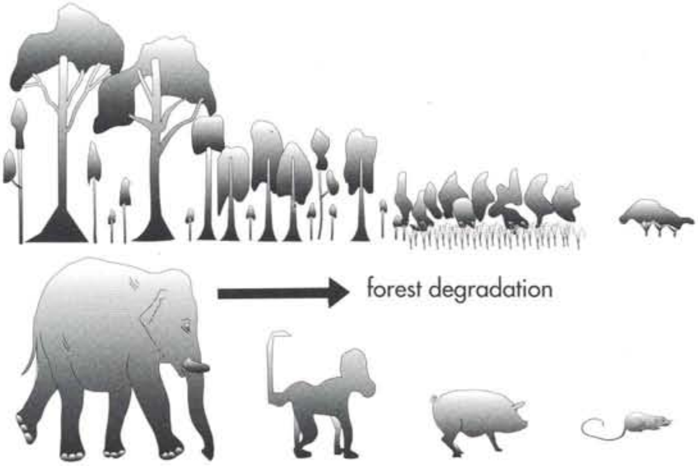


Figure 19. Succession of vertebrate pest problems from the forest margin to degraded farm lands in Sumatra, Indonesia.

Surveys of farmer perceptions about their major problems in the humid forest zone normally put vertebrate pests (wild pigs, monkeys, rats) high on the list. Yet, soil fertility aspects appear to get much more research attention than do vertebrate pests. In cooperation with Wye College (UK) a study has been initiated of vertebrate pest problems in North Lampung (an ASB benchmark area) and in Jambi. The hypothesis tested was that with increasing distance to the forest margin, problems of vertebrate pests shift from elephants, to wild pigs and monkeys, to rats, but that the problems do not decline with decreasing size of the animals (fig. 19). The shift in problems is a result of the diminishing habitat for forest species and probably a decrease in biological control (by tigers, small cats, snakes). For farmers in North Lampung attempting to grow rice, rat damage is the major problem. They consider any soil management by mulching unacceptable; as the mulch may protect the rats from predators, it may increase damage that the rats do. They also note that despite the benefits of surface mulch, they have to keep the soil surface clean to manage the rat problem. Systems based on tree crops do not suffer from rat damage and are generally seen as more appropriate for farmers who can afford to bridge the early unproductive period of tree crops.

The wild pig problem, which has a strong cultural dimension in Muslim communities, brought out an interesting difference between Lampung and Jambi. In both areas, rubber is planted and pigs are abundant; but pig damage to young rubber is a major concern in Jambi while in Lampung it is not. The main reason for this difference appears to be that in Lampung, young rubber is intercropped with cassava, which is apparently more attractive to the pigs, while in Jambi cassava is not grown, and fencing is the only pest control option that farmers use.

In Jambi, leaf-eating monkeys (*Presbytis melalophos nobilis*, locally known as 'simpai') damage young rubber trees and are not excluded by fences. They are a major problem. An inventory was made of possible control options, ranging from site factors (for example, distance to forest edge) and strategic control options (for example, interplanting with repellants or alternative food sources) to tactical control (for example, staying in the field to guard the trees). The physical damage appears to be unaffected by the change from locally selected (seedlings) to improved germplasm (rubber clones). Farmer tolerance of the damage, however, decreased considerably, because the improved planting material is more expensive. It is planted at final density (not to be thinned), while the cheaper, locally obtained seedlings are planted at higher densities and are later thinned. Monkey damage may be one of the reasons why the current farmer-developed jungle-rubber agroforests are so well adapted to the local environment. The introduction of 'domesticated' tree germplasm is therefore not as straightforward as it might appear at first sight.

The monkeys should be recognized as an important part of the ecosystem, and they must be taken into account in the intensification of rubber agroforestry on the forest margins. A simple model of this interaction between monkeys and rubber trees suggests that trees that have been damaged once are likely to be damaged repeatedly, because their regrowth forms an attractive food for monkeys, while the undamaged trees will have grown beyond their most sensitive stage.

CONTROLLING IMPERATA WITH SHADE

Imperata cylindrica is a widespread fallow species in Southeast Asia, but it is also a major weed. It can be devastating to early stages of tree-based production systems because of a combination of factors: competition for water and nutrients, allelopathic effects and increased risk of dry-season fires. Imperata can be controlled by soil tillage, herbicides and shading. However, a review of the literature reveals little quantitative information on the duration and intensity of the shade that is required for adequate control. A simple experiment was, therefore, initiated with shade cloth of different light interception levels (0, 55, 75, 88%). Shading effects on growth of standing biomass were measured at monthly intervals (fig. 20), and on regrowth 3 months after harvesting. Light interception of 55% had hardly any effect on regrowth, and for effective control of regrowth, 88% interception was needed for at least 2 months. In cooperation with Groningen University (the Netherlands), ICRAF is analysing the sugar content of the rhizomes to test the hypothesis that depletion of readily available carbohydrate resources in below-ground storage organs is the main mechanism determining the control of regrowth by shading.

These data explain why imperata infestation is so problematic in young rubber and other tree crops. In the 1st few years, food crops can be intercropped but by the time shading has reached a 55% level, food crops such as maize will no longer give satisfactory yields. Sufficient imperata control is not achieved until canopy closure produces 90% shade, which usually takes a few more

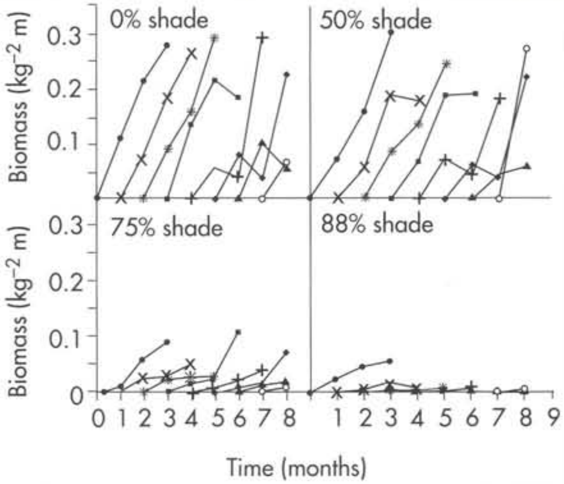


Figure 20. Above-ground biomass of Imperata cylindrica *regrowing after different durations of 4 levels of shading (0, 55, 75 and 88%), in North Lampung, Indonesia. The various symbols refer to series, where biomass was removed and regrowth started after different durations of shade as can be seen from the intercept of each line with the X axis.*

years. However, this 'window of opportunity' for controlling imperata is as vulnerable to fire in the dry season as imperata itself.

LAND-USE TRANSITIONS IN HILL ZONE WATERSHEDS, NORTHERN THAILAND

ICRAF research sites in North Thailand are selected to represent areas of the Montane Mainland Southeast Asia ecoregion where traditional land-use systems, many with major shifting cultivation components, are under heavy stress and associated with poverty, growing conflict and environmental degradation. Major factors influencing land-use change include 1) population growth and migration, 2) expanding transportation and communications systems, 3) opium crop-substitution programmes, 4) increasing economic and social integration of formerly remote rural areas and ethnic minority communities, 5) increasing national concern about watershed deterioration and deforestation, and 6) growing influence of local and national environmental movements. While these trends are of growing relevance in all countries of the ecoregion, their convergence and high degree of influence in North Thailand present an excellent opportunity to explore potential roles for agroforestry in helping to reduce rural poverty, manage conflict and increase the sustainability of natural resource management.

Since broad approaches to landscape management within a watershed context are particularly important in this ecoregion, our primary site in North Thailand is the Mae Chaem watershed, an area of nearly 4000 km^2 where prevailing conditions reflect these influences. As in many other areas of the ecoregion, major traditional land-use systems correspond with 3 ecological zones most easily distinguished by ethnic groupings and altitudinal boundaries:

Lowland zone (valley floor--700 m). Traditional land use is dominated by paddy rice and homegardens cultivated by ethnic Northern Thai communities. Economic integration has brought commercial vegetable and soybean production in paddies, expansion of upland soybeans up slopes into forest lands and increased opportunities for off-farm employment.

Middle zone (~600–1200 m). Traditional land use by Karen ethnic minority communities employs a composite shifting cultivation system that includes pockets of paddy rice, supplemented by short cropping, long forest fallow rotational shifting cultivation of upland rice, and other managed landscape elements such as protected watershed forest. Population growth and encroachment by lowland and highland communities have resulted in shorter fallow periods, decreased productivity and deterioration of protected forest areas. Infrastructure and economic integration have added new cash crop and off-farm opportunities, while national park and protected watershed zones have reduced the area of available land, leading to recent conversion by some communities to fixed-field rice–soybean rotations.

Highland zone (~1000–1800 m). Traditional land use by Hmong ethnic minority communities was dominated by long cropping, shifting cultivation with an opium component and very long forest fallow (abandonment). Infrastructure, opium crop-substitution, economic integration and population pressure have transformed this system, which now centres on intensive commercial vegetable production on steep slopes. Loss of forest cover, soil erosion and heavy pesticide use in watershed headlands are major concerns of the downstream society.

Although very little systematic data are available on how these changes are affecting local livelihoods, agronomic sustainability or environmental conditions, pilot projects have begun to develop approaches for addressing issues and conflicts associated with changing land-use practices in these zones. One of the most promising of these is the Sam Mun Project, located in the Mae Taeng subwatershed, ICRAF's secondary research site in North Thailand. Working closely with university researchers and other agencies, forestry officers built on previous studies and experience in developing the project's participatory land-use planning approach. Results have led to an agroforestry system that is a community watershed mosaic, in which shifting cultivation is replaced by fixed-field cultivation and communities cooperate in managing all landscape components in local watersheds. Although expanded tree crop and forest components are still young, management systems and further improvements are continuing after the end of support from the UN Fund for Drug Abuse Control and the Ford Foundation. Key elements of this approach are now being further adapted and tested in Mae Chaem under 2 projects: a government project under the patronage of Queen Sirikit, and a CARE-Thailand project funded by Danish Cooperation for Environment and Development. Despite such progress, support for widespread expansion of the approach is limited by lack of data on expected overall impacts on rural poverty and sustainable natural resource management.

Thus, ICRAF's research programme aims at understanding 1) land-use dynamics and livelihood patterns in Mae Chaem and how they are changing, 2) potential roles for improved agroforestry systems and their impacts on rural poverty, land-use patterns and environmental conditions (deforestation, watershed functions, biodiversity and greenhouse gas emissions), and 3) policies that may facilitate or constrain their expansion. Working in close collaboration with key local partners—the Royal Forest Department, Chiang Mai University, the Queen Sirikit forest development project and CARE-Thailand—and through links with various other local and international research programmes, activities initiated this year are beginning to provide the basic building blocks for analyses at the watershed level to answer 'what if' questions related to alternative policies and development programmes:

- Construction of a spatial database of the entire Mae Chaem watershed, beginning with a detailed digital elevation model and plans for its expansion to include 1) available data on geology and soils, 2) changes in land-use patterns, based on remote-sensing analyses conducted under the global Land Use and Cover Change project, 3) village locations, market centres, infrastructure and administrative boundaries, 4) links with demographic, socioeconomic, agricultural production and climatic time series data available from government agencies and NGOs.
- Survey of sites for detailed field research on major current land-use systems and promising agroforestry improvements, nested within the watershed or at selected sites where promising improvements are more mature, and designed to facilitate the scaling-up of findings through links with spatial data available for the entire watershed. Initial studies focusing on the economic and financial profitability of these practices in the context of local livelihood systems are being launched through a training workshop in June 1997, and further studies are being planned to examine their agronomic sustainability and environmental externalities.
- Additional studies are being developed to 1) review policies and previous experience related to land and tree tenure institutions and community management of natural resources, 2) assess the influence of transportation infrastructure and germplasm distribution systems, and 3) examine effects of trade and macroeconomic policies on local land-use systems.

Although initiation of field research activities in North Thailand has been delayed because of the limited availability of funding, a new grant from the Asian Development Bank to support policy research in Indonesia, Thailand and the Philippines is expected to allow further development and expansion of field research in North Thailand during 1997.

CAPACITY BUILDING

Efforts were made to strengthen the relationship between ICRAF and colleges and universities in the region. A number of students at all levels—undergraduate, MSc and PhD—participated in research activities in Southeast Asia. These students were from Brawijaya University and the Institut Pertanian Bogor in Indonesia and the University of the Philippines. Several students from universities in Europe and the United States were also involved, supported by their own funding. Participants from the region attended the ICRAF experimental design course given in Nairobi (see p 276–278) and a training course, 'Ecosystem modelling tools for the analysis of impacts of global change on sustainable management of tropical forests', given in Bogor by ICSEA/Biotrop. An informal workshop, 'Soil biodiversity research planning for the Alternatives to Slash-and-Burn Programme', was also held in Lampung, Indonesia, 26–30 August.

TO SUM UP . . .

To sum up, 1996 was a watershed year in the Southeast Asia regional programme in applying at landscape scale the concept of agroforestry as a way of managing natural resources. This is transforming our approach to agroforestry research from both a technical and a policy perspective. We shall continue to develop the concept in the context of the 3 key ecosystems upon which we focus: forest margins, imperata grasslands and hillslope farmlands. We look forward during the coming years to extending our research efforts to an ever greater degree throughout the region in order to assist our collaborators in applying the lessons learned, and the technologies developed, to accelerate progress towards the successful management of their land resources.

Humid tropics of western and central Africa

In Africa, the largest part of that widely treasured natural resource, the tropical rainforest, is found in western and central Africa. The scientific, economic, social, cultural and environmental importance of this ecosystem, extremely rich in its flora and fauna, cannot be overemphasized. Regrettably, available evidence indicates that the resources are rapidly being depleted. In West Africa, as in many parts of the tropics, the human population is increasing, with the consequent negative impact on the tropical rainforest. Deforestation for timber extraction and agriculture is occurring unabated. Small-scale farmers account for over 70% of the population and produce the bulk of cash and food crops. The cropping system is based entirely on the practice of shifting cultivation, in which farmers slash the forest vegetation, burn the biomass and then crop for a year or 2 before abandoning the land to fallow. The length of the fallow period varies from location to location. In high population areas, with a relatively fertile soil, it could be as short as 1 to 3 years. In areas where population density is low and soil acidity or aluminium toxicity is a limiting factor, the fallow length is over 10 years.

Food crops such as cassava *(Manihot utilissima),* maize *(Zea mays),* yam *(Dioscorea cayenensis* and *Dioscorea rotundata),* plantain *(Musa sapientum)* and cocoyam *(Colocasia esculenta)* are produced mainly for home consumption and local markets. The cash crops targeted for the external market include cocoa *(Theobroma cacao),* coffee *(Coffea arabica* and *Coffea robusta),* oil palm *(Elaeis guineensis)* and rubber *(Hevea brasiliensis).* The tree-based cropping system for cash crops is more permanent and thus causes minimal damage to the natural resource. Shifting cultivation for food-crop production, however, requires continuous expansion of cropping land at the expense of the forest.

SLASH-AND-BURN AGRICULTURE

The degradation of the natural resource base as a result of uncontrolled timber harvesting and the practice of slash-and-burn is nowhere more evident than in the humid lowlands of Côte d'Ivoire, Ghana and Nigeria. Some of these countries are now net importers of wood and fibre. Further exacerbating the situation has been the sharp fall in the price of cocoa and coffee beans on the world market. To compensate for the lost income, farmers have intensified food-crop production, thereby accelerating the process of deforestation.

It was in response to this gloomy prospect that in 1987, ICRAF in collaboration with the Institut de la recherche agronomique (IRAD) of Cameroon began their first collaborative agroforestry research programme for the humid lowlands of West Africa. The purpose was to work with a range of local and international institutions to develop alternatives to the practice of shifting cultivation. Strengthening NARS capability in agroforestry research is also an objective. It was thus not by accident that our programme site in Cameroon was chosen as a benchmark for the global ASB project.

The 3 benchmark sites (Yaoundé, Ebolowa and M'Balmayo) of the Alternatives to Slash-and-Burn Programme in southern Cameroon typify the range of conditions that prevail in much of the humid lowlands of West Africa. The Yaoundé zone is characterized by relatively high population density (80–100 persons km^{-2}) and fairly well-developed roads and markets. The soils are moderately acidic (pH 5 to 6, 1:1 water to soil). Agriculture is rapidly expanding and forest resources are just as rapidly being depleted. In Ebolowa, on the other hand, population density is low (5–20 persons km^{-2}) and the road and market infrastructure is poor. Soils are acidic and aluminium saturation is high, greater than 60%. Fallow periods are much longer and forest resources greater in Ebolowa. M'Balmayo, located between Yaoundé and Ebolowa, is a transition zone. These 3 sites thus represent the range of biophysical and socioeconomic conditions prevailing in southern Cameroon.

At the start of the programme in 1987, our research activities centred on describing the land-use system and identifying farmers' constraints. This was done by interviewing farmers, carrying out field surveys and reviewing available literature. The main constraints identified were pests and diseases, lack of access to markets, lack of storage facilities, rudimentary farming tools, declining soil fertility, lack of credit facilities, lack of high-value products, declining cocoa and coffee prices, and labour shortages.

Declining soil fertility and lack of high-value products were identified as areas that agroforestry practices could address. Between 1988 and 1993, our research activities focused on developing improved fallow systems that would increase food-crop production and make it sustainable, and in addition help mitigate declining soil fertility. To do this, we identified suitable agroforestry trees and shrubs that could be used to develop improved fallow systems and efficient fallow management techniques.

In 1993, we carried out an internal review of the regional programme. The review team recommended that 1) we continue with further investigation into the management of improved fallow systems and 2) we initiate activities leading to improved multistrata systems to diversify the production system. The multistrata system mimics the natural forest, and its role in mitigating the degradation of the natural resource base is significant.

CHANGES IN THE REGION

During the year, several programme and institutional changes related to agricultural, forestry and agroforestry research took place in the humid lowlands. Our host national institute completed mid- and long-term national research plans. ICRAF-Cameroon contributed to the agroforestry research component of the plans, which recognized the subject as an important element of any future national research effort.

The government of Cameroon also restructured its national research system by amalgamating the former animal and agronomic research institutes. The new structure is called 'Institut de recherche agricole pour le développement' (IRAD). This will undoubtedly put the ICRAF programme (the only national agroforestry research programme) on a stronger footing to build a multidisciplinary team and catalyse more agroforestry research in the region.

Another major development in the region has been the launching of the Ecoregional Programme for the Humid and Sub-Humid Tropics of Sub-Saharan Africa (EPHTA). The programme, part of one of the CGIAR ecoregional initiatives, is intended to bring together all partners in agricultural and forestry research in the ecoregion. It aims to harness opportunities for institutions to complement each other by specializing in different tasks and to make these institutions mutually accountable when they are addressing common problems.

In April 1996, 2 years after the idea was conceived, EPHTA was officially launched. ICRAF is 1 of the 4 IARC members of the initiative. ICRAF-Cameroon participated in most of the consultative meetings that culminated in the launching of the programme. ICRAF as an IARC and IRAD/ICRAF-Cameroon as the national agroforestry research programme contribute to the implementation of the regional initiative.

As part of our human resources development programme, we contributed to the training of national scientists. In 1995–96, PhD and BSc fellows and visiting scientists benefited from the programme and also contributed to our research effort.

In planning and implementing our research activities and training programmes, we collaborate with NARS, IARCs, advanced research institutions and NGOs. In August 1996, we organized our regional planning meeting, which was attended by most of our partners. The purpose was to review major research results of the year and plan for subsequent years. Emphasis was on identifying a suitable strategy or mechanism for future collaboration.

In the following sections, we present highlights of major research results and outputs of the various regional activities.

THE *PRUNUS AFRICANA* INITIATIVE

Prunus africana, in the family Rosaceae, is a tree native to the montane forests of Africa. It is found naturally from Ethiopia in the north, down to South Africa, as far west as Nigeria and as far east as Madagascar. The medicinal properties of its bark for the treatment of various ailments have been recognized by local communities for centuries. More than 20 years ago, medical science recognized its value for the treatment of benign prostatic hyperplasia, a condition of the prostate gland that is common in older men in Europe and North America. At that time, commercial harvesting of the species from natural populations in Cameroon began. The current world demand for bark is more than 3500 tonnes per year, most of which (2500 t) comes from Cameroon.

When people first started to collect bark from the tree, they did so from natural populations in a sustainable way—only a portion of the bark was removed from standing trees. But in the last 10 years, destructive harvesting by felling trees and stripping all the bark has become increasingly common. This kind of harvesting of all the mature, seed-producing trees severely reduces natural regeneration and destroys the natural resource base in collection areas. Too much destructive exploitation of the species combined with the restricted distribution of montane forest where it grows means that today certain populations of *P. africana* are classified as endangered by the Convention on International Trade in Endangered Species of wild fauna and flora (CITES).

The current market value of the final pharmaceutical product based on bark extract is estimated to be approximately USD 220 million yearly. Villagers in Cameroon are paid about USD 0.20 per kg of bark, a considerable income for these communities but less than 0.5% of the value of the finished product.

There are 2 main reasons for encouraging the incorporation of *P. africana* into agroforestry systems in Cameroon. First, grown on farms, the tree has the potential to generate a sustainable income and provide valuable products to rural communities. In addition to its valuable bark, *P. africana* produces high-quality timber for making furniture and tool handles. Second, planting *P. africana* in areas bordering natural forest (circa situ stands) could reduce pressure on the natural resource base. The species could thus be protected in its natural habitat, along with associated flora and fauna, such as the birds that rely on *P. africana* as a source of food and also disperse its seeds.

In 1995, ICRAF, in collaboration with the Kew/WWF/UNESCO People and Plants Initiative, IRAD and the Ministry of Environment and Forest of Cameroon, conducted an economic survey of the species in the western highlands of Cameroon. From interviews and field visits, it became evident that natural stands in several areas are threatened by the random and inappropriate method of bark extraction employed. As a step towards domestication and genetic conservation of the species, a rangewide collection of germplasm was carried out. Collection sites were the Mendankwe and Kilum Mountain Forest Reserves in North West Province, and Mount Cameroon in South West Province. The collection strategy used required the sampling of a minimum of 30 trees per site, to adequately represent the genetic base of populations. However, seed from only 26, 42 and 11 trees, respectively, was actually collected from the 3 sites. It was not possible to collect from 30 trees at Mendankwe because of overexploitation in the region, while at Mount Cameroon the phenology of fruiting made collection difficult.

Of the 3 areas from which seed was collected, natural *P. africana* is most severely threatened around Mendankwe. Interviews with residents have indicated that very little natural prunus survives in the region. In fact, having recognized the value of the species and observed the fast-depleting natural stock, a large number of farmers are already planting prunus on their farms. The high value that farmers place on the seed, as do the NGOs that deal with it, reflects its scarcity. Currently the seed of prunus is sold for about USD 4 per kilogram, which is higher than the price for cocoa or coffee beans (USD 1–2 per kg).

These observations suggest that while particular natural populations of the species may disappear within the next few years (unless active conservation measures are taken), the opportunities are good to conserve the species and enhance its potential contribution to the economic well-being of communities, through plantations or integration into agroforestry systems. Furthermore, as the US market expands, it is predicted that consumers will pay a premium for sustainably produced *P. africana* bark rather than knowingly contribute to endangering it in natural forests. And farmers would do well to market it in volume through cooperatives to gain a larger share of the product revenue.

During seed collection, leaf material was also sampled to assess ecogeographical variation among populations, by molecular genetics. A technique called RAPD (random amplified polymorphic DNA) analysis was used, in collaboration with the Scottish Crop Research Institute, UK. Data indicated significant differences between the Mount Cameroon region and the 2 other populations. This is consistent with the disjunct distribution of afro-montane forest in the western highlands of Cameroon and indicates that differences in performance may be expected between Mount Cameroon and the other populations in field trials. Data also indicated those areas in Cameroon in which circa situ or in situ conservation would be best targeted for conserving genetic resources in the species.

Seedlings have been successfully raised from collected seed, in collaboration with the Limbe Botanical Garden under the supervision of the Ministry of Environment and Forest of Cameroon and the DFID-sponsored Mount Cameroon Project. Seedlings will be planted out in the field, on land provided by the Cameroon Development Corporation, in May 1997. The purpose of the plantings will be to evaluate differences between progeny arrays and populations in important bark and timber characteristics, as well as survival and growth rates. Based on the data collected, decisions can be made on the best material for farmers to plant in the region. Future work will focus on further seed collection from Mount Cameroon, for the establishment of on-farm and on-station stands for further evaluation and seed production. In addition, work will be carried out on extending the longevity of *P. africana* seed, which is recalcitrant, and on deriving methods for the vegetative propagation of the species, with a view toward cloning superior genotypes and accelerating the interval between germplasm collection and seed production.

The value of the product and the importance of montane forests in Africa as reservoirs of biodiversity indicate that continued research on *P. africana* is worthwhile both for local communities and for the preservation of our wider world heritage.

THE COMPOUND GARDENS OF SOUTHERN CAMEROON

In recent years, studies have shown the importance of homegardens to farmers throughout the world. Although comprising a small proportion of the total area cultivated, homegardens are often a major source of farm income. A survey of homegardens in southern Cameroon was conducted to describe their biophysical and socioeconomic characteristics. The aim was to improve their sustainability and productivity and to assess opportunities for introducing high-value agroforestry trees to improve farmer welfare.

The survey was conducted by a PhD student under a collaborative agreement between the Université de Paris VI, the IITA Humid Forest Station, IRA and ICRAF; it was conducted in the 3 ASB benchmark sites.

The homegardens were characterized in terms of their 1) biological components and structural features, 2) soil nutrient status and 3) socioeconomic characteristics. The biological components and structural features were determined by identifying and enumerating the various tree and food-crop components. We also measured selected structural parameters such as height and diameter of tree stem and crown. Soil samples were collected and analysed for selected chemical properties such as pH, organic matter percentage, and levels of calcium, magnesium and potassium. The socioeconomic characteristics were examined by interviewing farmers using a questionnaire.

Surprisingly, farmers in the region hardly recognized the difference between what researchers refer to as a homegarden and the cocoa plantation. This is particularly the case where the cocoa farms are located near the house. Homegardens are cropping systems located adjacent to a homestead in which fruit trees, medicinal plants, vegetables, food crops and small livestock are managed together and in which soil productivity is maintained through deposition of household waste, kitchen ash and animal manure. When the cocoa or coffee plantation is located far from the homestead, there is a clear demarcation and difference between the plantation and the homegarden. Based on the tree and crop composition, 3 types of homegardens were identified. These are the homegardens dominated by—

- seasonal or annual food crops such as maize and cassava
- biennial food crops such as plantain and banana
- perennial tree crops for fruit, timber or medicine

All 3 types are commonly found in the Yaoundé zone. However, the homegardens of the M'Balmayo and Ebolowa zone are composed mainly of biennials and perennials (table 13). There are 2 main reasons why annual crops are found more frequently around Yaoundé than elsewhere. First, opportunities for marketing seasonal and annual crops are better in Yaoundé. Second, small stock are usually tethered or kept in enclosures, reducing the amount of damage they can do to annual crops. Small stock are free ranging in Ebolowa and M'Balmayo.

The species composition and the area of the homegardens varied from zone to zone. The number of species and the area appeared to increase as one moved from Yaoundé to Ebolowa (table 14).

Table 13. Types of homegardens in ICRAF's 3 study zones

Dominant vegetation	Study zone (no. of each type)		
	Yaoundé	M'Balmayo	Ebolowa
Seasonal or annual food crops such as maize and cassava	7	0	0
Biennial food crops such as plantain and banana	17	14	11
Perennial tree crops for fruit, timber or medicinals	16	26	29
Total	40	40	40

Table 14. Plant species and mean area of homegardens in southern Cameroon

Study zone	Species		Mean surface area
	no.	mean no.	(m^2)
Yaoundé	74	25	1600
M'Balmayo	72	21	1825
Ebolowa	101	30	2100

In Yaoundé and M'Balmayo, there were important differences between homegardens with easy access to markets and those without. The homegardens with good access were characterized by a higher density of vegetables and other annual crops such as cocoyam, cassava, maize and sweet potato *(Ipomoea batatas).* Those in remote areas have more fruit trees, especially exotic species. Economic factors thus appear to strongly influence the composition and distribution of the components of homegarden systems.

Analysis of the vertical distribution of the various species showed that all types of gardens can be made up of 3 strata: low (< 2 m), middle (2–8 m) and high or top (> 8 m). The annual and biennial crop homegardens almost completely lack the middle and high strata. Thus, the potential for growth in these strata is largely unexploited in these systems.

The soil analysis showed that soil pH, soil organic matter (SOM), calcium, magnesium and potassium content of the soils are homogeneous within a homegarden, regardless of the species distribution. There were no consistent differences between soil properties of homegardens of different types ($p > 0.05$). However, the nutrient content of the soils of the homegardens was significantly higher than that of a secondary forest (table 15). Household waste, crop residues and ash from the kitchen are the major sources of nutrients applied to the homegardens (table 16), which probably explains their relatively high soil fertility as compared with that of the secondary forest. Given the apparent importance of these sources of nutrients, future research should document the amount of nutrients added by various farmer strategies.

Major decisions about field operations and commercialization of the products from the homegarden system are made by both male and female household members. The women are generally responsible for the vegetable and other seasonal food-crop components while the men control the management and marketing of the biennial food crops and perennial tree components of the system.

About half the produce from homegardens is used in the household. Some fruits and medicinal

Table 15. Topsoil properties of homegardens and secondary forest in southern Cameroon

	Soil properties									
	pH (1:1 water : soil)		SOM (%)		Ca ($\text{cmol}_c\ \text{kg}^{-1}$)		Mg ($\text{cmol}_c\ \text{kg}^{-1}$)		K ($\text{cmol}_c\ \text{kg}^{-1}$)	
Study zone	Hg	Sf*	Hg	Sf*	Hg	Sf*	Hg	Sf*	Hg	Sf*
Yaoundé	6.9	5.2	4.4	2.5	10.8	2.6	2.1	1.0	0.4	0.11
M'Balmayo	6.8	6.5	4.1	4.8	11.4	5.2	2.0	1.8	0.6	0.15
Ebolowa	6.5	4.8	4.7	3.2	11.8	3.0	2.5	0.9	1.4	0.15

SOM = soil organic matter; Hg = homegarden; Sf = secondary forest

* Source: Alternatives to Slash-and-Burn Programme, final report, phase 1, 1995

Table 16. Percentage of respondents using various sources of fertilizers in the homegardens of southern Cameroon

	Study zone (% respondents)		
Source	Yaoundé	M'Balmayo	Ebolowa
Crop residues	59	81	61
Household waste	36	75	41
Ash from kitchen	12	49	19
Animal manure	5	0	0

Total number interviewed = 120; total percentage is > 100% as some farmers use more than 1 source of nutrients.

No one reported using inorganic fertilizer.

plants are sold on the local market. Hardly any form of storage or processing facilities for products from the system exists in the region. During harvest periods, local market prices fall drastically, especially in M'Balmayo and Ebolowa, where farmers claim that they can barely get a price that covers transportation costs for most of their products.

The opportunity for further improvement of compound gardens is very promising. The relatively low density of the middle and top strata plant communities, particularly in type 1 and type 2 homegardens, offers an excellent opportunity to improve the productivity of those systems in the region. The Southeast Asian experience shows that a multistrata system consisting of up to 5 strata can be effectively developed. To maximize the economic benefit, careful identification, selection and integration of appropriate components is necessary. It is critical that farmers be involved in the identification, development and testing of these new components. There is also a need to create new economic opportunities through processing and transforming high-value primary products into value-added finished goods and services. Improvements in the present state of technology, rural marketing and entrepreneurship are needed.

As a follow-up to this activity, we have already launched research aimed at domesticating and conserving priority fruits and medicinal plants for possible inclusion in homegardens. For selected categories of local fruit tree species such as *Irvingia wombolu* and *Ricinodendron heudelotii,* we are now collaborating with a private European company to evaluate the potential to transform kernels to high-value products for the international market. We also plan to develop an improved multistrata system in a large-scale research programme in collaboration with national (ONADEF) and international partners in the region. The potential for domestication research is considerable. Although some genetic improvement work has been done on exotics citrus and mango, none has been done on most of the local tree crops.

PROVENANCE EVALUATION OF *CALLIANDRA CALOTHYRSUS*

MAIZE YIELDS FOLLOWING PROVENANCE EVALUATION

In our earlier species screening and systems improvement trials conducted in Cameroon, calliandra *(Calliandra calothyrsus)* emerged as a winner for improved fallows, based on its high biomass productivity, beneficial effects on soil nitrogen replenishment and tolerance of moderately to very acid soils. In most of these trials, a single seed source was used. In 1993 and 1994, we therefore established 2 experiments on contrasting soil conditions in Yaoundé (moderately acid soils) and Ebolowa (very acid soils). In both trials, we evaluated 15 provenances, which came from the native range of the species in Central America with 2 landraces from Indonesia (see ICRAF annual report 1995 p 150–152). The provenances evaluated are shown in table 17.

The growth performance and variation between provenances tested in Yaoundé was reported last year (ICRAF annual report 1995 p 150–154). In 1995, we harvested the biomass, incorporated the

Table 17. Variations in dry-matter degradation characteristics of edible forage from provenances of Calliandra calothyrsus, *Yaoundé, southern Cameroon*

Provenance[†]	a[‡]	b	c	PD
A. 8/91	150	530	0.0165	680
B. 10/91	188	498	0.0161	685
C. 11/91	206	517	0.0147	723
D. 12/91	182	637	0.0098	819
E. 13/91	204	483	0.0130	688
F. 15/91	193	459	0.0175	653
G. 18/91	212	434	0.0157	645
H. 134/91	210	427	0.0221	637
I. 147/91	178	414	0.0166	592
J. 45/92	190	469	0.0103	659
K. 51/92	207	510	0.0106	717
L. 53/92	199	280	0.0226	480
M. 61/92	170	385	0.0199	555
N. 62/92	186	636	0.0100	822
Mean	191	477	0.0154	667
Minimum	150	280	0.0098	480
Maximum	212	637	0.0226	822

a, soluble fraction; b, degradable fraction; c, rate of degradation, h^{-1}; PD, extent of degradation at time *t*; as g kg^{-1} dry matter

[†] Oxford Forestry Institute provenance number

[‡] estimates from the non-linear equation, $PD = a + b(1 - e^{-ct})$

leaf biomass into the soils of the respective plots and planted maize without applying fertilizer.

In addition, although not part of the original trial design, maize was planted in 'control' plots around the trial area, which had been under grass during the 2-year trial period. Maize grain yield data were recorded for each of the plots. This trial was not designed to assess the impact of different provenances on subsequent maize growth, and we fully recognize the caveats that the small plot size (5 x 5 m) raises with regard to above- and below-ground competition for resources during the 2-year growth period of calliandra. Nevertheless, some observations are worth recording. Maize grain yield in the calliandra plots ranged from 3.07 to 4.71 t ha^{-1}, all of which were significantly higher than the 1.58 t ha^{-1} recorded after 2 years of grass fallow. The variation in maize yield following calliandra was significantly related to accumulated litterfall over the last 30-week period of calliandra growth (range 0.70–3.60 t ha^{-1}, $r^2 = 0.38$, regression d.f. = 1, residual d.f. =13), and also to leaf biomass at calliandra harvest (range 3.24–7.59 t ha^{-1}, $r^2 = 0.36$).

These observations support our hypothesis that genetic variability within calliandra can be exploited for more effective improved fallow systems. Contrasting provenances will now be selected and evaluated for their efficacy for improved fallow in rigorously designed trials.

FODDER QUALITY OF CALLIANDRA PROVENANCES

In the humid lowlands, availability of forage for small stock is not a major problem. However, free ranging—the traditional livestock management system—is adversely affecting crop production. It also discourages farmers from increasing the amount of their stock, thus causing continued dependence on bush meat as a protein source. Both farmers and researchers believe that if a system that would ensure a continuous supply of high-quality fodder could be developed, it would be possible to intensify small stock production. In fact, the humid zone programme of ILRI has been working on this strategy for quite some time. We thus also evaluated forage quality of the calliandra provenances discussed above.

Dry matter (DM) degradation characteristics of 14 of the 15 provenances tested in Yaoundé were evaluated by ILRI. Leaf samples from upper, middle and lower canopy layers were randomly harvested. The leaf samples were air dried, ground and passed through a 2.5-mm sieve. A 5-g equivalent of the same sample of each provenance was weighed and placed in 9 x 18–cm nylon bags of pore size 41 microns. The bags were incubated in duplicates in each of 3 rumen-fistulated zebu castrates (average liveweight, 250 kg) for 6, 12, 24, 48, 72 and 96 h. The steers were housed in individual pens, with free access to water and mineral salts (92–97% NaCl, > 2% Fe, 3% Mn, 0.33% Cu, 0.007% I, 0.0025% Co). The steers grazed *Panicum maximum* pastures and were supplemented with wheat bran at a rate of 2 kg $animal^{-1}$ day^{-1} during the period of the study. Data on dry-matter degradation characteristics were analysed as a randomized block design with steers as replicates.

The results showed that the soluble and degradable fractions of DM degradation characteristics differed significantly ($p < 0.001$) among provenances

A farmer in Nkolfep, Cameroon, applies calliandra leaves to fertilize his soil. During the dry season he uses cuttings to feed his goats.

(table 17). The soluble fraction ranged from 150 g kg^{-1} in provenance 8/91, to 212 g kg^{-1} in provenance 18/91. The lowest degradable fraction (280 g kg^{-1}) was found in provenance 53/92, and the highest (637 g kg^{-1}) in provenance 12/91. The rate of degradation varied from 0.0098 h^{-1} in provenance 12/91 to 0.0226 h^{-1} in provenance 58/92 while the extent of degradation ranged from 480 g kg^{-1} in provenance 53/92 to 822 g kg^{-1} in provenance 62/92.

A cluster analysis suggests 4 groups of provenances, among which wide intraspecies variation in rumen degradation characteristics was evident. Degradation constants, measured by the Sacco nylon bag method, and gas production are strongly related to digestible DM intake of browse. Thus, intraspecies variation in DM degradation reported in this study could result in differential intakes of the provenances when given as sole diets and to the differential rate of synthesis of microbial N per unit intake. Using the average extent of DM degradation reported here as a forage quality index, provenances of *C. calothyrsus* in clusters 3 and 4, namely, 51/92, 11/91, 13/91, 45/92, 10/91, 15/91, 18/91, 134/91, 12/91 and 62/92, seemed to be of higher quality than their counterparts in clusters 1 and 2. It is encouraging to note that of these, provenances 13/91, 11/91 and 134/91 were also among the highest biomass producers. It should be recognized, however, that this experiment used leaves from intact trees rather than from coppiced or browsed trees, which could be used for animal feeding. It remains to establish a correlation between the fodder quality of intact and coppiced trees.

Other workers have also reported similar intraspecies variation in DM degradation for *Sesbania sesban, Leucaena leucocephala* and *Erythrina* ssp.

Voluntary intake of *C. calothyrsus* foliage by sheep is influenced by the form of presentation. Further studies are therefore needed to determine whether the higher extent of DM degradation could be translated into animal output, which is a better determinant of forage quality. This is currently under investigation through collaborative research between ICRAF and ILRI. Use of calliandra in improved fallow management is on the rise. Integrating the livestock component into the improved system is part of our plan for 1997 and beyond. We will use the results we now have to select provenances appropriate for developing the management of improved fallows and for developing intensive feed gardens targeted to improve small-stock production in the region.

SHORT-TERM IMPROVED TREE FALLOWS

LONG-TERM ON-STATION RESEARCH

In 1988, we established a long-term trial at our research station near Yaoundé to evaluate the potential of managed tree fallows as an alternative to the current widespread practice of shifting cultivation. In such slash-and-burn systems, naturally regenerating forest fallows are cleared and in the first rainy season after clearing a mixture of seasonal, annual and biennial crops is planted. Maize, the dominant seasonal food crop, is harvested at the end of the 1st season. The land is then essentially allowed to revert to fallow in the 2nd and subsequent seasons, initially to allow maturity and later as a storage mechanism for biennial root crops such as cassava.

In our study, trees (*Leucaena leucocephala* and *Gliricidia sepium* mixtures) were planted in rows 4 m apart with a within-row spacing of 0.25 m. Gross plot size was 11 x 16 m and treatments were replicated 4 times. Initially 4 treatments were evaluated (table 18):

Treatment 1	A control treatment of continuous maize cropping with 1 season of maize and 1 season natural fallow each year
Treatment 2	Continuous maize cropping with 1 season of maize grown between the rows of trees (regularly pruned back as hedgerows) and 1 season of tree fallow during which the hedges were allowed to grow unchecked
Treatment 3	2 years of tree fallow followed by 2 years of cropping as in treatment 2
Treatment 4	The same as treatment 3, but starting with the cropping cycle

In 1994, modifications were made in the trial design and management:

- Pruning height of trees in T3 and T4 was reduced from 0.5 m to 0.05 m above ground level. This was to minimize above-ground

Table 18. Fallow cropping cycles and maize grain yields (t ha^{-1}) Yaoundé, Cameroon

Treatment	1990		1991		1992		1993		1994		1995		1996	
	1st	2nd	1st	2nd	1st	2nd	1st	2rd	1st	2nd	1st	2nd	1st	2nd
T1a	1.52	NF	2.98	NF	3.54	NF	2.54	NF	2.17	NF	2.33	NF	2.69	NF
T1b	1.52	NF	2.98	NF	3.54	NF	2.54	NF	NF	NF	NF	NF	3.58	NF
T2	2.13	TF	3.70	TF	4.79	TF	5.09	TF	4.55	TF	3.33	TF	3.68	TF
T3	TF	TF	TF	TF	6.28	TF	6.09	TF	TF	TF	TF	TF	6.51	TF
T4	2.72	TF	4.48	TF	TF	TF	TF	TF	5.27	TF	4.82	TF	TF	TF
SED	0.38	–	0.28	–	0.14	–	0.44	–	0.14	–	0.36	–	0.35	–

NF = natural bush fallow

TF = tree fallow of *Leucaena leucocephala* and *Gliricidia sepium* mixture

T1 control treatment of continuous maize cropping with 1 season of maize and 1 season natural fallow each year; in 1994, plots were split to allow the comparison of a 2-year natural fallow (T1a) with a 2-year tree fallow (T1b)

T2 continuous maize cropping with 1 season of maize grown between the rows of trees (regularly pruned back as hedgerows) and 1 season of tree fallow during which the hedges were allowed to grow unchecked

T3 2 years of tree fallow followed by 2 years of cropping, as in treatment 2

T4 same as treatment 3, but starting with the cropping cycle

competition for light in the crop growth phase following fallow clearance.

- Root trenching and backfilling were done around all plots to a depth of 60 cm to reduce below-ground interference. This exercise was repeated twice each year.
- Treatment 1 plots were split to allow the comparison of a 2-year natural fallow (T1a) with a 2-year tree fallow (T1b) (table 18).

Throughout the trial period, records were kept of tree biomass production, maize grain and stover yields, weed dynamics and biomass, and in 1996, soil analysis was undertaken from a range of depth intervals in all plots. In this report we highlight the maize yield and soil analyses results.

The practice of allowing 1 season of natural fallow in continuous cropping (T1a) maintained maize yields at relatively high levels over the 7-year period on this moderately fertile Alfisol, which is mainly deficient in nitrogen (table 18). The introduction of a 2-year natural fallow period in 1994 (T1b) resulted in a significant increase in yield from 2.69 to 3.58 t ha^{-1} in 1996. Standard hedgerow intercropping with 1 season of tree fallow each year (T2) gave consistent and significant increases in maize yield over the annual cropping with 1 season of natural fallow. Over the 7-year period, the hedgerow intercropping with 1 season of the tree fallow system (T2) yielded an aggregate of 27 t ha^{-1} of maize grain compared with 17.8 t ha^{-1} in the natural fallow system (T1a).

Allowing 2 years of tree fallow (T3 and T4) resulted in consistently high and significantly greater maize yields than in all other treatments, resulting in a 7-year aggregate of 36.1 t ha^{-1}. We should emphasize that this 7-year aggregate was achieved on twice the land area of the other treatments in this trial. However, in areas such as southern Cameroon, where land scarcity is not yet a problem, this is not an issue. Returns to labour are likely to be much more important, coupled with a family's ability to meet its food requirements in any 1 year.

A summary of the soil analysis reflects the maize yield trends discussed above (fig. 21). Within the topsoil, important fertility indicators (organic C, available P, pH and exchangeable Mg, Ca, K) under the hedgerow intercropping system (T2) tended to be higher than under the annual cropping and seasonal fallow system (T1a). However, the apparent differences were not significant at the 5% level. In contrast, the systems that allowed 2 years of tree fallows (T3, T4), and hence greater potential for nutrient cycling, showed substantially and significantly higher values of all fertility indicators measured.

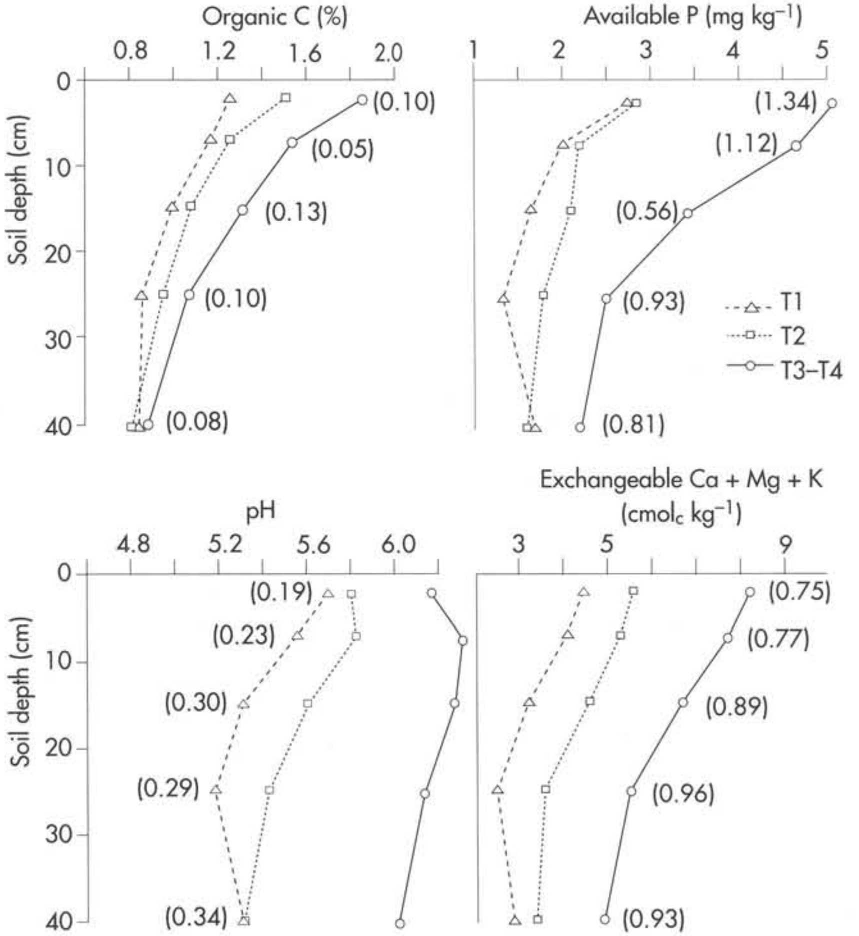


Figure 21. Changes in soil properties in an Alfisol after 7 years of contrasting land-use systems, Yaoundé, Cameroon, 1996. Treatments: T1 control treatment of continuous maize cropping with 1 season of maize and 1 season of natural fallow each year; T2 continuous maize cropping with 1 season of maize grown between the rows of trees (regularly pruned back as hedgerows) and 1 season of tree fallow during which the hedges were allowed to grow unchecked; T3–T4, mean 2 years of tree fallow followed by 2 years of cropping, or vice versa. Figures in parentheses are SED for each soil-depth interval.

In conclusion, the results of this long-term trial suggest, at least from a biophysical perspective, that managed tree fallow systems have the potential to maintain high levels of maize production without degrading the soil resource base.

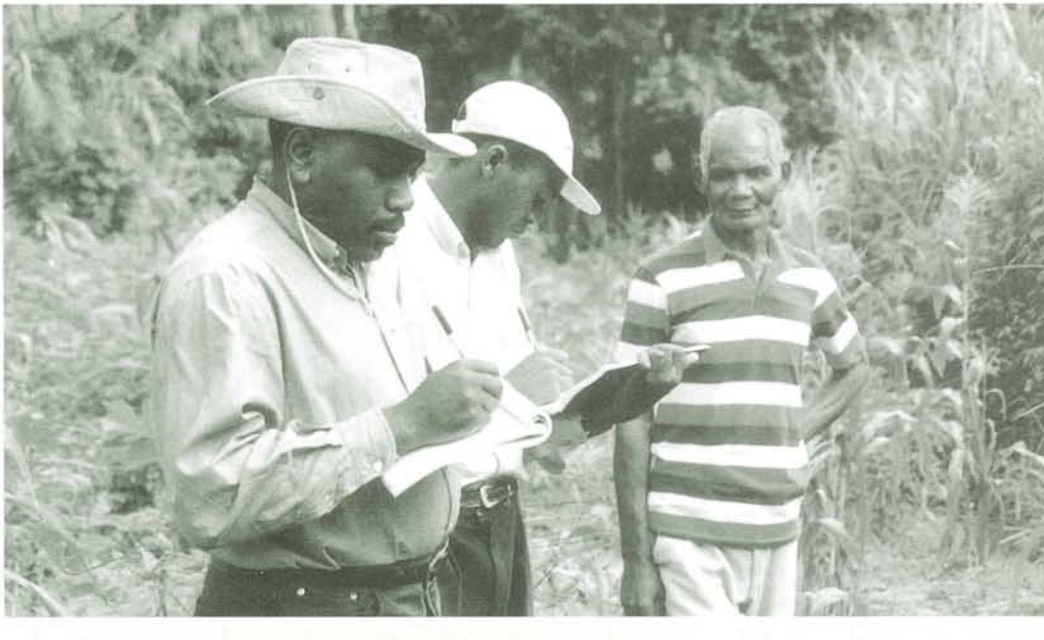
MOVING TREE FALLOWS ONTO FARMS: FARMERS' PERSPECTIVES

Our on-farm research in Cameroon first started in 1989. Initially this work focused on assessing the biophysical performance of hedgerow intercropping systems analogous to treatment 2 in the above trial. *L. leucocephala* and *C. calothyrsus* were the species evaluated. By 1993 we were working with nearly 50 households in researcher-designed, farmer-managed trials.

By 1994, however, 2 important facts had become apparent. First, the biophysical performance of the hedgerow intercropping system was substantially inferior under farmer management to that achieved on station. Second, except for 1 or 2 instances, farmers' response was far below expectation.

Having observed the potential of 2-year fallow systems in our on-station research, we decided in 1994 to convert our on-farm conventional hedgerow systems into improved fallow systems, analogous to T3 and T4 in table 18. Most of these trials have therefore been under fallow in 1995 and 1996 and will be first cropped, under the new system, in 1997. To enhance their demonstration value to village communities, some of these trials have been brought under full researcher control, with village field days being held at key phases in the system management. The rest of the trials are managed by farmers.

In 1995–96, we conducted a socioeconomic survey of households involved in the collaborative on-farm testing of the improved fallow



Researchers in Cameroon record a farmer's comments about his experiences with the improved fallow technology. Many of the trials with this technology are managed by farmers.

technology. The specific objectives of the study were to generate baseline data on socioeconomic conditions of the trial households, to collect data on key farm and household characteristics that are likely to influence the performance and adoption of improved fallows, and to assess farmers' perceptions of the improved fallow technology and the problems of land shortage and soil infertility that the technology addresses. Here we report on the latter objective of farmer perceptions.

The study was conducted in Nkolfeb and Abondo villages near Yaoundé, and Biba village near Ebolowa. Interviews were conducted with 44 of the 51 households hosting on-farm trials in the 3 villages.

Farm size averaged about 8.8 ha, including 4.6 ha in cocoa, 4.0 ha in food crops (about a third is cultivated at any given time) and 0.2 ha in homegardens. According to 64% of the respondents, land availability was not a major problem;

A number of farmers were involved in a socioeconomic survey of households collaborating in on-farm testing of the improved fallow technology. Here they look at one of their farms and its trees, Biba near Ebolowa, Cameroon.

73% confirmed that if and when they did need more land, they would be able to obtain it within the village. These findings are surprising, given that 2 of the study villages are in areas with high population density, where mature forests no longer exist and even secondary forest areas are shrinking. Since 1990, only 2 (4.5%) of the sample households have cleared forest for cropping, compared with 66% who did so before 1980. However, farmers have simply not yet realized that agricultural land is no longer available, and that it is for this reason that primary forests have been completely cut down and secondary forests reduced in size.

Nor do they seem to realize that the fertility of their soils is decreasing. They in no way associate deforestation with declining soil fertility. In spite of decreasing yields and shorter fallow periods, farmers do not feel that soil fertility is a major problem, and 52% believed that the soil in more than half of their fields was fertile. Only 4.5% of the respondents said that over 50% of their crop fields were characterized as poor in soil fertility. When asked to categorize the soil fertility status of their various plots, they described 51% as fertile, 34% as of average fertility, and only 15% as poor.

When asked if soil erosion was a problem, 75% reported that less than 25% of their fields were located on steep slopes (steep, as defined by each farmer), while 43% stated that the same proportion was on a gentle slope. These findings suggest that erosion is not a major problem. The incentive to adopt hedges for the purpose of erosion control in the study villages therefore appears to be very low.

Improved fallows can play an important role in curbing deforestation. By shortening the fallow period of a field, farmers reduce the area of land a household needs to sustain itself and can thus help reduce the slashing and burning of forest areas. However, as the farmers surveyed generally felt that land was available and that soils were fertile, they have little incentive to adopt improved fallows. There is thus a divergence between society's and farmers' interests—farmers do not see the need to adopt a technology, such as improved fallows, that will not provide immediate advantages but will in the future have important benefits for society.

In short, the farmers' immediate concern is how best to increase their cash income and the returns for their labour. The problem of the degradation of the natural resource base and deteriorating environmental quality is noted—but is not the main issue for farmers.

Thus we are trying to modify improved fallows so as to help farmers earn more. For example, whereas previous on-farm trials had included maize as the crop between the alleys, we are now encouraging farmers to use high-value crops, such as vegetables, in the improved fallow technology. Indeed, enthusiasm for improved fallows is highest in the areas of greatest land pressure and market access, where vegetable growers are using the technology to improve yields and to produce stakes for their yams and tomatoes. Other farmers have noted that the technology reduces labour requirements for land clearing and weeding as compared with slashing a secondary forest. Farmers prefer *C. calothyrsus* to *L. leucocephala* because the latter seeds prolifically and soon becomes a weed.

In 1997, we plan to expand our on-farm testing beyond the villages where we are now operating. We have already reached an agreement with 3 NGOs—Cercle international pour la promotion de la création(CIPCRE), Institut africain pour le développement économique et social (INADES) and WWF-Cameroon (Worldwide Fund for Nature). INADES and WWF have secured funding for our collaborative work. For the work with CIPCRE, we have obtained funding from a USAID technology transfer grant provided through the West Africa Rice Development Association (WARDA).

Our strategy is to test improved fallows in more appropriate ecozones, that is, where farmers perceive land shortage and poor soil fertility to be major problems. We also seek to diversify the products obtained from agroforestry and in particular to help farmers increase their cash incomes and returns to labour. For example, in West Province, where we have started work with CIPCRE, land shortage is acute and the farmers use imperata *(Imperata cylindrica)* and napier grass *(Pennisetum purpureum)* biomass to fertilize their soil. The topography is sloping, and soil erosion is a widely perceived constraint. We therefore plan to introduce improved fallows of calliandra for soil fertility improvement, erosion control and honey production. Honey has great potential as a cash enterprise, and beekeeping is well known in the area and is part of local tradition. Calliandra is known to be an excellent source of nectar, and it has been tested for honey production in Southeast Asia. Farmers will also be testing other agroforestry practices that they have selected: *Cajanus cajan* short-term improved fallows, calliandra live fences, windbreaks, woodlots and fodder banks. The trials will be farmer designed and farmer managed, to allow farmers to manage the technologies as they see fit and to modify and incorporate them into their farming systems as they deem best for their conditions.

In the villages of southern Cameroon where we are already working, our strategy is first to effectively demonstrate the potential of improved fallows under farm conditions by initially taking full responsibility for the management of the system. We then plan to target innovative households and encourage the production of high-value crops using the improved fallow system. An NGO (Sucre Village) specializing in the extension of beekeeping technology will be our partner to test calliandra woodlots for honey production.

REGIONAL SYMPOSIUM

Since the late 1970s, with the growing concern over the continuing depletion of tropical rainforest, several NARS, IARCs and NGOs have been actively involved in agroforestry research and development in the humid lowlands of West Africa. Yet on only a few occasions have those involved come together to discuss progress on specialized topics such as hedgerow intercropping or fallow management. The broader picture of the range of work done has remained unknown and unassembled, often leading to duplication of efforts.

To promote regional cooperation, ICRAF organized the Regional Symposium on

Agroforestry Research and Development in the Humid Lowlands of West and Central Africa, held 4–8 December 1995. The symposium was coordinated by IRAD and ICRAF; it was cosponsored and organized with IITA and the Centre de coopération international en recherche agronomique pour le développement (CIRAD). The objectives were—

- to take stock of agroforestry research and development activities in the region
- to exchange information on research results and identify information gaps
- to set research priorities, in consultation with the major actors
- to develop a way to strengthen regional collaboration in agroforestry research and development in the humid lowlands of West Africa

A total of 67 participants from 7 West and Central African countries (Côte d'Ivoire, the 2 Congos, Gabon, Ghana, Nigeria and Senegal), 1 East African country (Kenya) and 3 European countries (France, Germany and the UK), representing 24 NARS, 6 NGOs, 4 IARCs and 3 overseas advanced research institutions, attended the meeting.

Participants presented 45 papers, covering the physiology and management of agroforestry trees, research on improvement of both crop- and livestock-based systems, the socioeconomic aspects of agroforestry research, and other topics.

The manuscripts are now being edited by CIRAD Forêt in France, who will publish the symposium proceedings.

In 4 working groups, the participants discussed agroforestry tree improvement, agroforestry systems research for soil and crop improvement, silvopastoral and apicultural research in agroforestry systems and multistrata system research. The detailed recommendations recorded by these groups have been documented and are available on request.

At a plenary session, the participants endorsed setting up an expert taskforce on agroforestry research for West and Central Africa. As an interim measure, a temporary committee was put together to define the mandate and the composition of the expert taskforce. The members of the temporary taskforce include 1 representative from NARS; 1 each from NGOs in Cameroon, Côte d'Ivoire, Gabon, Ghana and Nigeria; and 1 each from CIRAD, ICRAF, IITA and ILRI. The 4 institutions that participated in the organization of the meeting will be responsible for following up on this resolution.

CAPACITY BUILDING

TRAINING

During the year we participated in a number of activities towards institutionalizing of agroforestry research and development in national systems. Some of these activities are presented here.

Degree-related training

In the degree-related training programme, we encourage young national scientists from various schools of agriculture and forestry to undertake a special project in agroforestry at the IRAD–ICRAF research sites. The students are supervised by the IRAD–ICRAF staff and their school or college advisers. Five candidates from the Technical School of Agriculture, Dibombari and Bambui, and the School of Forestry in M'Balmayo spent an average of 1 month each at our project site. They participated in various aspects of on-station and on-farm research. A BSC student from the University of Dschang conducted his special project for 6 months. He evaluated the effect of soil type and rhizobium inoculation on early growth of *Calliandra calothyrsus.*

We also give opportunities to national scientists assigned to the project to obtain an MSC degree in agroforestry. At the end of their training, the trainees return to the project to strengthen the human resources of the agroforestry research unit.

A PhD student who started his field work in 1995 completed his study and was awarded a degree by the Université de Paris VI in France in February 1996. Another PhD candidate completed data collection and returned to the State University of New York, USA, to finalize his thesis.

In-service training

ICRAF gives various national organizations and NGOs involved in agroforestry research and or development in the region an opportunity for in-service training of individual scientists. Such organizations assign their candidate to the IRAD–ICRAF project for a period of 1 to 3 months. The candidates, closely supervised by the project staff, participate in our field activities, thereby acquainting themselves with the basic concept of agroforestry research methodologies, both on station and on farm. At the end of their assignment they all go back to their respective organizations.

Visiting scientists

University lecturers involved in agroforestry teaching may become visiting scientists. Qualified individuals are awarded a fellowship by ANAFE to conduct their special study at an ICRAF research site for a maximum of 3 months. A professor from the University of Dschang spent 3 months at our project site, studying vegetative propagation of 15 *C. calothyrsus* provenances.

INSTITUTIONAL COLLABORATION

We collaborate with a number of NGOs to do on-farm evaluation of improved fallow for soil fertility management and apiculture. These are listed at the back of the report. Our major partner in implementing the ASB project is IITA, and IITA is also the convening centre for EPHTA, in which we participate. We also plan and conduct specific collaborative field research with IITA.

We are now developing a joint proposal with CIRAD for research on *C. calothyrsus* root–rhizobium association.

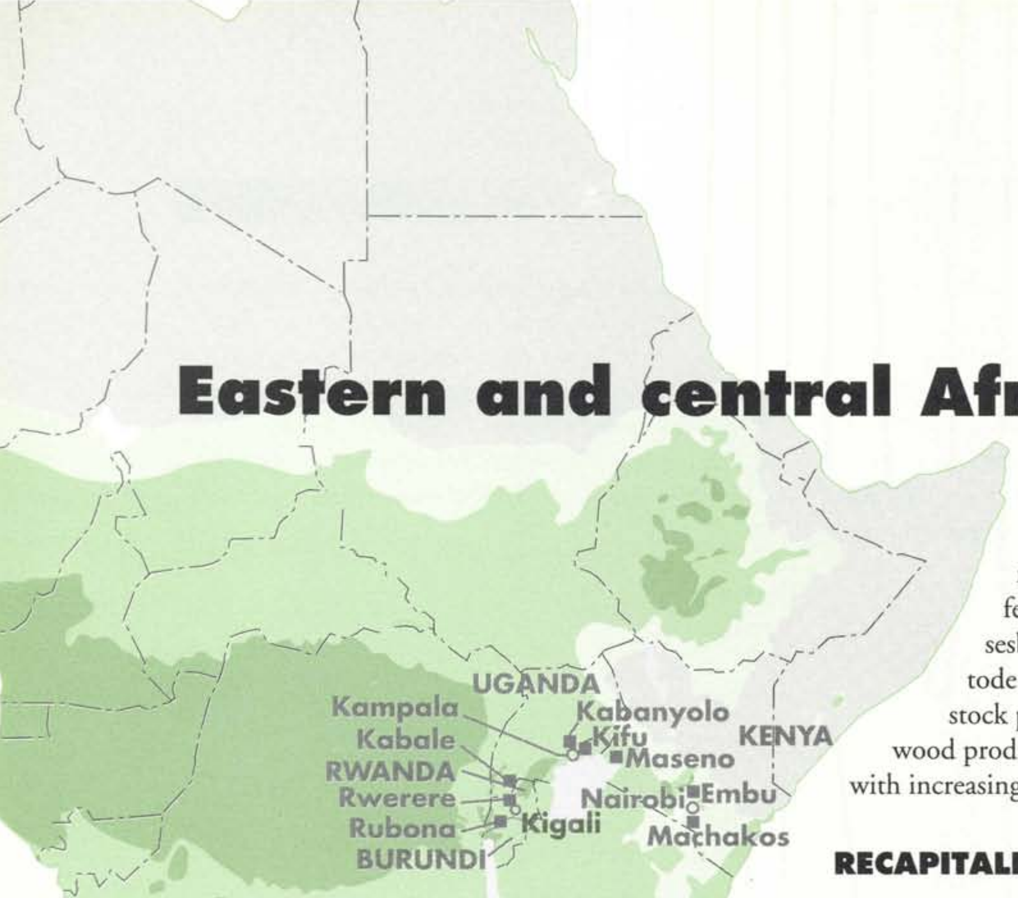
We collaborate on the evaluation of *C. calothyrsus* provenances with the Oxford Forestry Institute of the UK.

Together with staff of ILRI, we evaluated fodder value of *C. calothyrsus* provenances. We are currently developing a joint proposal with ILRI on livestock management, to be implemented under the ecoregional programme.

TO SUM UP . . .

As part of our contribution to multistrata system development, we will continue with the ongoing genetic improvement and domestication work on priority high-value agroforestry trees. In collaboration with other partners such as IRAD, IITA and ONADEF (Office national de développement des forêts), we plan to initiate a field trial aimed at developing improved multistrata systems. This, together with our improved fallow work, will form the basis of our contribution to the Alternatives to Slash-and-Burn Programme and the Ecoregional Programme for the Humid and Sub-Humid Tropics of Sub-Saharan Africa.

Eastern and central Africa



EAST AFRICAN HIGHLANDS

The AFRENA network for eastern and central Africa focuses on the bimodal highlands of the region, at elevations above 1000 m and rainfall of 1000–1800 mm per year. Research is conducted in collaboration with various NARS, NGO and IARC partners in Kenya, Rwanda and Uganda.

Four priority flagship themes of relevance to the entire region have been identified for the network (see ICRAF annual report 1995 p 28–30):

- soil fertility replenishment and maintenance
- terrace management and erosion control
- wood production in farming systems
- fodder production through agroforestry

This year, we report on several substantive findings—initial results on recapitalizing soil fertility and on integrating biomass transfers with phosphorus fertilizers, long-term results on sesbania fallows, the sesbania nematode problem, tree fodder for livestock production, upperstorey trees for wood production, and changes in tree cover with increasing land pressure.

RECAPITALIZING SOIL FERTILITY

The concept of soil fertility replenishment as an investment in natural resource capital, initially proposed 2 years ago (ICRAF annual report 1994 p 38–40), began to be tested in the 1st long-term recapitalization experiment planted near Maseno in western Kenya during the long rains of 1996. This work is done in collaboration with the Tropical Soil Biology and Fertility Programme (TSBF) and students from several universities.

BIOMASS TRANSFER AND INTEGRATED USE OF PHOSPHORUS FERTILIZER

A prototype recapitalization experiment was initiated in the long rains of 1996 on a P-depleted Oxisol (Kandiudalfic Eutrudox) in western Kenya to compare leafy biomass of tithonia and urea fertilizer as sources of N in factorial combination with 2 sources of P fertilizer (phosphate rock and triple superphosphate—TSP) and gradual buildup of recapitalization rates. Soil properties were bicarbonate-EDTA extractable P = 1.0 mg kg^{-1}, pH (1:2.5 soil:water suspension) = 5.1, KCl extractable Ca = 3 $cmol_c$ kg^{-1}, and clay = 29%. The treatments together with a no-P control were replicated 3 times as a randomized complete block design in 100-m^2 plots.

The P fertilizers were TSP, a commercial P source with 20% P, and Minjingu phosphate rock (PR), a finely ground and reactive indigenous source of P (13% P) from Tanzania. The P sources were broadcast and manually incorporated at 50 and 250 kg P ha^{-1} before sowing maize. The 50-kg P rate will be repeated yearly, while the 250 rate is a 1-time 'recapitalization' rate that is expected to last for 10 years. Fresh leafy biomass of *Tithonia diversifolia* (1.8 t dry weight ha^{-1}) was spread on the soil surface and manually incorporated in the top 15-cm soil layer before the maize was planted. *T. diversifolia* is a composite shrub common in the field boundaries of eastern Africa. The tithonia biomass contained about 3.3% N, 0.3% P and 3.1% K. Urea application was split—part applied at planting and the remainder applied 4 weeks after emergence. The rate of N application was balanced at 55 kg N ha^{-1} for tithonia and urea. Tithonia, however, also added about 5 kg P ha^{-1} and 60 kg K ha^{-1}. Results are available from the 1996 long rains to compare the integrated use of tithonia biomass or urea in combination with P.

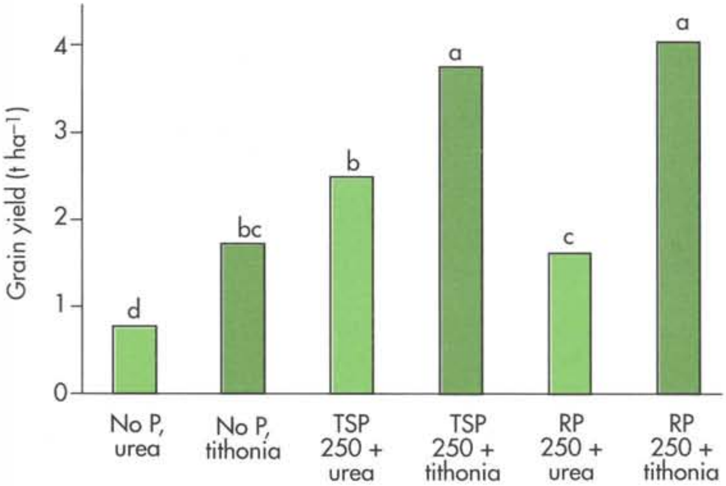


Figure 22. Combining Tithonia diversifolia *biomass transfer (1.8 t ha^{-1} of dry mass) with Minjingu phosphate rock (PR) and triple superphosphate (TSP) both applied at a recapitalization rate of 250 kg P ha^{-1}, on maize grain yield on an Oxisol with pH 5.1 near Maseno, Kenya. The amounts of N supplied by urea and* T. diversifolia *were the same, 60, kg N ha^{-1}. Columns with the same letter are not statistically different.*

Application of P, as either TSP or PR, significantly ($p < 0.001$) increased maize grain yield with both tithonia and urea application (fig. 22). Maize yields averaged for the 2 N sources were comparable ($p > 0.10$) for TSP and PR. There was a significant yield increase when tithonia was added to the P fertilizers, in comparison with commercial N fertilizer. Minjingu PR is highly reactive and rapidly releases plant-available P on this acid soil. When compared with TSP, the relative agronomic effectiveness (RAE) of the PR—

Biomass from common shrubs such as Lantana camara *can substantially increase maize yields. Lantana and the equally ubiquitous* Tithonia diversifolia *often grow plentifully on field boundaries and are thus readily available.*

defined as (yield increase with PR/yield increase with TSP) x 100—averaged 74% at 50 kg P ha^{-1} and 80% at 250 kg P ha^{-1}. Such high RAE confirms that Minjingu PR can be an agronomically effective source of P for maize on acid soil, even in the 1st season of application.

Maize grain yields were consistently higher ($p < 0.001$) after the application of tithonia than they were after urea in the absence of added P and with each P source (fig. 22). The nitrogen was added at equal rates of 60 kg N ha^{-1}, and the urea application was split as recommended. That the benefit from tithonia was greater than that from urea could be partially attributed to the addition of 60 kg K ha^{-1} and 5 kg P ha^{-1} in the tithonia biomass. Application of tithonia increased soil-extractable K ($p < 0.01$), but labile soil P fractions (resin P and bicarbonate inorganic and organic P) were not measurably greater following tithonia than after the urea application.

Biomass from existing locally available shrubs such as *T. diversifolia* and *Lantana camara* that commonly grow or trees on field and farm boundaries might be a more economic source of nutrients for crops than biomass from planted trees (ICRAF annual report 1994 p 108). Use of biomass from existing boundary hedges would require no added cost for seedlings nor would it decrease the field area devoted to crop production.

Research continues to identify and quantify the mechanisms responsible for the effectiveness of high-quality tithonia biomass for soil fertility improvement, in both the presence and the absence of added P fertilizer. In a related study on the same soil in collaboration with the TSBF, tithonia leafy biomass at a higher rate of 5 t dry matter ha^{-1} (15 kg P ha^{-1}) was compared with 15 kg P ha^{-1} as either TSP or a mixture of TSP and tithonia on the basis of 50:50% P. Tithonia and TSP were broadcast and incorporated to a soil depth of 15 cm. No crop plants were grown, to eliminate plant uptake as a factor affecting soil P fractions.

Both tithonia and TSP, at equal P rates, rapidly increased plant-available P in the soil as determined by resin extraction. Resin P was generally comparable following either application, indicating that tithonia rapidly releases a considerable fraction of its total P as plant-available P. Tithonia, unlike TSP, increased soil biological activity, as determined by microbial biomass P at 2 weeks after application (table 19).

Tithonia was also more effective than TSP in reducing the sorption (fixation) of P by iron and aluminium oxides in the soil (table 19). The reduction in sorbed P at 2 weeks after TSP application can be attributed to saturation of soil sorption sites by the added P. The comparable levels of resin P following TSP and tithonia applications suggest that tithonia similarly reduces sorbed P through saturation of sorption sites by released P. The fact that tithonia reduced sorbed P more at 2 weeks than did TSP and the continued reduction in P sorption at 16 weeks with tithonia (table 19) suggest that tithonia, unlike TSP, also reduced P sorption by producing organic anions during decomposition that compete with P ions for soil sorption sites.

The integrated use of tithonia with TSP rather than sole application of TSP did not increase the amount of labile soil P, as determined by resin extraction. Neither did it enhance the reduction in sorbed P (table 19). The integrated use of tithonia with TSP, however, resulted in greater soil biological activity, as determined by microbial biomass P (table 19), than either sole tithonia or sole TSP produced. The influence of this enhanced microbial biomass P on P availability and crop yields will be the subject of future research.

In summary, the effectiveness of fresh tithonia leafy biomass for soil fertility improvement can be partially attributed to tithonia's rapid release of plant-available P, N and K. Applying tithonia at relatively high rates can also increase P availability by reducing P sorption on iron and aluminium oxides in soil. The integrated use of tithonia with commercial inorganic P fertilizers might also enhance soil biological activity and cycling of nutrients through labile organic P pools in the soil.

ON-FARM TRIALS WITH MAIZE

Researcher-managed experiments have confirmed that biomass from *T. diversifolia* and *L. camara*

Table 19. Effect of tithonia leafy biomass and triple superphosphate (TSP) on increase in microbial biomass P and decrease in P sorbed at 0.2 mg P litre^{-1} in solution

Weeks after application	Increase in microbial P (mg P kg^{-1})			Reduction in sorbed P (mg P kg^{-1})		
	Tithonia	TSP	Tithonia + TSP	Tithonia	TSP	Tithonia + TSP
2	4.3**	1.8	7.8**	49**	41*	30
16	1.6	0	3.7**	27*	10	20

* and ** designate significance at $p = 0.05$ and 0.01, respectively.

All values are relative to a control with no added TSP or tithonia.

substantially increase maize yields. On-farm trials of biomass transfer were thus initiated in 1995, 1) to confirm whether farmers could achieve the results obtained in on-station, researcher-managed experiments and 2) to determine the adoption potential of the technology and examine farmers' assessment of it. We report the results of the 1st 2 seasons of the trials—the short rains of 1995 and the long rains of 1996.

During visits to the on-station biomass transfer trials, farmers from West Bunyore and Central Bunyore of Vihiga District in western Kenya volunteered to test the technology on their farms. The trials were researcher designed and farmer managed. During the 1st season, each of the 36 participating farmers was asked to evaluate the fallows in 3 treatments:

- applying an equivalent of 5 t ha^{-1} dry matter of lantana (about 97 kg fresh matter per 25 m^2)
- applying an equivalent of 5 t ha^{-1} dry matter of tithonia (about 99 kg fresh matter per 25 m^2)
- control—with no biomass additions

The plot size was 5 x 5 m, it was replicated 3 times, and maize was the test crop. Farmers also had the option to use farmyard manure provided that they applied it uniformly across the 3 treatments.

The number of farmers involved in the 2nd season of the trial increased to 70. Plot size was expanded to 10 x 10 m, with 1 replication per farm. Most of the farmers said they wished to drop the lantana treatment. The amount of biomass to be applied was left to the discretion of each farmer, to allow them to apply what they could easily get. Rainfall and other environmental conditions affecting maize production were similar during the 2 seasons.

Maize yields following the applications were measured. For the cost–benefit analysis, residual yield increases during the 2nd season after application were estimated to be 40% higher than the control yield and during the 3rd season, 37% higher. These estimates were derived from the results of on-station trials.

During the long rains, 23 farmers were interviewed concerning the labour they used to collect, transport and apply tithonia biomass. In addition, 10 casual labourers were monitored while they collected tithonia to check the accuracy of the farmers' data. The questionnaire also included other variables to obtain farmer assessment of the technology.

Partial budgets were drawn up to assess the benefits and costs of using the technology. The benefit was an increase in maize yields over 3 seasons; the only cost was the cost of application of biomass, which was collected from existing hedges and did not have an alternative use. Labour was valued at its opportunity cost, that is, the prevailing wage rate, the equivalent of USD 1.22 per 6-hour day, including USD 0.28 as the value of lunch.

Two approaches were used to conduct the cost–benefit analysis. First, we used average values (for example, the average quantity of tithonia applied, the average time taken, and the average incremental yield obtained) to arrive at the average net present value (NPV) for the sample farmers. Second, we calculated the net present values for each farmer based on that farmer's own particular costs and returns. This latter measure permits us to better understand the variation in returns obtained by farmers. Data are based on

25 farmers for the short rains and 62 farmers for the long rains.

Biomass application

During the short rains in 1995, the experimenting farmers in Central Bunyore applied average dry matter weights of 4.1 t ha^{-1} of tithonia and 3.1 t ha^{-1} of lantana. In West Bunyore the average amount applied was 4.7 t ha^{-1} of tithonia and 3.7 t ha^{-1} of lantana. About 93% of the farmers in Central Bunyore applied between 2.5 and 5 t ha^{-1} of tithonia and 67% applied the same rate of lantana (table 20). The values for West Bunyore are 93 and 86% for tithonia and lantana, respectively.

During the long rains of 1996, the average amount of tithonia biomass collected and applied was 2.4 t ha^{-1} (SD =1.2), a decline of 48% compared with the previous season. This lower rate is more realistic, as it represents what the farmers could more easily get. Although the quantity applied per hectare declined, the total fresh weight of biomass that farmers applied increased from 94 kg to 171 kg, suggesting an increasing interest in testing the technology. The proportion of farmers who applied between 2.6 to 5 t ha^{-1} was greater in West Bunyore than in Central Bunyore (table 20).

There was some variation in the way that farmers applied the biomass: 70% incorporated it and 30% left it on the surface; 75% applied the mulch after sowing while 25% applied it before sowing.

Maize yields

In the short rains, tithonia applications increased maize yields by 60% over control plot yields ($p < 0.001$) (table 21). Lantana had much less effect, increasing yields by 30% ($p < 0.001$).

In the long rains, yield responses to tithonia applications were on average 63% higher than control yields ($p < 0.001$). The data suggest that

Table 20. Number of farmers who applied various amounts of biomass in Central Bunyore and West Bunyore locations

Range of application (t dry matter ha^{-1})	Central Bunyore (Ebukanga) Tithonia	Lantana	West Bunyore (Ochinga) Tithonia	Lantana
Short rains 1995				
< 1.25	0	0	0	0
1.26–2.5	1 (7)	5 (33)	1 (7)	2 (14)
2.6–5	14 (93)	10 (67)	13 (93)	12 (86)
Long rains 1996				
< 1.25	3 (10)	–	2 (8)	–
1.26–2.5	20 (65)	–	9 (36)	–
2.6–5	7 (23)	–	13 (52)	–
> 5	1 (3)	–	1 (4)	–

Values in parentheses are percentages.

Table 21. Effect of rates of application of tithonia and lantana biomass on grain yields

Rate of application (DM ha^{-1})	Grain yield (t ha^{-1})					
	Tithonia		Lantana		Control	
	SR 95	LR 96	SR 95	LR 96	SR 95	LR 96
< 1.25	–	1.64 (0.65)	–	–	–	–
1.25 – 2.5	–	1.80 (0.49)	–	–	–	–
2.5 – 8.1	1.59 (0.82)	2.13 (0.92)	1.33 (0.64)	–	–	–
Mean	1.59 (0.82)	1.84 (0.68)	1.33 (0.64)	–	0.99 (0.50)	1.13 (0.48)
No. of farms	27	61	27	0	27	61

Values in parenthesis are the standard deviation

farmers who applied the greatest amount of biomass (2.5 to 8.1 t ha^{-1}) recorded 100% yield increases and those who applied less than 1.25 t ha^{-1} recorded 50% yield increases. However, differences in yields among the different categories were not statistically discernible ($p = 0.17$). Farmers' assessment of the yield effects of tithonia were generally positive; 70% noted that tithonia plots had higher yields than the control plots.

Labour use

The average amount of time taken to collect 1 kg of fresh tithonia biomass was 4.0 minutes (SD = 1.8). Three-quarters of this time (3 min) was for collection and one-quarter for application. The collection time included the time spent to walk to the collection point, but that was brief, as none of the farmers had to walk more than 200 m.

Data from the monitoring of casual labourers were similar to those given by farmers. The labourers required 2.5 minutes (SD = 0.2) to collect 1 kg of biomass, as compared with 3.0 minutes for the farmers, as mentioned above.

The data thus show that to apply the average rate of 2.4 t ha^{-1} dry matter during the long rains required 178 workdays. However, the labour requirements of biomass transfer are probably underestimated because labour cannot be extrapolated with accuracy from 100 m^2 to 1 ha, for 2 reasons: 1) work rates are slower on larger plots because farmers tire and cannot work at the same rate as they do on small plots and 2) as quantities applied increase, the distance to the point of collection increases.

Economic analysis

Coefficients and prices used in the analysis are shown in table 22. In the short rains analysis, 37.4 t ha^{-1} fresh biomass was applied, using 420 workdays, and yields increased by 61% (table 23). The average net present values per hectare, using average values for costs and benefits, as compared with the control plot were substantially negative, with a mean value of USD –330. In the analysis based on each farmers' individual performance, only 1 of the 25 farmers had a

Table 22. Coefficients and prices used in the economic analysis

Coefficients and prices	Values	Data sources
Quantity of biomass applied—short rains	37.4 t ha^{-1} fresh biomass	measured in on-farm trial
Quantity of biomass applied—long rains	18.9 t ha^{-1} fresh biomass	measured in on-farm trial
Plot size—short rains	25 m^2	measured in on-farm trial
Plot size—long rains	90.38 m^2	measured in on-farm trial
Time taken for collection and application	4 min kg^{-1} fresh biomass	farmer survey
Labour cost	USD 1.22 day^{-1}	farmer survey
Incremental yield: short rains	61%	measured in on-farm trial
Incremental yield: long rains	63%	measured in on-farm trial
Maize price	USD 0.146 kg^{-1}	market price after harvest, 1996
Discount rate	20% per year	assumption
Residual yield increase: season 2	40%	on-station trials
Residual yield increase: season 3	37%	on-station trials

Table 23. Net present value per hectare of maize, using average values for costs and benefits as a result of applying tithonia

Season	Quantity of fresh biomass (t)	No. of workdays† taken to collect/apply	Cost of labour (USD)	Incremental yield (kg)	Increase in gross revenue (USD)	Increase in net income (USD)
Crop yields following tithonia application, short rains 1995						
Season 1	37.4	420	514	604	88	−425
Season 2 (residual)	–	–	–	242	35	35
Season 3 (residual)	–	–	–	223	32	32
						NPV = −330
Crop yields following tithonia application, long rains 1996						
Season 1	18.9	210	257	709	103	−153
Season 2 (residual)	–	–	–	284	41	41
Season 3 (residual)	–	–	–	262	38	38
						NPV = −76

† 1 workday = 6 hours

positive net benefit, as compared with the control plot. The extra costs that all the other farmers incurred were more than the extra benefits they gained from using tithonia.

In the long rains, economic performance was considerably better, perhaps because application rates were lower and yield response per unit of biomass applied increased (table 23). Farmers applied 18.9 t ha^{-1} fresh biomass, using 210 workdays and increasing maize yields by 63%. Net present values declined on average by USD 76. Ten of the 62 farmers achieved positive net present values.

Sensitivity analysis was also conducted to assess the effect of changes in key parameters on performance (table 24). If the maize price is adjusted upwards to its peak price during the year, the losses in NPV, using average costs and benefits, are reduced to an average of USD –232 ha^{-1}. If the wage rate is halved, losses are still USD –100 ha^{-1}. Changes in the discount rate from 20 to 5% have little effect on the NPV.

Break-even prices for labour and maize were also computed. Losses would be reduced to 0 if the wage rate fell to USD 0.35 day^{-1} or if the maize price rose to USD 0.51 kg^{-1}, both of which are highly unrealistic. The use of tithonia biomass on maize was highly unprofitable during the short rains of 1995 under a wide range of scenarios.

However, for the long rains 1996 data, some changes in the parameters result in positive average net present values. For example, when the price of maize is raised to its peak season price, the average NPV is USD 43 ha^{-1}. Farmers would break even using the technology if the wage rate was USD 0.81 day^{-1} or if the maize price was USD 0.22 kg^{-1}.

That the results are highly sensitive to the product price has important implications. If the physical response of higher value crops to tithonia applications is similar to that of maize, then profitability will be higher. This is clearly illustrated by farmers' experience with applying tithonia biomass to a vegetable such as 'sukuma wiki' (*Brassica oleracea* cv *acephala*—kale) that is marketable locally.

Table 24. Sensitivity analysis to assess effects of changes in key parameters

	Net present value ha^{-1}	
	Short rains 1995 (USD)	Long rains 1996 (USD)
Base analysis	–330	–76
Maize price +76% (peak season price)	–232	43
Wage rate –23% (value of lunch excluded)	–225	–22
Wage rate –50%	–100	40
Discount rate 5%	–345	–75
Discount rate 20%	–311	–77
Break-even wage rate (USD day^{-1})	0.35	0.81
Break-even maize price (USD kg^{-1})	0.51	0.22

ON-FARM TRIALS WITH SUKUMA WIKI

Following the long rains of 1996, we held a meeting with the farmers from West and Central Bunyore who had evaluated maize responses to tithonia application. Over 70% of the farmers were pleased with the maize yield responses they had observed, and many were keen to try tithonia application on other, higher value crops, such as the popular sukuma wiki, during the short rains of 1996.

Farmers were asked to set up 2 plots, 1 on which tithonia was applied and a control with no fertility input. It was recommended that a rate of application of 2.5 kg of point-placed fresh tithonia per square metre (equivalent to 5 t ha^{-1} dry matter) be aimed for, but it was recognized that many farmers would not be able to achieve this rate. They were therefore provided with standard-sized bags holding a known weight of fresh tithonia

Applying tithonia biomass to relatively high-value vegetable crops such as sukuma wiki (Brassica oleracea cv acephala), *or kale, is showing good economic returns on the labour expended.*

leaves and were asked to record how many bags they applied to their plots. The size of plot they wished to use was left to their choice but was recorded. From these data, amounts applied were calculated in tonnes per hectare of fresh weight. Based on previous survey data, the labour required to collect and incorporate the tithonia biomass (4 min kg^{-1} fresh weight) was calculated and costed at USD 0.20 per hour.

Farmers were also asked to record how much sukuma wiki they picked and sold from each plot each day and the price they received. Based on the extra labour required to collect and incorporate tithonia and the additional income derived, increases in net revenue resulting from the tithonia application were calculated for each farmer.

Our analyses are based on the experience of 13 farmers from West Bunyore and 10 from Central Bunyore, who provided the information they had been requested to collect from the 2 plots. As would be expected, the plot size chosen by farmers was variable, ranging from 60 m^2 to 1200 m^2, with an average plot size of 430 m^2 and 190 m^2 in West and Central Bunyore, respectively (table 25). The rate at which they applied the tithonia was also highly variable (fig. 23), ranging from 5 to 24 t ha^{-1} fresh weight. Not surprisingly, the rate of application was related to the size of plot the farmers chose, higher rates being recorded on smaller plots, with an average rate of application of 10.8 t ha^{-1} and 17.5 t ha^{-1} in West and Central Bunyore, respectively (table 25).

Table 25. Mean effects of tithonia green manure on value of sukuma wiki sold at 2 locations in western Kenya, 1996

Location	No. of farmers	Mean plot size (m^2)	Mean tithonia application (t ha^{-1} fresh weight)	Application labour cost (USD ha^{-1})	Mean value of kale sold (USD ha^{-1})		Mean increase in net revenue (USD ha^{-1})
					Control	Tithonia	
West Bunyore	13	430	10.8	142	487	1254	625
Central Bunyore	10	190	17.5	229	585	1629	815

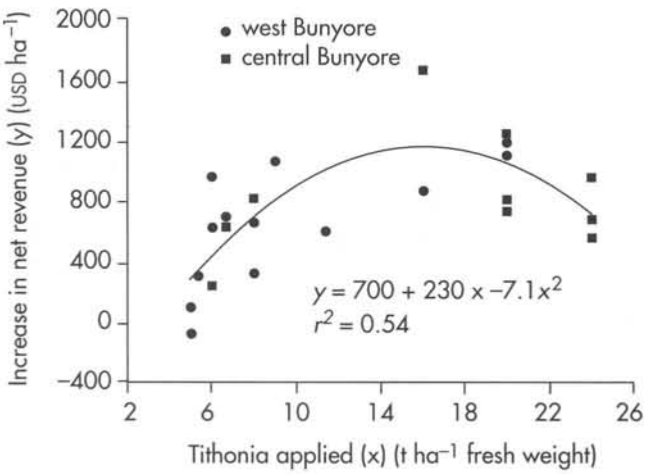


Figure 23. The effect of tithonia biomass application to sukuma wiki (kale) on increases in net revenue on 23 farms in West and Central Bunyore, western Kenya, 1996 (5 t ha^{-1} fresh weight is equivalent to approximately 1 t ha^{-1} dry weight).

Farmers recorded substantial increases in both gross and net revenue from plots in which tithonia was added. Increases in net revenue ranged from USD 91 to 1665 ha^{-1} with only 1 farmer out of 23 recording a net decrease in income of USD –82 ha^{-1} (fig. 23). Farmers informed us that the price they obtained for their sukuma wiki varied with quality and time. Bigger, softer leaves that were pest and disease free fetched a higher price, and in general prices increased during the latter end of the harvest period because of a prolonged dry spell. Farmers also observed that not only did they obtain more leaves when tithonia was applied but that the leaves were of a higher quality and commanded a higher price.

In farmer-designed and -managed trials such as this, we do not expect to be able to develop robust response functions because of the variability introduced by contrasting soil conditions, rainfall, and farmers' management and monitoring. Nevertheless, our analysis did show a clear relationship between the amount of tithonia applied and the increase in net revenue (fig. 23), which is very encouraging. The relationship suggests that the optimum rate of application of point-placed tithonia biomass to sukuma wiki lies between 14 and 18 thousand kg fresh weight ha^{-1}, or 1.4 and 1.8 kg fresh weight m^{-2}.

These highly profitable responses of a popular local vegetable to tithonia biomass transfer are encouraging for researchers and farmers alike. In general, vegetable crops, although nitrogen demanding, do require a balanced supply of phosphorus and, in particular, potassium. Given the fact that leaves from sukuma wiki are harvested over an extended period, the supply of nutrients should not only be balanced but also be released slowly and be available over time. The breakdown of biomass from tithonia may result in the regulated release of a balanced supply of nutrients, which appears ideal for sukuma wiki production. Indeed, farmers who have had experience of applying diammonium phosphate (DAP) to sukuma wiki have informed us that the beneficial effects of nutrient inputs through tithonia are more prolonged, as the harvest period extended beyond that experienced with DAP.

CONCLUSION

Although the net present values for 2 seasons were negative for biomass application on maize, there are strong reasons for optimism concerning biomass transfer:

- The biophysical response to tithonia applications was strongly positive.
- The performance of the technology with maize improved markedly in the 2nd season. This may indicate that farmers are learning more about the technology and implementing it more effectively. That farmers applied a lower rate of tithonia in the 2nd year may have contributed to its higher economic performance.
- On-station trials show a strong synergy between applications of P and tithonia.
- The crop has been tested most widely on maize, but recent results show that the economic performance is much more positive on higher value crops such as sukuma wiki.

On the other hand, it should be noted that because of the high labour requirements and limited supplies of tithonia available, the technology is likely to be practical on only a limited portion of the farm.

In 1997, following the 3rd season of biophysical measurements on biomass transfer, farmers will be left to continue experimenting with the technology on their own. Many are beginning to test it on crops of value higher than that of maize. Researchers will continue to monitor their management of the technology, and in particular, they will monitor whether farmers expand its use on their own. On-farm research has also been initiated with other groups of farmers to confirm the positive on-station results of combining biomass transfer with phosphorus applications. These trials will assess biophysical response under farmers' management and obtain farmers' assessment of the technology.

REPLENISHING SOIL FERTILITY THROUGH IMPROVED SESBANIA FALLOWS AND PHOSPHORUS FERTILIZATION

Short-duration, planted tree fallows using *Sesbania sesban* have shown their value in restoring nitrogen fertility in southern Africa and in capturing subsoil nitrate in eastern Africa

(ICRAF annual report 1995 p 64–68, 76–88). This year we report on their biomass accumulation, N mineralization and economics on a long-term improved fallow experiment, methods of establishing them, their nematode problems and weed control.

An experiment was conducted in western Kenya to compare the effects on maize production of a planted *S. sesban* fallow, a natural uncultivated fallow and continuous maize cropping and the financial benefits of each, for a period of 7 seasons. The experimental site was at 1420 m elevation with mean annual rainfall of 1800 mm distributed in 2 growing seasons per year (March to August and September to January). The site had not been fertilized in recent history; the soil was a Kandiudalfic Eutrudox with pH (1:2.5 soil-to-water suspension) = 5.1, organic C = 15 g kg^{-1}, bicarbonate-EDTA extractable P = 2 mg kg^{-1} and clay = 46%—therefore, a P-depleted and high P-sorbing soil.

The experiment was established in March 1993 in a randomized complete block with 4 replications and 3 treatments (table 26). In the 1st season (March to August 1993) all treatments were cropped with unfertilized maize. *S. sesban* (Kisii provenance) was seeded directly between maize rows to give a between-row spacing of 2.25 m and a within-row spacing of 0.4 m (11 100 trees ha^{-1}). For the next 3 seasons, maize was not grown in the sesbania fallow and vegetation was allowed to regrow naturally, with no management in the natural fallow. In January 1995, at the end of the 4th season (22 months), all woody plant material in the sesbania and natural fallows was removed from the plots, while the leaves and litter were incorporated into the soil during land preparation for a subsequent maize crop. At the beginning of season 5, all plots were split into 2 subplots—1 with no P added and the other with a recapitalization rate of 200 kg P ha^{-1} broadcast and incorporated once as triple superphosphate (TSP). Maize was grown in all treatments for the next 3 seasons. All above-ground maize and weed biomass were removed from plots after each maize harvest.

Net benefits were determined from the difference between maize and sesbania value and the added costs. The benefits were discounted at 10% per season. The prices for maize and sesbania seeds, fertilizers, fertilizer transport and chemicals for control of pests were determined through a

Table 26. Description of the 3 treatments in each of the 7 seasons

Treatment	Land use						
	Season 1	Season 2	Season 3	Season 4	Season 5	Season 6	Season 7
Continuous maize	M	M	M	M	M ± P	M	M
Sesbania fallow	M/SF	SF	SF	SF	M ± P	M	M
Natural fallow	M	NF	NF	NF	M ± P	M	M

M = maize; P = phosphorus applications; SF = sesbania fallow, established by relay sowing in maize in season 1; NF = natural fallow market survey in the area, as were the values of maize grain and sesbania fuelwood. Maize stover was assumed to be of no value. Only 30% (3 t ha^{-1}) of the sesbania wood from stems (> 2 cm diameter) was valued, because farmers typically give some wood to neighbours and friends. Labour was valued at its opportunity cost, that is the prevailing wage rate. Labour requirements for land preparation, fertilization, planting, weeding, pest control, harvest, postharvest and fallow clearance were obtained from other research in the area. Sensitivity analysis was conducted to assess the effects of changes in labour wages, amount of P fertilizer, costs of sesbania pest control, amount of firewood valued and methods of sesbania establishment on net benefits. All monetary values were converted to US dollars (USD) at the mean exchange rate of 53 Kenyan shillings to USD 1.

Table 27. Biomass and N and P content of the components of 20-month-old sesbania fallow in western Kenya

Sesbania plant part	Total dry weight (t ha^{-1})	N content (kg ha^{-1})	P content (kg ha^{-1})
Total wood	19.7	177	8.2
Wood, > 2 cm diameter	10.1	77	3.6
Leaves + pods	1.9	66	2.6
Litterfall	3.3	69	1.9

SESBANIA BIOMASS AND NITROGEN MINERALIZATION

The total above-ground standing biomass of sesbania at the end of the 20-month fallow was 24.9 t ha^{-1} dry weight. Most of this biomass was wood, which was removed from plots (table 27). Sesbania leaves and pods (1.9 t ha^{-1}) and litterfall (3.3 t ha^{-1}) contained 135 kg N ha^{-1} and 4.5 kg P ha^{-1}. Although some of these nutrients might have been utilized by sesbania during the fallow phase, most of them were recycled for the benefit of subsequent maize crops. Some of the recycled N may represent a net input to the system through biological N_2 fixation and capture of nitrate from subsoil below the rooting depth of maize. Removal of sesbania wood, therefore, resulted in export of 177 kg N ha^{-1} and 8.2 kg P ha^{-1} (table 27).

Nitrogen mineralization in the soil was much greater following sesbania fallow than after either natural fallow or continuous unfertilized maize. In the 3 months after the fallows, the increase in inorganic N in the top 1 m of soil was 126 kg N ha^{-1} following sesbania, as compared with 33 kg N ha^{-1} following natural fallow and 31 kg N ha^{-1} following continuous maize. The high-quality litter (C : N ratio = 14) and leaf material from sesbania quickly decomposed and released nutrients, whereas nutrient release was slow from the lower quality, dead, above-ground biomass of weeds (C : N ratio = 27) in the natural fallow.

ECONOMICS OF SESBANIA FALLOWS

Sesbania fallows and the application of P to maize increased maize grain yield in the 1st season after the fallows (ICRAF annual report 1995 p 67–69). Total maize grain yield for the entire 7 seasons (long rains 1993 to long rains 1996), averaged for the 2 levels of P application, was 10.6 t ha^{-1} with the sesbania fallow, 8.4 t ha^{-1} with continuous maize and 7.7 t ha^{-1} with the natural fallow. Mean grain yield, averaged for the 3 treatments, was 9.9 t ha^{-1} with added P and 6.5 t ha^{-1} without P.

Net benefits calculated for the entire 7 seasons were negative for continuous maize and positive for the sesbania fallow with application of P to maize (fig. 24). The negative benefits for continuous maize cultivation without P fertilization reflect low maize yields on this P-depleted soil and cultivation expenses every season. The application of P in season 5 increased maize yield in the continuous maize system (ICRAF annual report 1995 p 67–69), but the increase in yield in the subsequent 3 crops was counteracted by the increased cost for the P fertilizer. Continuous cultivation of maize monoculture also led to increased pest and disease pressure, which may have limited maize yield even with the application of P fertilizer.

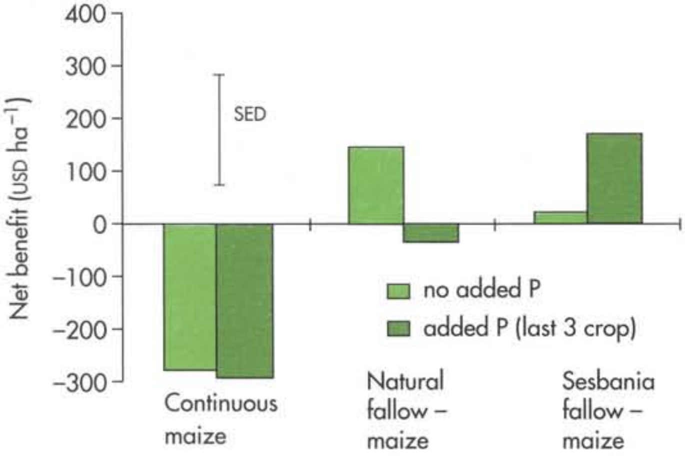


Figure 24. Sesbania fallows plus P fertilization are more profitable than continuous maize or natural weedy fallows in a 7-crop trial near Maseno in western Kenya.

Net benefits were positive for the natural weedy fallow without P fertilization. The fact that benefits for the natural fallow were much higher than for continuous maize reflects the greater total maize yield for the 7-season period and a substantial reduction in labour during the 3 fallow seasons when maize was not planted. Net benefits decreased with P fertilization in the natural fallow. The P-fertilized maize after the natural fallow was limited by N deficiency because of microbial tie-up of soil inorganic N during the decomposition of the low-quality weed biomass with high C : N ratio. The extra costs of the fertilizer exceeded the value of increase in maize yield in the case of natural weedy fallows.

Net benefits for the sesbania fallow were negligible without P fertilization, but they increased markedly with it, even though only 3 crops benefited from the P application. The higher net benefits for sesbania fallow than for continuous maize reflect greater total maize yield for the 7-season period and, again, a substantial reduction in labour during the 3 fallow seasons when maize was not planted. Fertilizing with phosphorus after the sesbania dramatically increased maize yield. The plant-available N in the soil after the sesbania was sufficient for a high yield of maize because the nitrogen was released rapidly as the recycled sesbania biomass decomposed. The increase in inorganic N in the top 1-m layer of soil during the 3 months following fallows was 126 kg ha^{-1} after the sesbania fallow and 33 kg ha^{-1} after the natural fallow; it was 31 kg ha^{-1}

after continuous maize. Rotating maize with sesbania may also have reduced the pest and disease pressure on subsequent maize.

The sensitivity analysis revealed that net benefits for the systems with P fertilization were strongly influenced by the labour wage rate (fig. 25). The net benefits indicated in figure 24 are based on labour being valued at the current wage rate of hired farm labourers (USD 1.22 day^{-1}). The labour rate would decrease were the use of family labour to increase, especially during nonpeak periods, when the opportunity for off-farm employment is limited. Under such conditions of reduced labour wage, the relative economic attractiveness of sesbania fallows as compared with continuous maize would decrease. On the other hand, the labour rate could increase in environments in which there is greater opportunity for off-farm employment. Under those conditions, sesbania fallows would become relatively more attractive than continuous maize.

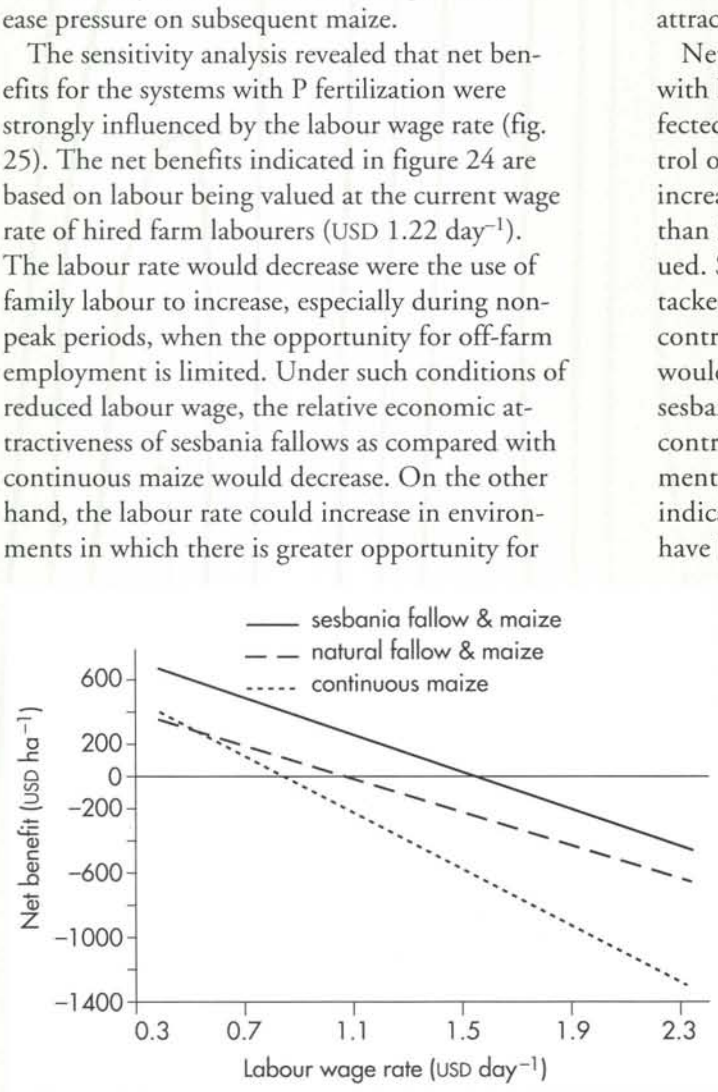


Figure 25. Effect of labour wage rate on net benefits during 7 crop seasons for a sesbania fallow with P fertilization on maize, in Maseno, western Kenya.

Net benefits for the sesbania fallow system with P fertilization of maize were strongly affected by the valuation of fuelwood, pest control of sesbania and P fertilization. Net benefits increased by 45% (USD 75 ha^{-1}) when all rather than 3 t ha^{-1} of the wood from sesbania was valued. Sesbania at the western Kenya site was attacked by the mesoplatys beetle, which was controlled with chemicals. The net benefits would have increased by USD 222 ha^{-1} if sesbania pests had not been a problem and pest control had not been required in this experiment. Subsequent research in western Kenya indicates that the P application to maize could have been reduced to 100 kg P ha^{-1} without a reduction in maize yield, to provide a residual effect for 3 crops. A reduction in application of TSP fertilizer from 200 to 100 kg P ha^{-1} increased net benefits by USD 170 ha^{-1}. Maize yield was very low and limited by P in season 1 when sesbania was relay established. Other research results indicate that P fertilization to this maize could at least double grain yield. Doubling maize yield in season 1 with application of 50 kg P ha^{-1} while applying 150 rather than 200 kg P ha^{-1} in season 5 with no change in yield would increase net benefits by USD 89 ha^{-1}. The net benefits would be even higher if the 50 kg P ha^{-1} had a positive residual effect on maize yield in the following 2 crops.

The results indicate that sesbania fallows with P fertilization are economically profitable for maize. As labour wages increase, sesbania fallows become more attractive when compared with continuous maize cultivation. The benefits of attractiveness of tree fallows also increases because the fallows produce fuelwood, of economic value. Planted tree fallows on P-deficient soil would be most attractive when P is applied to maize both before and after the fallow.

SESBANIA FALLOWS AND THE ROOT-KNOT NEMATODE PROBLEM

Sesbania sesban—the most promising species for short-duration planted fallows in eastern and southern Africa—is known to be an important host of root-knot nematodes *(Meloidogyne* spp), which are a serious pest of many field crops (for example, bean, tobacco, potato, cotton) and vegetables (for example, tomato, eggplant, capsicum). Maize—the most important food crop and grown immediately after sesbania fallows—is not, however, affected by the root-knot nematode. Susceptibility to nematode is particularly a problem for the crops with which it is traditionally grown in rotation (for example, tobacco, beans or cotton) or intercropped (bean or cowpeas).

Unlike the pests that affect above-ground foliage, soilborne pests, particularly nematodes, are not easily recognized. If sesbania fallows are to fulfil the exciting potential of replenishing soil fertility in N-depleted soils (ICRAF annual report 1994 p 141–142; annual report 1995 p 64–69 and p 76–88), a number of issues concerning the root-knot nematode must be addressed. Particular attention should be paid to 1) the frequency and severity of root-knot nematode on farms, 2) the effect of sesbania on root-knot nematode populations and the impact of these populations on susceptible crops grown simultaneously or sequentially with sesbania, 3) the comparison between sesbania fallows and natural fallows with regard to the root-knot nematode problem, 4) the susceptibility of sesbania itself to nematode infestations, 5) the soil conditions that enhance the potential threat of nematode to sesbania and crops, 6) the required interval between sesbania fallow and a nematode-susceptible crop to minimize the risk of serious infestations, and 7) the potential tolerance or resistance to root-knot nematode among sesbania provenances or alternative species.

Research on root-knot nematodes began in 1994 at the Maseno Agroforestry Research Centre in western Kenya to investigate some of the above issues. Additional work is also being undertaken in southern Africa (see ICRAF annual report 1991 p 66–67).

ROOT-KNOT NEMATODES ON THE FARM

To determine the extent of the root-knot nematode problem in western Kenya, where sesbania is beginning to be integrated with crops, 14 farms in Vihiga District have been monitored for their nematode populations and their effects on a range of crops. These farms have been growing maize or maize–bean intercrops for many years. Soil samples from the top 30 cm were taken at the start of the 1995 long rains from 10 locations on each farm, and a composite sample for nematode observations was prepared for each farm. Five test crops—tomato (*Lycopersicon esculentum* cv Money Maker), pepper (*Capsicum annuum* cv Long Red Cayenne), cowpea (*Vigna unguiculata* cv local), amaranthus (*Amaranthus hybridus* cv local), and bean *(Phaseolus vulgaris* cv Rose Coco)—known to be susceptible to root-knot nematode and 2 *Sesbania sesban* provenances (Kakamega and Kisii) were planted on these farms in single-row strips over an area 7 x 5 m in the 1995 long rains. Tomato, pepper and sesbania were established using seedlings raised in a nursery, while cowpea, amaranthus and bean were established by directly sowing seeds, as is the common practice with these crops. Spacing between rows was 1 m and between plants within rows, 0.3 m. Soil and crop root samples from each test strip were taken 60 and 120 days after planting for observation of nematode populations and damage.

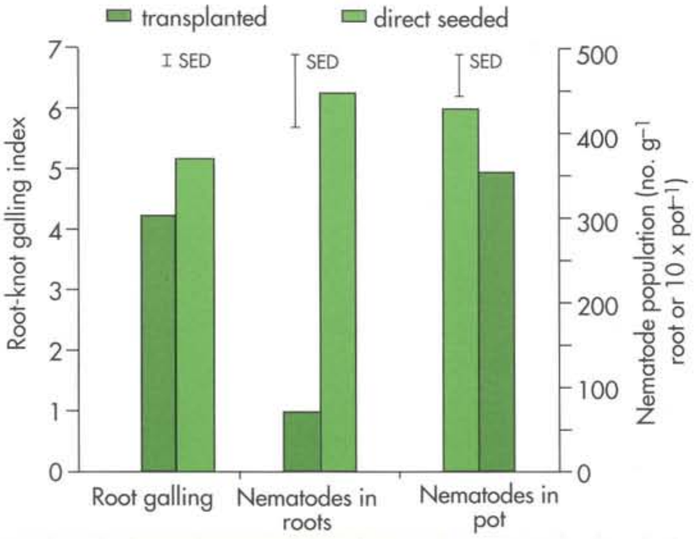


Figure 26. Populations of the most commonly occurring parasitic and non-parasitic nematodes on farms that have been cropped previously with sole maize and maize–bean intercrop in western Kenya (average of 14 farms).

Although a number of parasitic nematodes were observed across farms, the most commonly found ones were root-lesion *(Pratylenchus* spp), root-knot (*Meloidogyne* spp), reniform (*Rotylenchulus* spp) and spiral (*Helicotylenchus* spp, *Scutellonema* spp, *Rotylenchus* spp) nematodes (fig. 26). The root-lesion nematode populations were particularly high in fields that had previously been cropped with sole maize, which is not surprising considering the parasite's well-known association with cereal crops. Although the extent of economic damage caused by root-lesion nematode is not known, poor growth of maize in monocropped fields is often attributed to the presence of high populations of nematode and the black-root lesions it causes. While root-knot and reniform nematodes were absent where maize was grown as a sole crop, both were observed on farms where maize was intercropped with bean. This can be explained by the fact that many food legumes are known to be susceptible to root-knot, reniform and root-lesion nematodes. Populations of spiral and non-pathogenic nematodes were abundant on most farms, irrespective of their cropping history. The pathogenicity of spiral nematodes is poorly understood, but some of them are destructive to crops such as *Scutellonema bradys* on yam and *Helicotylenchus multicinctus* on banana.

At 60 days, while tomato recorded the highest populations of root-knot nematode (124 juveniles g^{-1} root), bean recorded the highest populations of root-lesion nematode (96 juveniles g^{-1} root), and both crops showed clear symptoms of damage caused by the respective nematodes. The extent of root-knot infestation was assessed by the standard rating of root galling on a 0-to-10 scale, where 0 is no infestation and 10 is extremely severe infestation. Tomato suffered the maximum from root-knot infestation on all farms and showed very high symptoms of root galling (indices > 5) on 93% of the farms. Sesbania showed root galling indices > 1 on 64% of the farms and bean > 1 on 29%. As all crops had matured by 100 days, nematode assessment at 120 days was done only for sesbania. Root galling on sesbania increased gradually with age (to an average of 3.7 at 120 days). Cowpea and pepper were affected by root-knot nematode on very few farms (< 14%). Amaranthus did not grow normally because of severe phosphorus deficiency and died soon after germination on all farms.

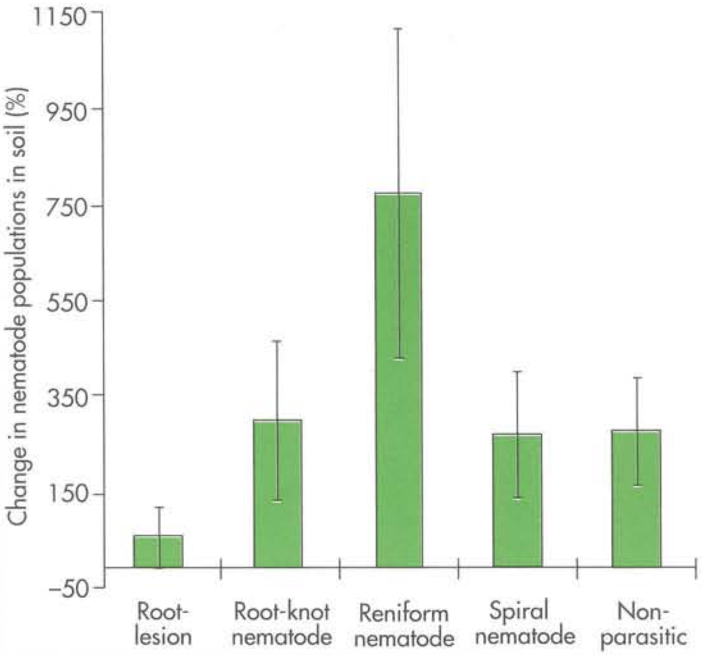
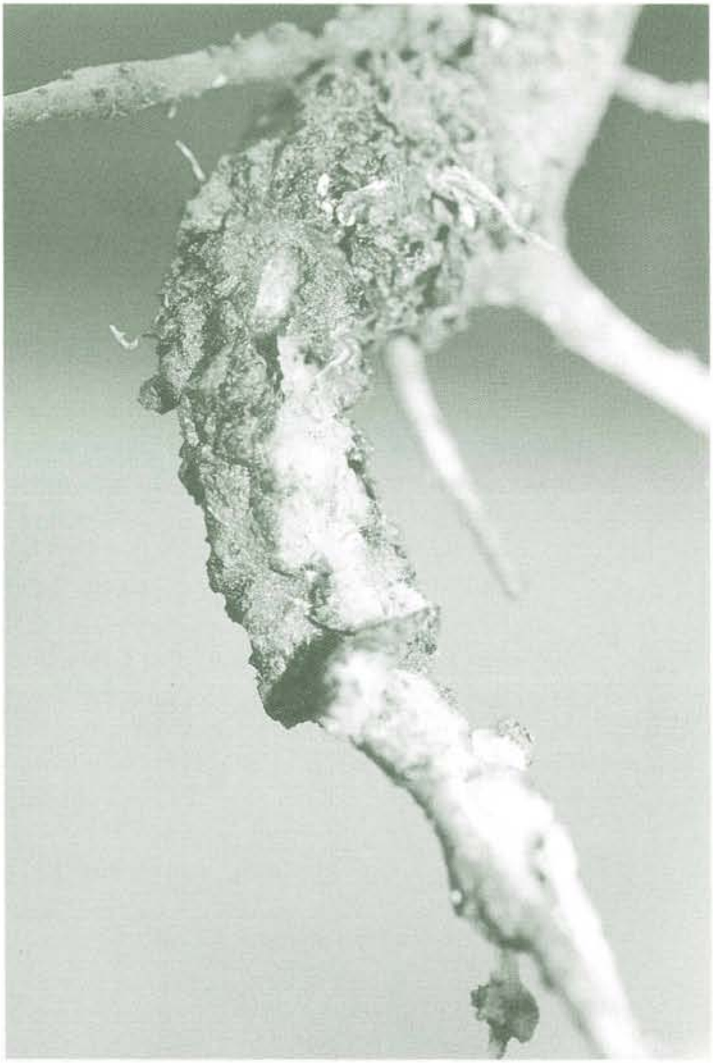


Figure 27. Percentage of change in the soil population levels of different parasitic and non-parasitic nematodes following the growth of Sesbania sesban *4 months after planting on farms in western Kenya (average of 14 farms).*

Sesbania had caused a 3-fold increase in the populations of root-knot nematode, nearly an 8-fold increase in reniform nematode, a 2.7-fold increase in spiral nematodes and a 2.8-fold increase in non-parasitic nematodes over the 4-month growth period (fig. 27). The buildup of these nematodes was generally much higher on fields cropped previously with maize–bean intercrop than with sole maize. Sesbania reduced the populations of root-lesion nematode by half during the same period of growth where maize was the previous crop, but it increased the populations by 140% where the previous cropping system was a maize–bean intercrop. Averaged across all farms, sesbania increased root-lesion nematode by 60%. These results clearly show that root-knot nematode is widespread wherever crops (such as bean) susceptible to this nematode have been grown previously and that sesbania can build its populations further by serving as a



*The root-knot nematode (*Meloidogyne *ssp) attacks* Sesbania sesban, *a species proving very valuable for improved fallows. It affects the sesbania roots, as shown here, and then attacks crops often grown in rotation following the sesbania, including beans, cotton, potato and tomato. Researchers are now investigating possible measures to control the nematode.*

good host. They further indicate that the susceptible crops experience different degrees of damage for any given level of root-knot population.

A rangewide screening of *Sesbania* species germplasm collections is necessary to determine whether there is scope for selecting material resistant to the nematode.

SCREENING SESBANIA FOR NEMATODE TOLERANCE

Thirty single-plant accessions belonging to 4 provenances (Kakamega, Siaya, Kisumu, Kisii) of *Sesbania sesban* collected in western Kenya were evaluated to get a preliminary assessment of provenance differences in resistance to root-knot nematode. The study was conducted over a 4-month period in pots containing 1 litre of nematode-infested field soil. The evaluated accessions were planted by 2 methods: 1) transplanting of 6-week-old potted seedlings, raised in heat-sterilized soil, and 2) direct seeding. Each accession was grown in 8 pots with seedlings and 6 pots with seeds, with 1 plant per pot. At 60 days, 3 pots of each planting method of each accession were sampled, and at 120 days, the remaining pots were sampled to assess nematodes on the root-knot index (0–10 scale) and monitor juvenile populations in root and soil.

The transplanted seedlings grew much better than the direct-seeded plants; otherwise, ranking of accessions between the 2 planting methods was very similar. All accessions were visibly affected by the root-knot nematode, and the extent of infestation as measured by root galling index (RGI) increased over time. At 60 days, RGI of sesbania accessions varied from 1.7 to 4.7 compared with 6.5 for the most susceptible crop, tomato, and at 120 days it varied from 3.3 to 6.4, when the tomato died completely. Provenance differences for RGI were not marked except for Siaya provenance, which had shown significantly higher values than the others. Nematode populations (2nd stage juveniles, J_2) in the roots varied considerably. At 60 days they were highest in the Kakamega provenance (average 103 g^{-1} root), but at 120 days they were highest in the Siaya provenance (average 120 g^{-1} root). Nematode populations in the soil were more distinctly different among accessions than were the populations in the roots (fig. 28). Both Kisii and Siaya provenances accumulated significantly higher nematodes than did Kakamega; Kisumu provenance showed intermediate values. Accessions of Kakamega and Kisumu provenances were fairly homogeneous, but those of Siaya and Kisii provenances have shown considerable variability in soil juvenile populations.

These results suggest that although provenance differences may exist for tolerance to nematode, there is little likelihood of finding an accession of *S. sesban* among the Kenyan germplasm that is completely free from the nematode problem.

However, a large-scale screening will be undertaken through a collaborative project with the International Institute of Parasitology, UK,

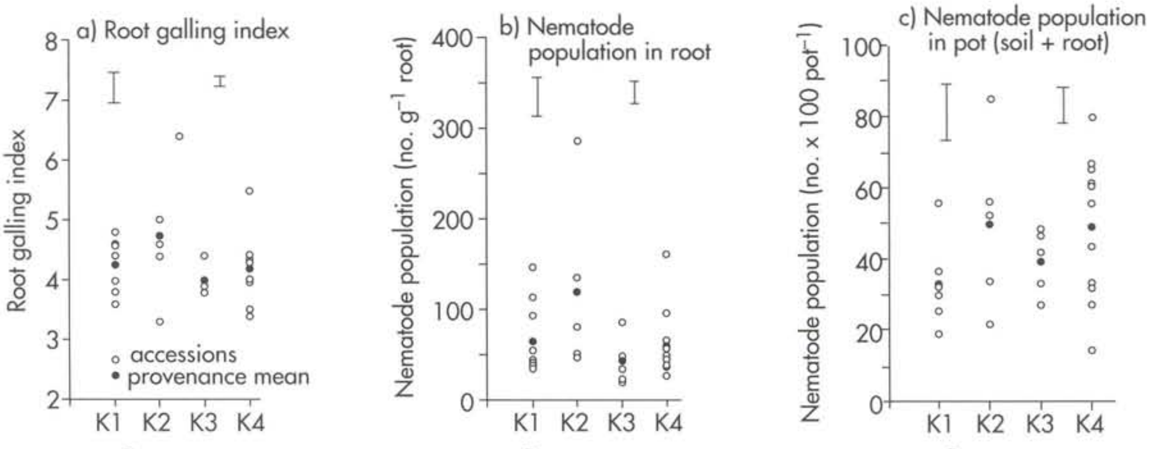


Figure 28. Response of single-plant accessions of 4 Sesbania sesban *provenances to root-knot nematode. K1 = Kakamega, K2 = Siaya, K3 = Kisumu, K4 = Kisii.*

supported by DFID. It must be recognized that a provenance resistant to nematode may not be interesting for fallow technology for that characteristic only; it must also produce a large amount of biomass, as the fallow effect on subsequent crops is determined to a great extent by the total biomass produced by the fallow. Fortunately, the Kakamega provenance, which had a smaller nematode population in the soil than all others tested in the above study, was found to produce a large quantity of biomass (see ICRAF annual report 1990 p 46).

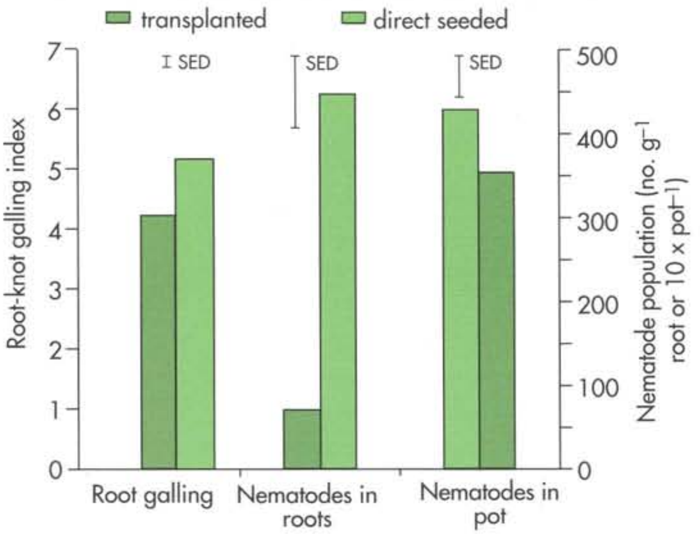


Figure 29. Effect of transplanting vs direct seeding on infestation and reproduction of root-knot nematode on Sesbania sesban *at 120 days after planting in pots.*

TRANSPLANTING OR DIRECT SEEDING?

Transplanted sesbania recorded significantly smaller nematode populations per gram of root and consequently suffered less damage from the nematode (indicated by the root galling index) compared with the direct-seeded sesbania (fig. 29). As the seedlings used for transplanting were raised in sterilized soil, they were free from nematodes when they were transplanted. The transplanted seedlings, with a good root system, established quickly and thus were better able to withstand the nematode infestation. This indicates that the deleterious nematode effect on sesbania growth can be reduced by transplanting seedlings produced in nematode-free soil. Bare-root seedlings, with which sesbania can be conveniently established on the farm, can be produced free from nematodes easily by treating the soil in the nursery bed with a nematicide. The total nematode population in the pot (that is, the population in soil and roots combined) was 20% higher for transplanted than for direct-seeded sesbania, primarily because the large root biomass of transplanted plants accumulated a large nematode population. This suggests that the planting method of sesbania fallows may not make much difference in the overall buildup of root-knot nematode populations and their effect on subsequent crops.

POTENTIALLY RESISTANT FALLOW SPECIES

Two preliminary tests were conducted in pots, one with different *Crotalaria* species and another with a number of tree and shrub species, to evaluate them for their tolerance or resistance to root-knot nematode. While crotalarias are suitable for

1-season fallows, the other species being evaluated can be considered as alternatives to sesbania for 1- to 2-year fallows. Plants of the test species were established, either by transplanting seedlings or direct seeding, and grown for 4 months in replicated pots containing infested soil. The plants were sampled for observations of root galling and nematode populations at 60 and 120 days after planting.

The *Crotalaria* species screened included *C. agatiflora, C. endecaphylla, C. grahamina, C. greenwayii, C. incana, C. laburnifolia, C. mucronata, C. ochroleuca, C. pancira, C. paulina, C. recta* and *C. vallicola*. None of these species have shown any symptoms of root galling or juvenile populations in the roots at any stage of observation. There was no difference in their reaction to nematode between transplanted and direct-seeded plants. Although the resistance of certain *Crotalaria* species to root-knot nematode is well known, the mechanism of resistance is not understood. These preliminary results suggest that any of these *Crotalaria* species can be considered for short-duration planted fallows on soils infested with root-knot nematode, provided their agronomic performance is satisfactory. Their performance is now being tested on farms.

Striking differences were noted among other tree and shrub species suitable for 1- to 2-year planted fallows in respect of

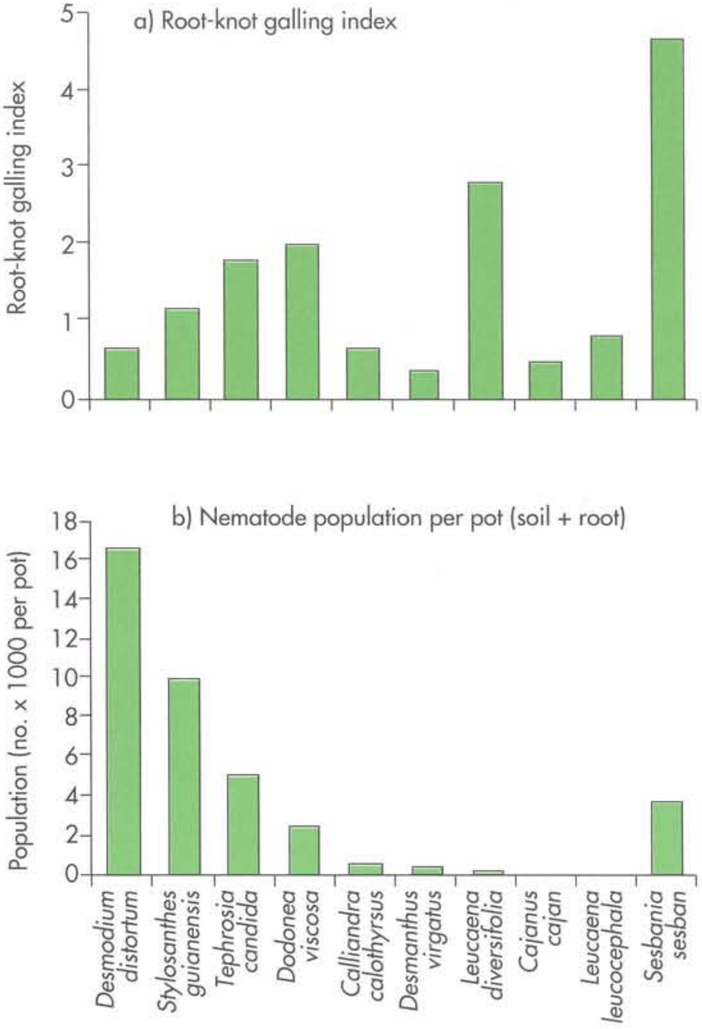


Figure 30. Average root-knot galling and root-knot nematode population observed with different tree species suitable for planted fallow technology at 120 days after planting in western Kenya. No populations were observed on either Senna siamea *or* Crotalaria agatiflora.

the buildup of nematode populations in soil and root and in the manifestation of root-knot symptoms (fig. 30). Neither *Senna siamea* nor *Cajanus cajan* showed root galling nor did the nematode population increase in their soil or roots. Obviously, such species can be considered for fallow technology without concern about the nematode problem. However, species that show high sensitivity to root-knot nematode or increase its population over time should be judged carefully. *S. sesban* was the most susceptible of all species tested, with an RGI of 4.7 and nematode populations of about 4000 per pot. *L. diversifolia* and *L. leucocephala* have shown clear symptoms of root-knot infestation, with an RGI of 1 to 3, although they did not accumulate high nematode populations in either the soil or the roots. *Stylosanthes guianensis* and *Desmodium distortum* accumulated higher nematode populations than sesbania but exhibited fewer galls on their roots. Calliandra exhibited similar symptoms, but it did not contribute to the high buildup of nematode population. *Tephrosia candida* and to a lesser extent *Dodonea viscosa* showed root galls and accumulated high nematode populations over time. Although *Desmanthus virgatus* showed high nematode population inside the root in the early stages, lack of root galls and decrease of population over time suggest that this species does not favour multiplication of the nematode. These and other potential fallow species will be further tested on farms for the effect of nematode on their growth and on subsequent crops.

There is, therefore, a definite nematode problem with *S. sesban,* which we are now understanding better. There are apparently feasible low-cost solutions such as spraying nematicides on bare-root seedlings, using other fallow species such as *Crotolaria grahamiana,* or using multiple tree species in fallows. What is still needed is the quantification of yield decreases in bean or other susceptible crops grown after sesbania fallows in the eastern African highlands.

FODDER FOR DAIRY COWS

Embu in Kenya is AFRENA–ECA's flagship location for research on tree fodder and livestock in agroforestry systems. The KARI–KEFRI–ICRAF National Agroforestry Research Project has identified calliandra *(Calliandra calothyrsus)* as a suitable fodder tree for raising milk production of stall-fed dairy cows. A farmer could replace or substitute commercial concentrate dairy meal with calliandra fodder (see ICRAF annual report 1995 p 41–50), with positive effects on milk production and profitability; 3 kg of fresh calliandra can replace 1 kg of dairy meal.

During 1996, efforts continued towards involving many more farmers in testing the calliandra feed on farm and on farmer assessment of its effect on milk production. Over 50 farmers were involved in this work, which continues to turn out highly positive results and to generate increased interest for calliandra among farmers. The project has now developed to the point where farmers should take on responsibility themselves for seedling production. Therefore during 1996, steps were initiated towards promoting individual and community nurseries for calliandra seedlings. This work by farmers to establish nurseries is expected to lead to an increase in calliandra fodder hedges and gardens in the Embu area.

USING FARMERS' INDIGENOUS KNOWLEDGE TO SET PRIORITIES

A survey was conducted to document farmers' knowledge and management of indigenous fodder species. 'Indigenous species' include those that were exotic when introduced several decades ago but have now become well adapted and are well known by local farmers. Other objectives were to assess farmer preferences for different species and the underlying reasons for those preferences, to set priorities among indigenous species, and to define research agendas for them.

The survey was conducted in 3 zones along an altitude gradient in central Kenya. The high zone lies at 1400–1600 m and has 1200–1400 mm of annual rainfall. Farm size averages 1.9 ha, and over 80% of the farmers have improved-breed dairy cows, which they manage in zero- or minimum-grazing systems. Most farmers grow napier grass *(Pennisetum purpureum)* for their cattle; there are few communal grazing areas and pasture is rare. At the other end of the gradient is the low zone, where altitudes are 830–1130 m, rainfall averages 750–800 mm annually, and farm size averages 2.8 ha. Most farmers own local cattle. About 1/3 of the farm area is under pasture, and nearly all farmers use communal grazing land. The 3rd, middle, zone is transitional. Goats are important in all 3 zones; 47 to 67% of the farmers own goats.

Thirty cattle-owning households were selected at random in each zone and interviewed using a structured questionnaire. Farmers also used the 'bao' game to rate their 6 most preferred species across criteria important to them. Farmers rated the species by putting 1 to 3 seeds in the pocket next to a branch of each species, 3 being the highest rating and 1 the lowest (see ICRAF annual report 1993 p 28). Survey results were presented to the respondents at field days, during which farmers elaborated on the findings.

Overall, farmers in the 3 zones used a total of 160 species for fodder. Over 90% of the farmers in each zone used indigenous trees for fodder. The percentage also using exotics ranged from 37 in the middle zone to 68 in the high. The main exotics, although now virtually naturalized, that farmers used included *Leucaena leucocephala* (28%), avocado *(Persea americana)* (14%) and *Grevillea robusta* (13%).

The fodder tree species that the farmers themselves ranked as most important varied considerably among the 3 zones (table 28). *Triumfetta tomentosa* was the most important in the high area, *Aspilia mossambicensis* in the middle area and *Melia volkensii* in the low. Farmers' main criteria for evaluating the trees included feed characteristics (palatability and the effect on milk production and on animal health and condition) and agronomic factors (drought resistance and compatability with crops). There was some variation in criteria among zones—for example, farmers in the high zone were interested in the effect of a particular tree on the production of cow's milk; in the low zones they considered the effect on goat's milk. Researchers added 2 criteria for farmers to evaluate: speed of growth of the tree and regrowth after pruning.

Table 28. Indigenous fodder trees and shrubs that farmers want to plant on their farms

Rank	High zone	Farmers wanting to plant (*n* = 19) (%)	Middle zone	Farmers wanting to plant (*n* = 22) (%)	Low zone	Farmers wanting to plant (*n* = 27) (%)
1	masiso, mugiso *(Triumfetta tomentosa)* mururi *(Commiphora zimmermanii)*	26 26	mucimoro, mucirigu *(Lantana camara)*	45	mukao *(Melia volkensii)*	67
2	mugumo *(Ficus* spp*)* muvevu *(Trema orientalis)*	21 21	muuti *(Aspilia mossambicensis)*	23	mucimoro, mucirigu *(L. camara)*	41
3	kirurite *(Tithonia diversifolia)*	16	mucugucugu *(Crotalaria goodiiformis)*	18	mutuva, muruva *(Grewia tembensis)*	33
4			kirurite *(T. diversifolia)* mugiti *(Indigofera* spp*)* muthunthi *(Maytenus putterlickioides)*	14 14 14	muuti *(A. mossambicensis)*	26

How the species rated on each criterion varied considerably (tables 29 and 30). For example, *A. mossambicensis* received high ratings on palatability for goats, effect on goat milk production, tree growth, and regrowth after pruning. Its palatability for cattle was rated medium. *M. volkensii* received high ratings on regrowth and palatability for goats but low ratings on palatability for cattle.

The percentage of farmers who wanted to plant indigenous trees for fodder if they received seedlings ranged from 63% in the high zone to 90% in the low. In the low zone, 60% preferred *M. volkensii* for planting, but unfortunately many farmers experience problems in trying to propagate the species. In the middle zone, 33% mentioned that they preferred lantana *(Lantana camara)*, which is surprising because researchers claim it is toxic to cattle. Lantana's high protein level (leaves have 21.4% crude protein) makes it very attractive, and when it is used as a supplement rather than for the base diet, toxic substances are likely to be diluted to harmless levels. *Triumfetta tomentosa* and *Commiphora zimmermanii* were the species preferred most for planting in the high zone, but each was preferred by only 17% out of the total of 30 farmers.

The survey was also useful for obtaining other information such as tree management and use of fodder as feed.

Table 29. Farmers' average rating of qualities of indigenous fodder trees and shrubs, high-altitude agroecological zone (number of farmers = 30)

Species	Growth after establishment	Regrowth	Palatability for cattle	Compatibility with crops	Health
Lantana camara	2.7 (0.47)	2.8 (0.40)	2.7 (0.50)	1.6 (1.00)	3.0 (0.00)
Vernonia lasiopus	2.4 (0.79)	2.5 (0.69)	2.1 (0.90)	2.2 (1.10)	2.5 (0.76)
Tithonia diversifolia	2.9 (0.33)	3.0 (0.00)	1.6 (0.98)	2.2 (1.00)	2.8 (0.50)
Triumfetta tomentosa	2.2 (0.93)	2.3 (0.86)	2.1 (0.90)	1.9 (1.07)	2.4 (0.81)
Commiphora zimmermanii	2.9 (0.34)	2.9 (0.33)	2.6 (0.53)	3.0 (0.00)	2.7 (0.65)
Bridelia micrantha	1.6 (0.73)	2.1 (0.90)	2.1 (0.69)	1.8 (0.98)	2.4 (0.73)

3 = good, 2 = medium, 1 = poor; SD is shown in parentheses

Table 30. Farmers' average rating of qualities of indigenous fodder trees and shrubs, mid- and low-altitude agroecological zones (number of farmers = 60)

Species	Growth after establishment	Regrowth	Palatability for goats	Palatability for cattle	Fattening of animal	Milk prod. of goats[a]
Lantana camara	2.8 (0.46)	2.8 (0.48)	2.4 (0.82)	2.1 (0.97)	2.5 (0.78)	–
Aspilia mossambicensis	2.6 (0.69)	2.6 (0.70)	2.6 (0.70)	2.3 (0.95)	2.5 (0.71)	2.5 (0.52)
Crotalaria goodiiformis	2.4 (0.78)	2.3 (0.75)	2.9 (0.45)	2.4 (0.84)	2.9 (0.25)	3.0 (0.00)
Indigofera lupatana	2.4 (0.82)	2.0 (0.76)	2.7 (0.59)	2.3 (0.70)	2.8 (0.40)	2.4 (0.55)
Melia volkensii	2.1 (0.91)	2.6 (0.76)	2.7 (0.57)	2.3 (0.85)	2.4 (0.72)	2.1 (0.88)
Acacia fruticosa	2.4 (0.67)	2.0 (0.89)	2.1 (0.60)	1.5 (0.85)	2.1 (0.83)	2.0 (1.00)
Acacia ataxacantha	2.8 (0.69)	2.8 (0.44)	2.3 (0.82)	1.6 (0.70)	1.8 (0.83)	2.4 (0.55)
Grewia tembensis	2.1 (0.85)	2.3 (0.73)	2.7 (0.46)	2.1 (0.97)	2.6 (0.76)	2.9 (0.38)
Maytenus putterlickioides	2.0 (0.84)	2.5 (0.70)	2.2 (0.81)	1.4 (0.81)	2.2 (0.79)	–

SD is shown in parentheses

[a] for the low-altitude zone only

– only 2 cases were available so data are not reported

Establishment, pruning and niches

Planting methods and management varied considerably across zones. In the high zone, many species, such as *C. zimmermanii* and tithonia *(Tithonia diversifolia)*, were established by planting cuttings. In the middle and low zones, farmers did not plant fodder trees, rather they protected seedlings of species that regenerate naturally. Farmers in the lower and middle zones generally grew fodder trees in pasture or in hedges on external boundaries; farmers in the high areas preferred hedges on external boundaries. Farmers gather fodder of some species, such as tithonia in the high zone and *C. zimmermanii* in the middle and lower zones, from off the farm, along roadsides or from communal areas. For future plantings, farmers in all zones said they would prefer external boundaries; in the middle and lower zones they also proposed planting in pastures and in fodder banks. Fodder trees were often coppiced and pollarded in the high zone, whereas in the middle and lower zones, goats and cattle browsed the fodder trees.

Feeding

In the upper zone, 80% of the farmers used indigenous trees for feeding improved cattle; half also fed them to goats. In the middle and lower zone, nearly all fed indigenous trees to goats, 25 to 69% also fed the tree fodder to local-breed cattle. In most cases, leaves and twigs were the only parts fed; fruits and pods were also fed for a few species, such as lantana and *C. zimmermanii.* In most cases, fodder trees were used for feeding throughout the year; in a few cases, they were reserved for dry-season feeding.

Other uses

In all zones, nearly all species were used for firewood. Several, such as tithonia, lantana and *C. zimmermanii*, were important species for live fences and hedges around the compound and boundaries. *M. volkensii* was rated as an important timber species; many other species were mentioned as being used for poles and timber. Other uses of species included for medicine, fruits, stakes and rope.

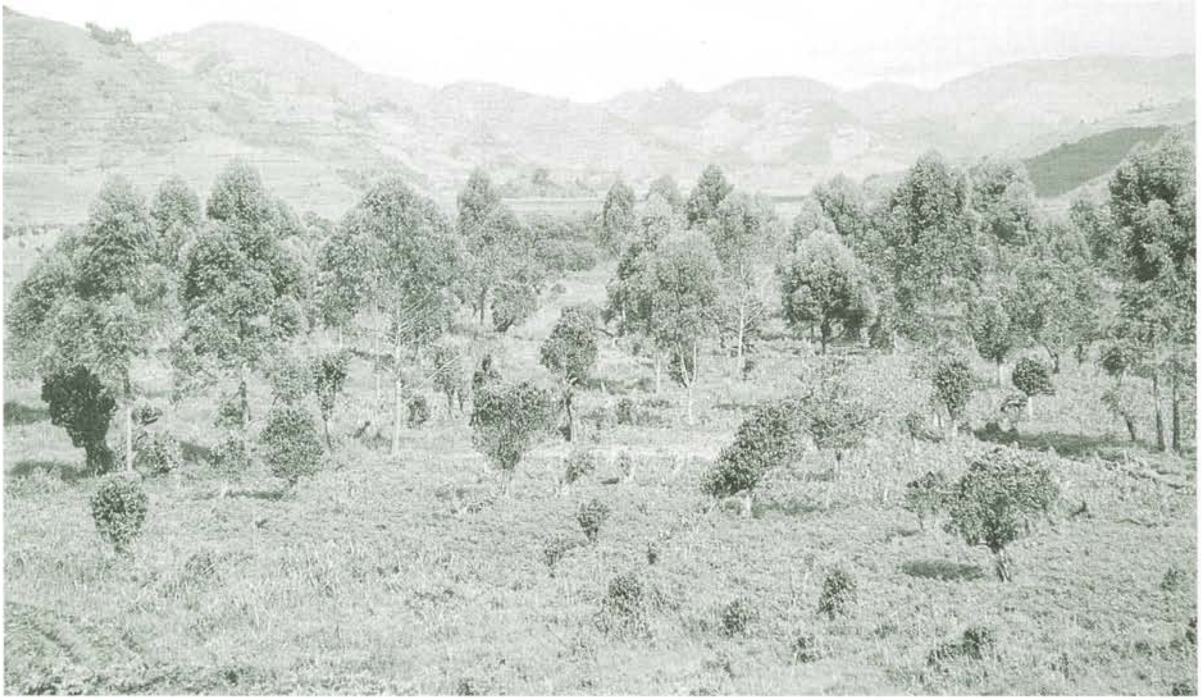
For the future

The survey has confirmed farmers' strong interest in improving the availability of fodder through cultivating indigenous species on farm. Moreover, the role of fodder trees is likely to increase in all 3 zones as a result of farm intensification and the decline in pasture, fallowing and communal grazing. This survey has identified the species that farmers are most interested in planting; future research is needed to compare the fodder yields and the nutritive and antinutritive qualities of these species. Research in close collaboration with farmers is also needed on management, such as cutting regimes. Finally, research is needed to develop propagation methods for *M. volkensii*, a much preferred species.

WOOD PRODUCTION FROM AGRICULTURAL LAND

Production of wood is one of the major objectives and expected outputs from agroforestry systems. Wood is a crucial requirement in most developing countries. In eastern and central Africa, fuelwood constitutes over 80% of the fuel used for cooking. Wood is also required as poles, for buildings and for other construction.

Dependence on forests and natural woodlands for our fuelwood needs has played a major role in accelerating deforestation and tree depletion in our environment. Through agroforestry systems, however, trees are now increasingly being incorporated into agricultural systems, both as boundary plantings and integrated within cropping fields.



Eucalypts are widely grown throughout eastern Africa as here in Uganda, providing wood that is critically needed for fuel, poles and construction. However, they cannot be incorporated into cropland as they compete aggresively with the crops for water nutrients.

AFRENA–ECA research in Uganda has provided the leadership in research on the theme of tree integration into cropping areas. Since 1990, research has focused on identifying tree species that could be incorporated into agricultural land without significantly interfering with the food crops. It is well known that *Eucalyptus grandis,* which is widely cultivated in the zone, is excellent in adaptability, growth rate and pole quality; however, it is not suitable for cultivating near crops because it competes aggressively with them for water and nutrients.

Results from upperstorey screening and intercropping with crops trials from Uganda have shown that most tree species grown as upperstorey trees will result in some competition with the crop. However, a few species such as *Grevillea robusta, Cedrela odorata* and the casuarinas do not depress crops significantly. One particular species, *Alnus acuminata,* was identified as having a positive interaction with food crops, whether established as upperstorey trees or as a hedge in cropping fields. Earlier results on these trials

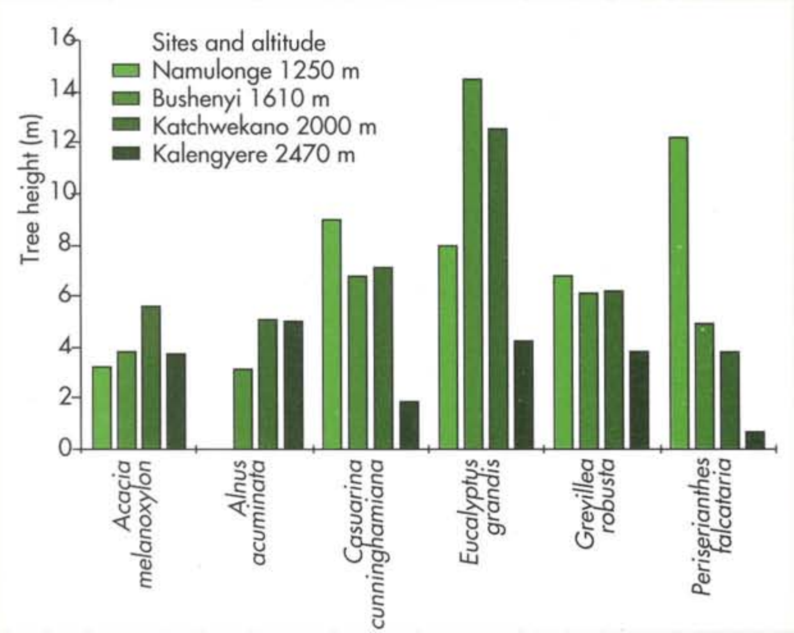


Figure 31. Height of trees at 41 months at 4 locations in Uganda.

are given in ICRAF annual reports 1994 (p 130–134) and 1995 (p 51–55).

Additional data from a multilocational tree screening trial (ICRAF annual report 1995 p 52–53) are given in figure 31, which clearly shows that in growth rate, *E. grandis* is in a class of its own. It performed well at all the altitude locations tested, although with a significant drop at the highest altitude (2470 m). *G. robusta* also grew well, maintaining good steady growth, especially at the altitude range of 1250–2000 m, with a drop in growth only at the highest elevation (2470 m). Another interesting species to highlight is *Periserianthes falcataria,* which showed a rather remarkable negative growth at higher altitudes. This species had the best height growth at the low elevation but its reduction in growth at higher altitudes was quite sharp, and it was the poorest at the highest elevation. *A. acuminata* did not grow well at the lower elevations but performed increasingly well compared with the other species at higher elevations (2000–2470 m). It is significant to note that at the highest elevation of Kalengyere (2470 m), *A. acuminata* outperformed all other species, including eucalyptus. This result for *A. acuminata*, combined with the positive results of its interaction with crops and the high quality and preference of its wood as fuelwood (see ICRAF annual reports 1994 p 130–134 and 1995 p 51–55), makes it an agroforestry species of high potential for the highlands of eastern and central Africa.

PERFORMANCE OF *ALNUS ACUMINATA*, *GREVILLEA ROBUSTA* AND *CEDRELA ODORATA* ON FARMS

To determine the potential impact of any species, it is important to assess it under farmers' circumstances. In Kabale District in southwestern Uganda, this means on the variable slopes of the hillsides in the area.

Most of the research results reported on upperstorey trees in Uganda have come from controlled on-station trials. The growth performances reported for the various species were therefore not influenced by the uncontrolled social and environmental conditions that exist in farmer fields.

In early 1995, a survey was held among farmers in 2 groups, the Two Wings agroforestry group, and the Uganda National Farmers Association, operating in Kabale District. This survey followed earlier farmer evaluations of agroforestry tree species used in AFRENA research in Uganda. The purpose of the survey was to identify which upperstorey tree species farmers would like to establish on their own fields.

The results of the survey showed a great preference for 3 tree species for poles and fuelwood production—*A. acuminata, G. robusta* and *C. odorata*. *A. acuminata* and *G. robusta* were selected because of their good growth and great fuelwood value. Both species provide side branches, which are periodically lopped for fuelwood while the main stem is left to develop as a pole. *C. odorata*, on the other hand, was particularly liked because of its straight pole and lack of side branches, which, according to the farmers, means that it will shade to a minimum any crops growing near it.

Farmers who were interested in establishing the trees formed an on-farm research group to test the performance of the 3 species on their own farms. The trees were to be established in rows, divided into 3 sections, 1 for each species. The number of trees in each row varied, depending on farm size; however, a minimum row length of 30 m was required. This would allow a minimum of 5 trees of each species, spaced 2 m apart in the row.

Altogether, 34 farmers were involved in this trial, and they established 54 experimental tree rows over a wide range of conditions. Some were on 'near-fields' close to the homesteads, some were on the middle of a sloping hillside, others were on 'far-fields' and hilltops, where they were exposed to strong winds as well as to potential damage from browsing livestock. These trees are all under the full management and control of the farmers themselves.

A full assessment of the trees is being done in 1997. Preliminary observations, however, confirm clearly the great potential of *A. acuminata* and, to a slightly lesser extent, *G. robusta* for the hillsides of southwest Uganda. Both species are showing good growth in most fields. *C. odorata*, on the other hand, has been unable to survive the unprotected and uncontrolled environment of the open hillsides. Tree survival has been low, 10–30%, compared with over 80% for *A. acuminata* and *G. robusta*, and the growth rate has also been low.

Farmers continue to express interest in *A. acuminata* and *G. robusta* for pole production. A major effort is being planned to assist them to raise their own seedlings of the species they prefer and to support a further expansion of establishment of these trees on the landscapes of southwest Uganda, to meet their various needs and fit their particular circumstances.

USING SHADE TO CONTROL COUCH GRASS

Couch grass *(Digitaria abyssinica)* is a weed widely prevalent in eastern Africa and one of the most difficult to control because it multiplies through underground rhizomes. It has to be controlled either by deep tillage that exposes and desiccates the rhizomes or by systemic herbicides, neither of which is easy for small-scale farmers in Africa to practise. A convenient and economical approach to control it is by shading it with improved shrub fallows. An experiment was conducted at Maseno in western Kenya to determine the intensity and duration of shade that would smother this grass weed.

On an area that was severely infested with couch grass, different intensities of shade were imposed by using nets that cut off 25, 50 and 75% of the light and black polyethylene sheeting that cut out virtually all the light. The nets were erected on posts 1.5 m tall, fixed on 4 corners of plots 3 x 3 m, covering the top and all sides to the ground level. The nets were rolled up during the night to allow rains to wet all plots uniformly and thus avoid the effects of the shade being confounded by different levels of soil water. The above-ground growth of the weed and its below-ground rhizomatous growth were monitored by periodical sampling of a quadrat 30 x 30 cm in the top 30 cm of the soil.

Shade of 25% did not affect the weed growth at any stage during the study (fig. 32). Nor did 50% shade influence weed growth in the 1st 6 months after it was imposed, but thereafter it reduced the above-ground as well as the below-ground biomass by 45 to 50%. The higher level of 75% shade was still ineffective for 4.5 months, but by 6 months it had reduced the above-ground growth by 48% and the rhizome growth by 33%. Although continued shading at 75% beyond 6 months reduced the weed growth further, it did

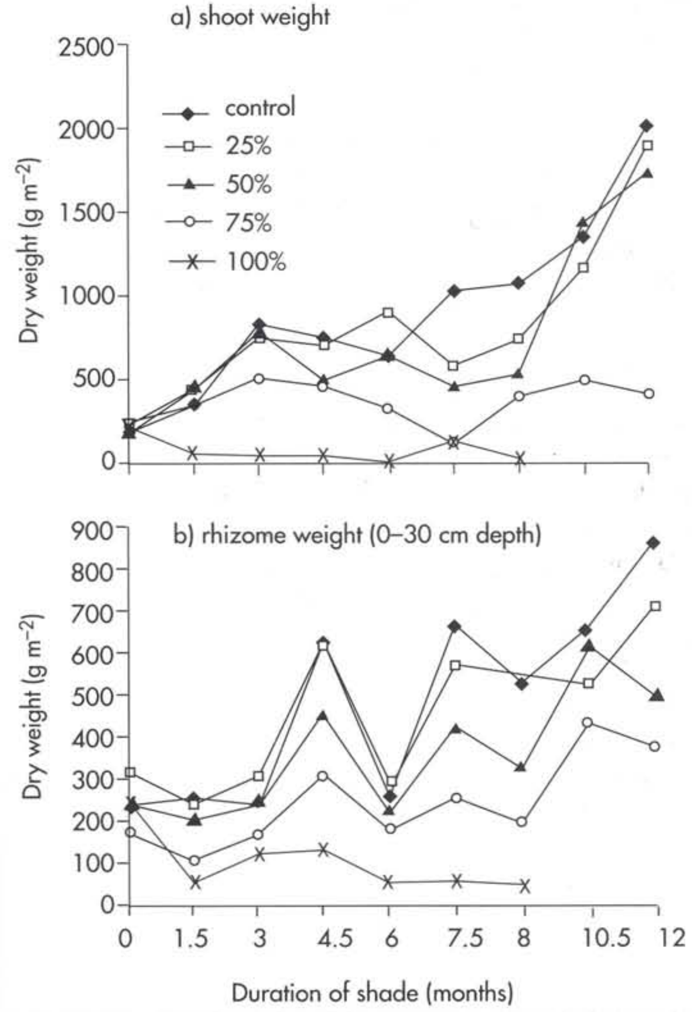


Figure 32. Biomass of above- and below-ground growth of couch grass, Digitaria abyssinica, *under the shade of different intensities and durations.*

not eliminate the weed even in a 12-month period. However, 100% shade reduced 95% of the above-ground growth and 50% of the rhizome growth within 3 months. Even with 100% shade it took a long time for the rhizome biomass to reduce, implying that high-intensity shade is required for a much longer period to eliminate the rhizomes. These results confirm that, as with imperata (p 110–111), a high level of shade, close to 100%, is required for at least 3 months to control couch grass.

Light interception by sesbania fallows planted on farms near Maseno was monitored to check whether the fallows produced the intensity of shade necessary to control the weed. Pure sesbania fallow, 1 year old, established by transplanting nursery-raised seedlings and hand weeded in the early stages, was found to produce over 80% shade for more than 3 months. But sesbania seeded directly with maize in the 'long rains' and grown as a pure tree fallow in the following 'short rains' did not develop a canopy adequate to smother the perennial couch grass.

Unfertilized sesbania on a P-deficient soil produced a maximum shade of only 65–70% and for only about 1 month. However, sesbania fertilized at a high rate of 250 kg P ha^{-1} through rock phosphate developed more than 80% shade that lasted for about 2 months. These results indicate that sesbania fallows grown for only 1 season (that is, 6 months) cannot control couch grass, but a growth of a year or more can make a considerable impact on weed reduction by shade from both the leaf canopy and the litterfall.

MORE PEOPLE . . . MORE TREES IN UGANDA

ICRAF, in collaboration with the International Food Policy Research Institute (IFPRI) and the Forestry Research Institute (FORI) of Uganda, used remote sensing and survey data from over 60 parishes to identify the key factors driving change in land use and tree cover. The study, located in 10 districts in east-central Uganda, covered areas with high variation in population density, land-tenure systems, and, as it turns out, change in land use and tree cover. This research is part of a 6-country project coordinated by IFPRI, funded primarily by the government of Japan and with additional support from the Rockefeller Foundation. (Highlights of related work in Indonesia are reported on p 75–79.)

Two aspects of the research make it unique. First, examination of entire parish landscapes provided information on off-farm—as well as on-farm—land use. Second, mapping the boundaries of different land-tenure systems made it possible, in many cases, to match land use and tree cover to specific land-tenure systems. Land use and tree cover were assessed at 2 specific times: 1960 and 1995 for 42 parishes, covered by aerial photography in 1995, and 1960 and 1989 for the remaining 22 sites (1989 was the date of the most recent remote sensing image). Field surveys were the main source of information on factors driving land-use change. Surveys were administered to one or more groups of individuals with knowledge of parish land-use histories. Fieldwork also involved drawing tenure boundaries on transparencies overlayed on aerial photos (or topographical maps where aerial photos were not available). The survey team visited sites to confirm these drawings.

Overall, land under agriculture increased from 57 to 70% during the 3 decades of the study. This expansion came largely at the expense of woodland and bushland, which fell from 28 to 18% of the total land area. The forested area decreased by half, albeit from a small base of 4%, to only 2% of total area. Of 20 parishes with some forest land in 1960, 10 had none by 1990. Land-use changes across individual parishes were often significantly different. For example, change in the share of forest and woodland taken together ranged from an increase of 28% for 1 parish to a decrease by half in another.

Tree cover (bushes and coffee trees, but not banana) was unchanged in 31% of the survey area. However, this masks some important shifts during the period under study. First, tree cover increased from 23 to 28% on agricultural land, which just offset the loss in tree cover on non-agricultural land. Thus, although tree cover was greater on non-agricultural land in 1990, the amount of difference in tree cover between agriculture and non-agricultural land was diminishing. Second, there was considerable variation in tree-cover change across parishes. Just over 40% of the parishes experienced increase or decrease in tree cover greater than 10%, ranging from a 30% increase to a 36% decrease. (It should be noted, however, that these changes in tree cover do not necessarily reflect changes in biomass because of differences in species and regrowth between the 2 times.)

Three main tenure systems coexist in the Ugandan field sites: mailo tenure (40% of the area), customary tenure (50%), and public land (10%). 'Mailo land' has its origins in the early 1900s, when the British allocated large areas to chiefs and notables. Over time, this land was subdivided through inheritance and often was given to tenants. Mailo land, which is found in 29 of the sampled parishes, has long been the most 'individualized' system, thus according owners considerable tenure security. However, later in this century, new laws have shifted power to tenants residing on mailo land. This has led, among other things, to overlapping or unclear rights on tenant land ('kibanja') and has also created a class of absentee owners. The customary tenure system, based on patrilineal inheritance, was found in 37 parishes and is similar across sites. Public land is derived from former crown land, supposedly inferior lands within mailo areas. Some public land is gazetted (for example, as forests), but much has been allocated to households. Public land is found in 24 parishes. In addition to identifying the areas under these broad tenure categories, other variables such as land transfer rights, grazing rights, tree cutting rights, and (for mailo land) whether owners were mainly resident or absentee also were included in the study.

Population density and growth, access to markets and tenure regimes were expected to have the greatest impact on land use and tree cover change. Multivariate regression models, including econometric corrections (2-stage least squares) for endogenous variables like population, were used to analyse these relationships for data from all 64 parishes. These models 'explained' over 60% of the variation in the sample, which is a good fit for cross-sectional data. Population density had a positive—but diminishing—

impact on conversion to agriculture. The effect diminishes because the area of frontier land shrinks with higher population density. As expected, population growth is associated with greater conversion. Customary land also was linked with greater conversion than was public land to agricultural land. This difference could reflect weak control within customary tenure or it could signify a greater demand for conversion in those areas. For mailo lands, absenteeism had no significant effect on conversion. Surprisingly, the greater the distance to tarmac roads the greater the conversion to agriculture. Perhaps this is because agricultural expansion near roads had already taken place before 1960, or perhaps more extensive (that is, land-using) agriculture is practised farther from major roads.

A fixed-effects econometric model, which eliminates potential biases from unobserved fixed effects at the parish level, was used to analyse data on tree cover at 2 different times for agricultural and non-agricultural land and by tenure regime. (These data were available for 42 parishes.) The adjusted *r*-squared statistic of 88% for this model indicates an extremely good fit. The trend, overall, was toward greater tree cover on agricultural land. Customary and mailo tenure were associated with increased tree cover, unlike on public land, indicating a lack of effective management or of incentives to plant trees on them. Resident (as differentiated from absentee) mailo tenure was also linked with greater tree cover. These results are consistent with a central hypothesis of ICRAF's policy research project: that uncertain property rights undermine incentives for sustainable natural resource management generally—and for tree planting in particular.

CAPACITY BUILDING

Six training courses were held in the region, 5 in Kenya and 1 in Ethiopia (for the list and details, see p 276–279). In addition, a number of individuals received training—postgraduate trainees, research fellows and student attachments. This region had more student attachments than did any other, partly because a number of undergraduates from Kenyan colleges and universities were attached for short periods to ICRAF headquarters.

TO SUM UP . . .

The AFRENA–ECA mode of networking is built on solid partnerhip between ICRAF and NARS and NGO partners in the zone. The progress made by the network in both research and capacity building over the years has been as a direct result of this partnership.

In 1996, major gains were made in the network's research activities. The outcome of the soil fertility research is heading towards the development of a pilot-scale programme on soil fertility replenishment for western Kenya. A dissemination programme on tree fodder has been initiated for the Embu zone in the central highlands of Kenya and on wood production for Kabale in the Kigezi highland region of southwest Uganda. This is all in line with the network's focus on research for development. It is anticipated that this dissemination component of our research will increase in the future, to make the results of research to be of direct benefit to farmers and the environment.

Semi-arid lowlands of West Africa

The AFRENA for the semi-arid lowlands of western Africa covers 4 Sahelian countries: Burkina Faso, Mali, Niger and Senegal. Dominating the region are poverty, the depletion of soil fertility and desertification. 'Parklands', the traditional farming system, closely integrates trees, crops and animals. It has successfully sustained the livelihood of many generations of Sahelian households, but it is now breaking down because of increased population pressure. ICRAF's programme in the region aims to simultaneously increase farmers' income, improve food and nutritional security, and protect the environment. The experience of the Sahelian farmer in nurturing trees on cultivated land and the scientific knowledge of ICRAF and its national agricultural research partners in the region are both important assets in the efforts to improve existing systems and practices and to develop appropriate new agroforestry technologies.

Traditionally, Sahelian farmers preserve scattered trees such as karité *(Vitellaria paradoxa)*, néré *(Parkia biglobosa)* and *Faidherbia albida* in their fields of staple food crops. These trees provide a myriad of products and services. *V. paradoxa* produces shea butter, in which there is great international interest as an ingredient in cosmetics; the fruit pulp of *P. biglobosa* is eaten fresh or turned into flour and the fat- and protein-rich kernels are made into a widely traded vegetable cheese; *F. albida*, sometimes called the 'miracle tree', is used for medicine, fuelwood, green manure, food, fodder, implements and leather tanning.

Farmers also use a wide range of strategies to restore soil fertility, such as harvesting animal manure by coralling animals in the farm after crop harvest, leaving crop residues in the field, and practising natural fallowing. However, the importance of these traditional strategies has gradually diminished because of increased population pressure and the resulting conflicts between sedentary farmers and pastoralists.

Today, staple foods receive few nutrient inputs, resulting in a cycle of lower crop yields, poorer soils, less income and worsening food security. Also, although research abundantly demonstrates that cereal yields respond positively to the application of nitrogen and phosphorus, little fertilizer is used simply because farmers are too poor to purchase agricultural inputs. To counter the fertility decline in their fields, farmers are manually spreading manure produced by animals kept at home, constructing water harvesting diguettes, and using the leaves of trees and shrubs such as *Guiera senegalensis* as a source of green manure. Reduced fallow periods and encroachment of agriculture on marginal lands have combined to degrade the already limited vegetation cover. The annual loss of forest land has been 0.4–0.8% since 1980, leading to an acceleration of the process of desertification.

FARMERS' RESPONSE TO THE CHANGES

Farmers have responded to these changes in various ways. Men have increasingly sought off-farm opportunities to earn income in cities,

Gardens must be fenced to protect them from grazing animals. Traditional dead fences, such as this one in Burkina Faso, must be rebuilt every year. Farmers are now encouraged to replace them with living fences, which quickly grow to be virtually impenetrable.

leading to a proliferation of female-headed households in the rural areas. Others who remain in the village are diversifying their activities. Many households have started to adopt a strategy of improving food security not solely by trying to increase food crop production but also by generating cash income. They do this through on- and off-farm activities, especially by producing dry-season cash crops (fruits, vegetables, cassava). At Kimparana village in Mali, for example, farmers report that selling 3 lettuce plants grown in their dry-season garden can pay for one meal for a family of 5 people. Similarly, a farmer collaborating with ICRAF's live hedge trials in Burkina Faso proudly explains that his now-fenced dry-season vegetable garden earns him money to buy the cereals that his impoverished farm soils can no longer produce in enough quantity to feed his family. Another way to generate income is by fattening cattle and small ruminants for sale. Now increasingly, commercializing parkland tree products such as indigenous fruits and fodder is an additional way in which farmers have responded to the change.

Farmers who have migrated to the cities have found new opportunities in the sale of fodder. The results of a 1996 survey of urban fodder markets in Bamako, Mali, show that vendors travel 30 to 50 km to fetch leaves of the fodder tree known locally as 'ngoni' *(Pterocarpus erinaceus)*, which they sell in the city, making USD 30 to 57 weekly, a relatively good income for the region. The results of a market survey of various non-timber forest products of 5 selected parkland trees in Burkina Faso showed that *Parkia biglobosa* products, for example, have annual sale values as high as USD 266 per vendor in some market points.

RESEARCH AND DISSEMINATION STRATEGIES

In 1995, ICRAF joined with IFAD, the main donor to the Sahelian AFRENA, to undertake an updated study of agroforestry constraints and opportunities in the Sahel. The study was carried out through field visits to the benchmark sites of IFAD-funded agroforestry projects in Burkina Faso, Mali, Niger and Senegal. Its results and recommendations form the basis for our new regional research and dissemination strategies for the medium term. This approach builds on the Sahelian farmer's experience in nurturing trees in cultivated land, incorporates this tradition in the new context of the major changes described above, and seizes the opportunities opened by farmers' responses to these changes. Our current research focuses on live hedges, fodder banks, soil fertility enhancement, the domestication of trees for cash generation and the need for an enabling policy environment, in ways that enhance the resilience of the parklands system.

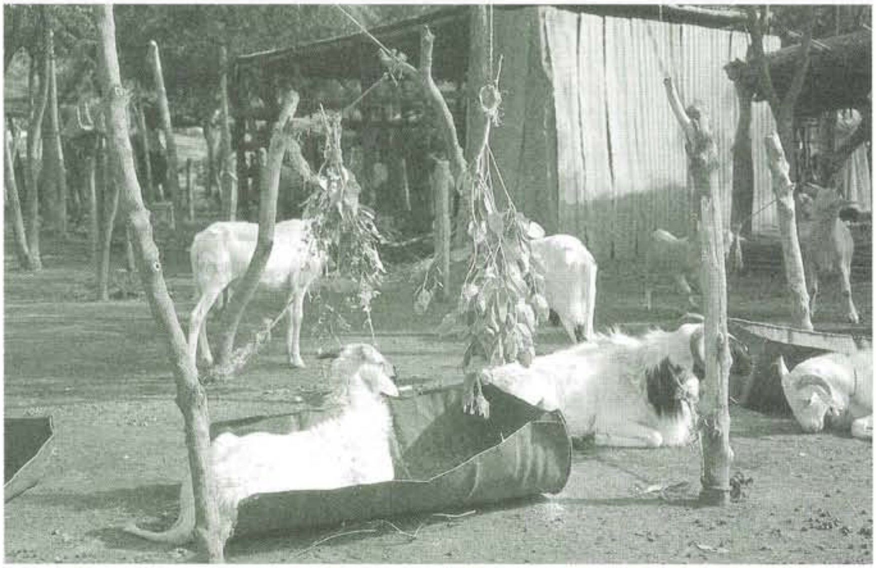
An ICRAF multidisciplinary team of 5 senior scientists in the region, based at Samanko, Mali, provides leadership and regional cohesion to the programme. The team's strategy is to forge links with the scientific community of the region, NARS, NGOs and other stakeholders. Work is ongoing in collaboration with ILRI and the ICRISAT Sahelian Centre to study variations in fodder production and fodder quality of selected Sahelian fodder tree and shrub species, including

Combretum aculeatum, Prosopis africana, Balanites aegyptiaca and *Faidherbia albida.* Collaboration has also been effective with IPGRI in collecting germplasm and is increasing with IFDC on soil fertility replenishment. In addition, ICRAF collaborates with regional research organizations in the Sahel—the Institut du Sahel of CILSS, the SAFGRAD programme of the Organization of African Unity, and CORAF. From its establishment onward, ICRAF's Sahelian programme has developed as a collaborative venture with NARS in Burkina Faso, Mali, Niger and Senegal. In addition to the earlier links with national research institutes, the African Network for Agroforestry Education (ANAFE) is now firmly established in the region and has selected 2 focal institutions, 1 each in Burkina Faso and Mali, to promote agroforestry education. Contacts with various local and international NGOs have paved the way for stronger collaboration with the NGO community. ICRAF's Sahelian programme collaborates with ICRISAT, ILRI and IPGRI in the CGIAR systemwide initiative on Desert Margins (DMI).

This year we report on research results on *Pterocarpus erinaceus,* a 'Cinderella' fodder tree; the parklands system; human resource development; and building agroforestry capability in institutions.

PTEROCARPUS ERINACEUS: A CINDERELLA FODDER TREE IN THE SAHEL

Cattle and small ruminants are an integral part of the prevailing agrosilvopastoral use of land in the semi-arid lowlands of West Africa. They contribute around 70% of farm cash income and play an important social role (at marriages, funerals and on similar occasions). They represent a savings account and insurance against long periods of drought and famine. Increasingly farmers rely on animals, espe-



In many parts of the Sahel, tree fodder is cut and fed to livestock during the long dry season, because grazing areas are too reduced for the animals to be able to feed themselves. The leaves of Pterocarpus erinaceus *are some of the most palatable—and marketable.*

cially cattle, for draught power. But the major constraint to livestock production in the region is the shortage of dry-season fodder.

By March or April, stored groundnut and cowpea residues needed to feed cattle, sheep and goats have usually run out. Livestock roam widely to find fodder and even then it is usually poor-quality roughage, low in protein and minerals. Grasses in grazing lands have almost no digestible proteins and very low mineral content—for example, an average 0.05% phosphorus instead of the minimum requirement of 0.12%. In some areas in Niger and Senegal this fodder shortage extends even into the wet season because of the lack of grazing areas. The health of animals suffers.

Tree leaves, pods and fruits are a valuable source of livestock feed, especially during the dry season. The share of tree fodder in the daily cattle diet in Senegal has been estimated at an average of 25%, varying from 5% at the beginning of the dry season to 45% at the end of it. Studies have evaluated the browsing time of fulani cattle in Nigeria at 5% in the rainy season and 15 to 20% in the dry season.

Because grazing areas are so reduced, it is now common for farmers to harvest tree fodder and feed it to the animals. Valuable indigenous fodder trees such as *P. erinaceus* prevent widespread starvation of livestock during the long dry season. During that period fodder shortage is so acute that leaves of many less palatable species are used as well (for example, *Lannea microcarpa, Sclerocarya birrea, Vitellaria paradoxa*).

Tree fodder is valued not only by subsistence farmers and pastoralists; its exploitation in the periurban areas, particularly in Mali, also represents a way for some urban dwellers to earn cash. An increasing number of small ruminants, mainly sheep, are fed with hay, crop residues, concentrates (cotton seeds) and tree fodder, the latter being the most dominant one in Mali, particularly in Bamako. Here the predominantly commercialized fodder is from *P. erinaceus* leaves.

THE SPECIES

Pterocarpus erinaceus belongs to the leguminous Papilionaceae family. The tree occurs in natural stands in western and central African savannas and reaches 12–15 m in height. Its hard wood is used for construction, for making tools and handicrafts, and for charcoal. The leaves provide high-quality fodder, commanding a price of USD 0.14 kg^{-1} in Mali and Burkina Faso.

Fodder is generally considered to be of poor quality when its net energy content is less than 3.1 MJ kg^{-1} and its digestible proteins are less than 2.5% of dry matter; it is excellent if its net energy is greater than 4.15 MJ kg^{-1} and its dry matter contains more than 5.3% digestible proteins. *P. erinaceus* fodder quality is excellent: its average nutritive value in dry matter is 5.3 MJ kg^{-1} net energy; it has 16% in crude proteins and 12% in digestible proteins, and also contains 0.15% phosphorus.

PTEROCARPUS ERINACEUS FOR CASH IN PERIURBAN FODDER MARKETS

Market studies were initiated in April 1996 at 3 periurban sites near Bamako (Hippodrome, Djikoroni-Para, Daoudabougou). The goal was to gain insight on current demand, prices and availability of fodder species. Specific attention was also given to the temporal variation in these parameters. Therefore, to achieve this objective, these market surveys will continue until June 1997. The underlying premise of the study is that periurban fodder markets will provide opportunities for farmers to earn additional income.

The 3 markets were selected randomly from the 10 markets where fodder species are sold in and around Bamako. A random sample of 25 vendors from the 3 sites was interviewed using a structured questionnaire. Each vendor was visited 3 times every week. Information was sought on type of fodder species, quantities supplied, source of supply, distance from source of supply to market, and prices received.

The data show that vendors have to travel distances ranging from 30 to 50 km to fetch fodder. The fodder was most often collected by climbing trees found in bush fallow. Vendors claimed that this is a year-round activity. They noted that during the rainy season it was more difficult to reach the trees, because of the wild bush. The fodder came from 4 species, 3 of the genus *Pterocarpus: P. erinaceus, P. lucens* and *P. santalinoides;* the 4th species was *Afzelia africana.* About 95% of the fodder was from *P. erinaceus,* 2% from *P. lucens,* 2% from *P. santalinoides* and the remaining 1% from *A. africana.* Most of the vendors were men, averaging 42 years of age.

Table 31 summarizes key parameters related to the sale of *P. erinaceus,* the most common species, in periurban markets. The data for the period April to October 1996 show that the vendors, who harvest the fodder themselves, had to travel considerable distances, averaging from 32 to 47 km, to find the fodder. Vendors bring their bundles, each weighing about 75–85 kg, on bicycles to market.

A huge price variation was observed for the first 6 months of the study in 2 out of the 3 markets (fig. 33). The small fluctuation in price observed at Djikoroni-Para may be attributed to the presence of other sources of fodder such as groundnut straw in this market, unlike at the other locations. The proximity of this location to the river favours off-season crop production. The highest prices are experienced during the dry-

Table 31. Selected parameters related to the commercialization of Pterocarpus erinaceus *in periurban markets near Bamako, Mali*

Market location	Av distance to collection area (km)	Av quantity sold per day per vendor (kg fresh weight)	Price range (USD kg^{-1} fresh weight)	Av daily revenue per vendor (USD)
Hippodrome	35	69	0.06–0.40	11.39
Djikoroni-Para	47	58	0.08–0.12	5.79
Daoudabougou	32	47	0.08–0.40	9.60

USD 1 = CFA 500

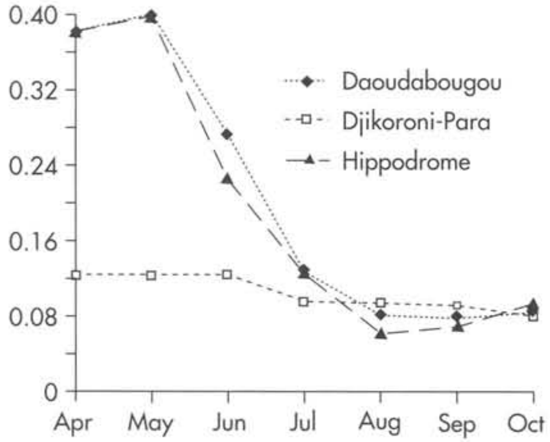


Figure 33. Evolution of prices of Pterocarpus erinaceus *in periurban markets over a 6-month period, Bamako, Mali, 1996.*

season months (through June). This is consistent with expected shortages of fodder during this period; the fodder consequently fetches high prices in the markets.

Daily estimates of gross revenues from the sales of *P. erinaceus* were USD 11, 6 and 10 per vendor at the Hippodrome, Djikoroni-Para and Daoudabougou markets, respectively. These represent 3–5 times the average daily earnings of a casual labourer in this region. Based on these estimates, it can be calculated that about 1360 t fresh weight of *P. erinaceus* is harvested each year from the wild in the surrounding areas of Bamako. A similar study undertaken in 1994 found that 1406 t of fresh tree fodder is sold yearly in Bamako.

According to the same study, 7500 to 8000 t fresh weight year^{-1} of tree fodder is needed to feed the estimated 11 000 sheep in Bamako.

These huge needs show the extent of the threat looming against the survival of the fodder species in the periphery of urban centres. The severe and frequent lopping of the remaining trees will undoubtedly lead to the disappearance of the species. In Mali some joint regulations between the forestry department and the tree fodder exploiters have been worked out for the management of natural stands of these fodder trees. This approach has yielded positive results but is certainly not enough to arrest the destruction of the trees since the need for tree fodder is expected to increase with the steady increase in urban population.

Tree fodder is rapidly becoming less and less available, even in the rural areas. A general decline of perennial vegetation is being brought about by the combined effect of drought and overexploitation of valuable fodder tree species such as *P. erinaceus.* The species has even disappeared in some parts of the region. Heavily lopped trees can no longer produce seeds for regeneration—and sometimes are even killed. This is putting enormous pressure on the existing fodder resources, particularly in the zones around urban centres.

PTEROCARPUS ERINACEUS FODDER BANK, AN AGROFORESTRY ALTERNATIVE

Since its early stages, our work in the Sahel has focused on fodder bank research to address dry-season fodder shortages and the environmental consequences of excessive fodder tree exploitation. (ICRAF 1994 annual report p 146–147). Ongoing experimental activities range from on-station species screening to on-station and on-farm management trials and seek to obtain information on the biophysical responses of fodder species to management practices and farmers' feedback on the potential of this technology.

A fodder bank trial established in 1991 at Nyenkentoumou station (800 mm mean annual rainfall) near Bamako, Mali, is assessing the potential of *P. erinaceus* to produce fodder in the dry season.

As described in the previous section, traditionally the species is exploited by lopping trees, mostly mature, in natural stands. The fodder bank technology being tested involves intensive coppicing of deliberately planted trees.

The species was planted in plots at 2 spacing arrangements: 0.5 x 2 m and 1 x 2 m. The 1st intervention was made at the end of the rainy season in October 1993 when the trees were cut to ground level. This drastic cutting occurred during a transition period between trial researchers. As a result, harvesting was delayed, and the 1st dry-season fodder harvest was not made until 1995, when the trees were cut to a height of 50 cm, at the end of March, April, May and June, and the harvest recorded at those 4 stages of regrowth. After each cutting, trees were allowed to grow unmanaged during the following rainy season. At the end of the rainy season, in October 1995, trees were again cut back to 50 cm, and the wet-season production was recorded. The cycle of recording was repeated during 1996 (table 32).

Results show that the species resprouts well when cut to a height of 50 cm at the end of the wet season and remains green in the dry season. In contrast, uncut *P. erinaceus* is deciduous and loses its leaves early—in the 1st half of the dry season.

Table 32. Dry- and wet-season fodder production (t DM ha^{-1}) of Pterocarpus erinaceus *at Nyenkentoumou, Mali*

	1995		1996	
Month cut	Dry	Wet	Dry	Wet
March	0.18	0.34	0.87	0.39
April	1.57	0.81	1.04	0.35
May	1.33	0.32	0.62	0.18
June	1.31	0.32	1.02	0.35
Mean	1.10	0.45	0.89	0.32
SED	0.39	0.20	0.19	0.09

DM – dry matter

There were no significant differences between the 2 spacing treatments. Consequently, the data presented are for fodder production at different times of year meaned across the 2 spacing treatments. In both years, the species produced more fodder in the dry season than at the end of the rainy season. This contrasts with exotic species such as *Gliricidia sepium* and *Leucaena leucocephala,* which at the same site produced much more leafy biomass at the end of the rainy season than after the dry-season harvest. These different regrowth patterns among species under management suggest opportunities to match production to livestock needs.

Because its leafy regrowth is intensive in the dry season, fodder of *P. erinaceus* has high market potential, as the fodder supply is lowest and the prices are highest in the dry spells of the year. (See previous section.)

P. erinaceus fodder banks can also help sustain smallholder livestock production, as subsistence farmers need little land on which to grow this

This 2-year-old fodder bank of Pterocarpus erinaceus *at Nyenkentoumou station in Mali is part of an on-station trial to assess the capability of this species to produce fodder during the Sahelian dry season.*

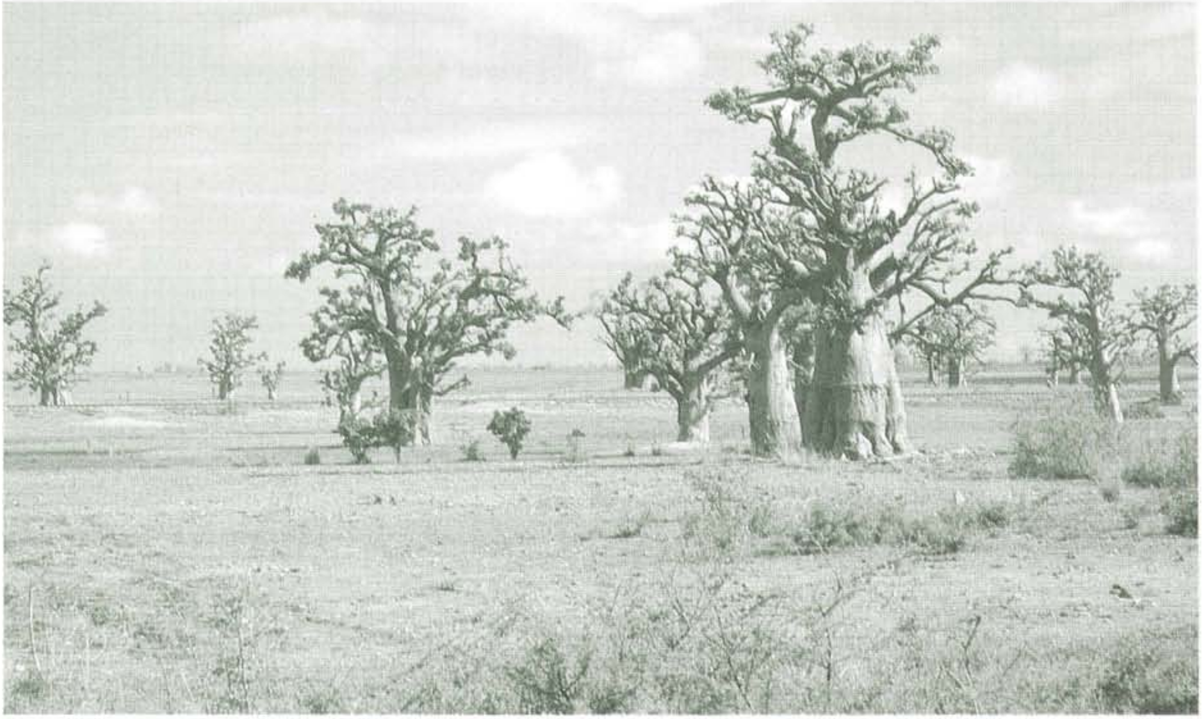
protein supplement. As the digestible protein maintenance needed for one tropical livestock unit (TLU) amounts to 25 g per day, only 0.04 ha of land with dry-season production of 0.5 t DM ha^{-1} is sufficient to guarantee the protein supplementation need for 1 TLU during the last 3 crucial dry months. Thus for an average herd size of 6 TLUs, 0.25 ha is needed to meet their dry-season protein requirements. This area would also supply the farmers with fuelwood when they cut back the fodder bank, both at the end of the rainy season and in the dry season.

Strong intraspecific growth differences have been observed in *P. erinaceus* trees in existing trials, suggesting possible genetic variability. Thus it seems likely that genetic selection could further reduce land and labour requirements. ICRAF has initiated vegetative multiplication studies as part of a tree improvement strategy for *P. erinaceus*.

Pterocarpus erinaceus fodder banks provide a real opportunity for periurban farmers to earn cash revenue. Average fresh fodder production between October and April of around 4.5 t ha^{-1}, as in the Nyenkentoumou trial, fetches an estimated gross income of around USD 630 yearly based on an average price of USD 0.14 kg^{-1}. Production costs occur mainly in the year of planting and are related particularly to the purchase of polyethylene bags, which cost about USD 170 for 1 ha. In a country where per capita yearly income is USD 270, this agroforestry practice should be attractive to periurban farmers.

PARKLANDS SYSTEM RESEARCH

Valuable parkland trees such as *Vitellaria paradoxa* (karité), *Parkia biglobosa* (néré) and *Adansonia digitata* (baobab) have various uses—



Baobab (Adansonia digitata)*, with fruits rich in vitamin C, is one of the valuable and valued trees of the parklands.*

and underrealized economic potential. Recent studies described here have shown that species such as *P. biglobosa* can increase the annual household income by about USD 266—that is, double it.

The parklands system is under threat as few trees are being replanted. This is accelerating the degradation of the system, and consequently there is an urgent need for its rehabilitation. Previous research shows that the fate of this land-use system is associated with farmers' management practices on agroforestry trees. Research in the AFRENA programme for the Sahel has focused its work on 1) typologies of parklands, 2) understanding farmers' management strategies of parkland trees as a 1st step in identifying opportunities for improvement and in determining potential policies that may lead to better tree management, 3) determining the economic potential of non-timber tree products of the parklands, and 4) understanding the tree–crop interactions in the system.

In addition a long-term mixed intercropping trial for soil fertility improvement involving

One of the dominant types of parklands features Faidherbia albida, *a valuable tree that has been selected for domestication.*

Albizia lebbeck, *Faidherbia albida* and *Prosopis africana* was established in 1991 in Burkina Faso.

TYPOLOGIES OF THE PARKLANDS SYSTEM

Following a climatic gradient, different areas in the Sahelian region were selected for identification of different parkland typologies. Mapping was undertaken in Burkina Faso and Mali. In Burkina Faso, village-level mapping was carried out in the Dori area by a team of geographers, foresters and social scientists. The Dori area is located in the northern limit of the semi-arid zone (latitude 14°N longitude 0°3'E) with annual rainfall between 300 and 400 mm.

Five principal types were identified in the Dori area:

- the pure *Faidherbia albida* parkland system, covering about 30% of the cropped fields
- the mixed *Faidherbia albida–Hyphaene thebaica* parkland system (25%)
- the *Balanites aegyptiaca* type (15%)
- the mixed *Hyphaene thebaica–Balanites aegyptiaca* parkland system (10%)

- the pure *Hyphaene thebaica* system (8%)

A more elaborate mapping was undertaken in Mali covering the entire middle Bani–Niger river basin (mean annual rainfall of 700–800 mm) and the Gondo–Mondoro region (mean annual rainfall about 500 mm). About 18 types of parkland were identified in the middle Bani–Niger river basin corresponding to the dominant species type (table 33). The total area of the middle basin is about 415 700 ha. These studies showed the importance of tree species such as *V. paradoxa, A. digitata, F. albida* and *Sclerocarya birrea,* all of which ICRAF has identified for domestication.

Faidherbia albida, B. aegyptiaca, S. birrea and *Acacia raddiana* are found in the parkland types of the Gondo–Mondoro region (table 34). In the north, there are more thorny species than grow in the southern parts, like in the middle Bani–Niger basin area.

Our results show that there is a high diversification of tree species in the parkland system, and this wide variety has useful economic functions. Knowledge about the diversity of the species and their respective functions provides insight into potential areas of parklands enrichment, as well as background information that will be useful for rehabilitating the system.

Table 33. Parkland types in the middle Bani–Niger river basin of Mali

Parkland type	Area covered (ha)	Percentage of total area
Vitellaria paradoxa	112 400	27.04
Sclerocarya birrea–Vitellaria paradoxa	109 700	26.39
Borassus aethiopum	39 200	9.43
Sclerocarya birrea–Prosopis africana	31 900	7.67
Vitellaria paradoxa–Adansonia digitata	29 700	7.14
Faidherbia albida	26 600	6.40
Vitellaria paradoxa–Prosopis africana	16 900	4.07
Vitellaria paradoxa–Faidherbia albida	12 700	3.06
Terminalia avicenioides–Prosopis africana	10 300	2.48
Faidherbia albida–Adansonia digitata	6 500	1.56
Adansonia digitata	5 800	1.40
Adansonia digitata–Prosopis africana	4 200	1.01
Combretum micranthum/ghasalense–Prosopis africana	3 300	0.79
Parkia biglobosa–Terminalia avicenioides	2 600	0.62
Adansonia digitata–Sclerocarya birrea	2 300	0.55
Borassus aethiopum–Hyphaene thebaica	900	0.22
Pterocarpus erinaceus–Faidherbia albida	400	0.10
Faidherbia albida–Hyphaene thebaica	300	0.07

average annual rainfall is 700–800 mm per year

THE NEED FOR BETTER POLICIES

The central hypothesis is that farmers manage existing parkland trees so as to increase the production levels of the main components: tree products, crops and animals.

A case study was conducted in the Dori area on the basis of the 5 parkland types identified. One village was randomly selected from each type. A sample of farmers was in turn randomly chosen from each selected village. In all, 40 farmers participated in this study. Field technicians were posted full time in these villages for 12 months to monitor the

Table 34. Parkland types in the Gondo–Mondoro region of Mali

Parkland type	Area covered (ha.)	Percentage of total area
Sclerocarya birrea–Balanites aegyptiaca	92 300	21.05
Terminalia avicenioides–Combretum glutinosum	92 000	20.99
Faidherbia albida	57 100	13.02
Balanites aegyptiaca–Acacia raddiana	53 600	12.23
Prosopis africana	52 700	12.02
Balanites aegyptiaca–Faidherbia albida	36 600	8.35
Sclerocarya birrea	16 600	3.79
Sclerocarya birrea–Combretum glutinosum	16 100	3.67
Faidherbia albida–Piliostigma reticulatum	4 100	0.94
Balanites aegyptiaca–Combretum glutinosum	3 800	0.87
Sclerocarya birrea–Piliostigma reticulatum	3 700	0.84
Lannea microcarpa	2 200	0.50
Combretum glutinosum	2 200	0.50
Anogeissus leiocarpus	1 900	0.43
Faidherbia albida–Vitellaria paradoxa	1 400	0.32
Piliostigma reticulatum	1 400	0.32
Adansonia digitata	700	0.16

average annual rainfall is 500 mm

ways farmers managed their trees. Open-ended questionnaires were also used to elicit information on farmers' perceived constraints with respect to managing agroforestry trees in the parklands system. Information was also collected on the mode of propagation of dominant trees, the effect of social customs and beliefs, and the prevailing attitude of farmers toward tree planting.

The results of this study show that 90% of all the dominant trees in the parklands system are propagated through natural regeneration rather than by farmers planting them. There were few cases where the principal species were planted. Reasons for not planting are associated with social customs and with beliefs that suggest that planted trees may not bear the same quality of products as those that grow naturally. Furthermore, the time needed for most of these trees to reach maturity is extremely long. Farmers therefore feel they may not benefit from the planted trees during their lifetime and would rather depend on the trees they find in their fields for meeting their needs. This study suggests that a well-conceived programme to domesticate agroforestry trees would have an important role to play in changing farmers' attitudes towards tree planting. For instance, if desired trees could provide the required services and products in a shorter time, it is most likely that farmers' attitudes would change. Such a breakthrough would go a long and crucial way in rehabilitating the parklands system.

The results of this study also shed light into different tree management strategies undertaken by farmers. The main ones include debranching, pruning, debarking, pollarding, thinning and burning. Debranching and pruning are performed to accelerate tree growth, increase biomass and fruit production, minimize the shade effect, procure organic matter for bare soils, reduce the population of crop predators (birds), obtain firewood and render the trees more resistant to wind. Debarking is undertaken mainly to obtain medicinal products and fibre. Pollarding is undertaken to enhance resistance to wind, reinvigorate the tree by accelerating new growth, reduce the presence of birds, obtain wood for fuel, construction and artwork, reduce shade on crops, and finally to protect the soil with the cut branches. Thinning and burning, mainly done with *Hyphaene thebaica,* reduce competition with crops and enhance fruit production; light burning is believed to accelerate the production of fruit.

Depending on the species, the age of the tree and its intended uses, management strategies were also found to correspond to specific objectives. For example, debranching was often undertaken on mature trees with the specific objective, as mentioned above, of increasing fruit production. Debarking of older *H. thebaica* trees was aimed at procuring organic matter to cover the bare soils, while the younger trees were pruned.

The survey also identified difficulties and constraints that farmers encounter in managing their trees. Among those frequently cited were possible injury to the farmer, risk of snake bite, and repression by government foresters, who apply the law regarding the use and felling of trees. This last constraint—repression by foresters—was by far the most frequently cited. Farmers do not feel that they own the trees in their fields, and their attitude towards foresters reflects their resentment. Tree mortality and removal of desired shade were identified as consequences of current management practices.

Foresters' goal to ensure that trees are protected, eventually for the benefit of the farmers as well as society, does not take into account farmers' diverse needs. A farmer may even cut down or uproot a tree when it is small, before a forester notes its presence, if the tree is of no potential value to the individual on whose land it is growing. If the tree grows to maturity, the farmer who cuts it stands to suffer severe sanctions from the forester. Effective communication between farmers and foresters thus seems lacking.

However, farmers' rights regarding trees remain somewhat ambiguous. For example, in some regions customary practice does not permit farmers to have rights to some species such as néré *(Parkia biglobosa).* Even so, farmers do not destroy these trees, because they do receive benefits from them. This is in spite of the rules about rights, which may be flexibly applied. The implication is that with adequate consultation and collaboration between farmers and foresters, tree management can be effectively undertaken by individual farmers to their benefit and to that of the society at large. Researchers need to work with farmers to develop proper and adequate tree management techniques that will satisfy farmers' needs and at the same time sustain the system.

The results from this study indicate that farmers strive to find a balance between the woody vegetation in their cropped fields and the cropped area. This corroborates the fact that trees are important in the land-use system and are maintained for the services they offer to land users.

Finally, developing a clear policy about tree management that gives farmers some sense of ownership may go a long way toward improving farmers' attitudes. The forestry legislation needs to be amended to respond to the concerns farmers have at this time. Recent efforts in the Sahelian countries seem to be going in the right direction—that of providing farmers incentives to properly manage trees. This, consequently, should have a positive effect on farmers' tree planting attitudes.

MARKET OPPORTUNITIES FOR NON-TIMBER FOREST PRODUCTS OF SELECTED PARKLAND TREES

Until recently, very little empirical evidence had been reported about the market opportunities at the farm level for products, specifically non-timber, and the economic potential of dominant trees in parklands. As part of work to characterize the parkland agroforestry system, research was conducted in collaboration with an International Foundation of Science–funded project at the Institut d'études de recherches agricoles (INERA) at Farako Ba (Burkina Faso) on use and farm-level commercialization of non-timber tree products. This information would shed light on the relative importance of these products with respect to market volume and value for land users and serve as useful input for other ICRAF programmes on the domestication of agroforestry trees.

A survey was conducted in the western part of Burkina Faso that lies between latitude 10° and 13° north and longitude 1° and 3° west. The climate of this region is Sudanian, with mean annual rainfall of 1000 mm in the south and 800 mm in the north. The vegetation is forest savanna. In each of the 4 villages of the study—Dimolo, Kayao, Kawara and Yasso—10% of the households were sampled. Each family was selected at random and monitored by female interviewers for 6 days to gather information about household utilization of non-timber tree products. This survey on traditional utilization of non-timber tree products involved 100 households. To study the commercialization of non-timber products, market surveys lasting a whole year were undertaken on 10 village markets in which all vendors were systematically interviewed. This approach enabled us to identify all products that are marketed. Information gathered included the nature of the products, their uses, their sources of supply, and quantities handled. To determine prices and weights, samples were bought.

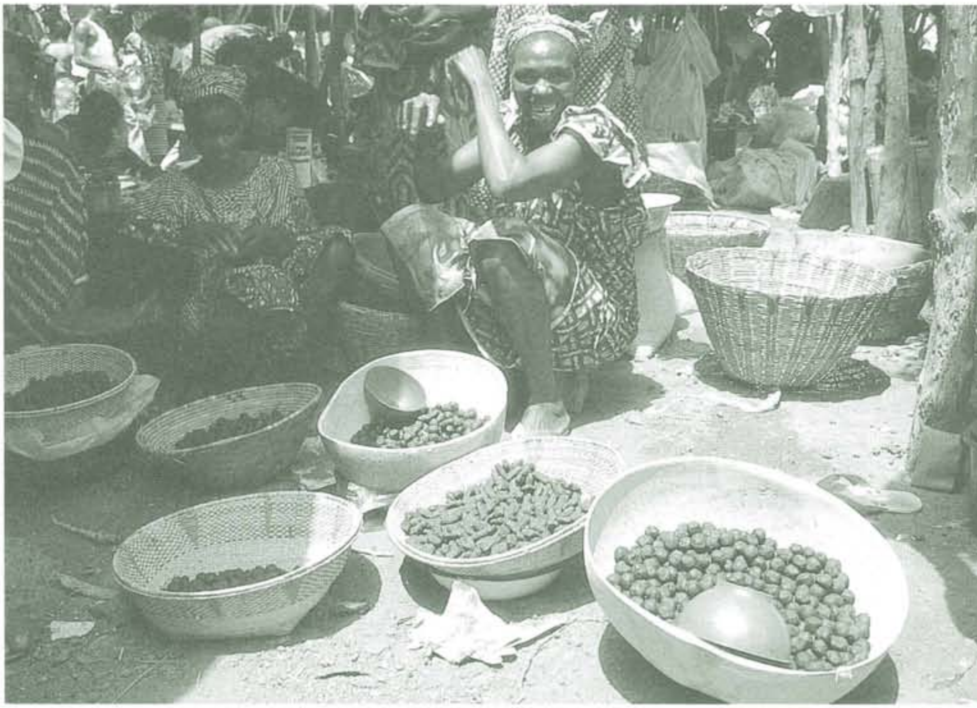
The results of this study identify some 30 products derived from 17 woody species marketed in the study area and summarize the main uses of the products. In their raw form, these products supply vitamins for the nutrition of rural people. A variety of the products marketed constitute an important source of local income (table 35). The principal species reported here are *V. paradoxa, P. biglobosa, A. digitata, Tamarindus indica* and *Borassus aethiopum.*

The main products from *V. paradoxa* are seed (kernel) and sheanut butter, which are used to make comestibles, cosmetics, medicines and soaps, and are sold in international markets. The caterpillar that lives in the *V. paradoxa* tree, *Cirina butyrospermi,* is a valuable source of protein in the local diet, and as a resource it has great potential to improve the low-protein diet that is common in the Sahel. The main products from *P. biglobosa* are the tangy paste made from the seeds, used as a spice, and the powder from the pods that is eaten fresh or boiled. Powder rich in vitamins from dry leaves, fresh leaves and the fruits are the principal products

Table 35. Values of marketed non-timber tree products (USD year^{-1} per vendor) at various locations in western Burkina Faso

		Market location				
Species	Products	Kawara	Kununkara	Lera	Sindou	Zete
Adansonia digitata	leaves	–	3	2	3	29
(baobab)	powder (leaves)	12	22	12	20	–
	fruits	38	13	7	40	–
Borassus aethiopum (rônier)	wine	121	144	62	72	–
Parkia biglobosa	grain	62	79	88	178	61
(néré)	soumbala	44	50	34	88	52
Tamarindus indica	fruit	52	40	26	26	–
(tamarinier)	seed	18	20	13	18	14
Vitellaria paradoxa	butter	30	33	30	33	31
(karité)	chenille	2	2	2	3	–
	soap	14	17	12	14	13

from *A. digitata*; the main products from *T. indica* are the fruits. *B. aethiopum* not only has fruits but is also tapped for palm wine. Most of these products figure prominently in the preparation of meals. The sheanut butter and oil are used to prepare a local dish known as tô; soumbala from *P. biglobosa* is used as a seasoning; and vitamin-rich baobab leaves are used in preparing sauces.



Soumbala paste, used as a seasoning, is a popular item at Kati market in Mali. The paste is made from the seeds of néré (Parkia biglobosa).

Returns from sales of the 3 leading species brought from USD 200 to USD 397 per vendor per year in these markets.

Fruits, seeds, leaves and other transformed products such as soumbala from *P. biglobosa* and sheanut butter and oil contribute significantly to household income. *P. biglobosa* products seem to provide the largest contributions, with a yearly value of up to USD 266 per vendor in Sindou. Most of the revenue obtained from the sale of these products directly benefits women farmers in the study area. This information should be useful in the final selection of priority species for domestication in the Sahel. Future research needs to examine the marketing channels, profit margins, future demand and market for these products.

THE *FAIDHERBIA ALBIDA* EFFECT

Of the different parkland systems commonly noted in West Africa, the ones with *Faidherbia albida,* either alone or in combination with other trees, are the most famous because of the increased soil fertility and crop yields under the *F. albida* tree. Trees commonly mixed with *F. albida* in Niger are *Adansonia digitata, Acacia senegal, Sclerocarya birrea, Parkia biglobosa, Vitellaria paradoxa* and *Cordyla pinnata.* Faidherbia systems are also common elsewhere in semi-arid sub-Saharan Africa, mainly in eastern and southern Africa. A stand of *F. albida* may vary in the number of trees per hectare from 10 to 50; it generally constitutes 40 to 80% of the trees when it occurs in combination with others. Trees in these systems are rarely planted by farmers but regenerate naturally.

Many mechanisms are held responsible for the increase in soil fertility under *F. albida;* they include biological nitrogen fixation, nutrient cycling from depth, concentration of nutrients from surrounding areas under the tree, capture of fine soil blown off by wind erosion and its eventual deposition underneath the tree canopy through rains, droppings of animals that take shelter under trees, and natural establishment of trees on preexisting islands of higher fertility such as termite mounds.

Recent studies at the ICRISAT Sahelian Centre in Niamey (Niger) have suggested that reduction of soil temperature by the partial shade of the tree could be an important factor in the 'albida effect'. The leafless canopy reduces the high radiation load to a level that avoids the harmful effects that high soil temperature would have on seedling establishment and early growth. Understanding which mechanisms—increased soil fertility or improved microclimate and reduced soil temperature by tree canopy—contribute to increased yields under trees has implications for determining the optimum stand density of *F. albida* in parklands systems.

The ICRISAT study was conducted on millet for only a short period of growth (6 weeks) outside the normal cropping period, in May, when soil temperatures are extremely high. Also, the soils on station, where this study was conducted, may have been more fertile than those in farmers' fields. Recognizing the limitations of this earlier study, ICRAF conducted an experiment in collaboration with ICRISAT scientists on farms in N'dounga, 30 km southeast of Niamey, to quantify the effect of soil fertility independent of 'other effects' of trees associated with improved microclimate.

The soils under the study were loamy sands (8% clay, 3% silt and 89% sand), slightly acidic (pH 6.0 in 1 : 2.5 H_2O), low in CEC (2.5 $cmol_c$ kg^{-1}, 1 N ammonium acetate), and very low in available phosphorus (3.7 ppm Bray 1), organic carbon (0.27% Walkely-Black) and total N (0.016 to 0.02% Kjeldhal) in the 0–15-cm soil layer. The study involved 5 treatments as follows: 1) no fertilizer, 2) 180 kg N ha^{-1}, 3) 60 kg P ha^{-1}, 4) 180 kg N and 60 kg P ha^{-1}, and 5) 90 kg N and 30 kg P ha^{-1}. These treatments were applied to 5 plots under each of 5 trees and to 5 in the open area corresponding to each tree, on 4 farms located close to each other. The plot size under trees varied from 11 to 52 m^2, depending on the size of the trees, which varied considerably (dbh: 44 to 75 cm, crown diameter: 10.14 to 17.39 m, and height: 11.5 to 14.5 m), but in the open the plots were 10 x 10 m. The treatments were allocated to plots under trees according to the scheme of a latin square to avoid the treatment effects being confounded with the cardinal direction of the plots, but they were allocated randomly in each of the open areas.

A local variety of pearl millet *(Pennisetum americanum)* was sown on 25 June 1996 in hills at 1 x 1 m spacing. Seedlings in each hill were thinned to 4 or 5 plants 3 weeks after sowing. All the phosphorus and half of the nitrogen was broadcast and incorporated in the soil prior to sowing. The remaining nitrogen was applied in the 5th week after sowing. On 31 July, which was a clear day, between 1400 and 1500 h, the canopy temperature was measured in the open and under trees, with the use of a Telatemp infrared thermometer. On 3 August, the photosynthetically active radiation (PAR) transmitted to the crop under the trees was measured with a Sunfleck ceptometer. The crop was harvested 105 to 108 days after sowing. The data were analysed, taking the presence or absence of trees as main-plot treatments and fertilizer rates as subplots.

The 1996 rainy season was characterized by erratic rainfall in the first half but well-distributed rainfall in the second (fig. 34). The weather

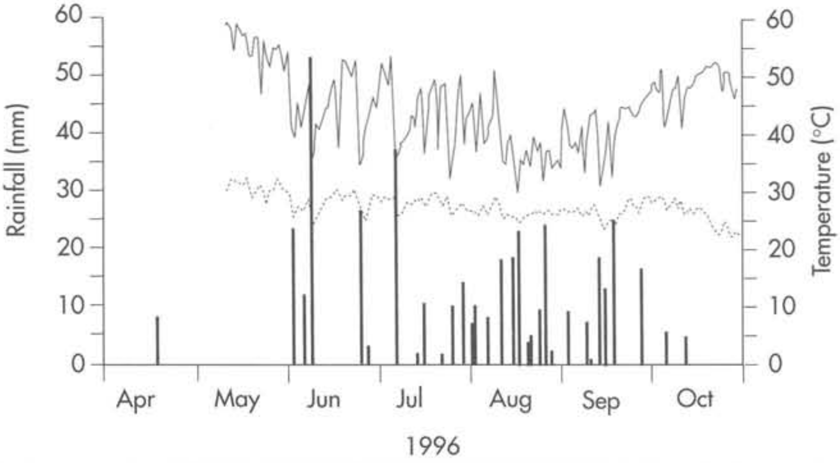


Figure 34. Conditions at the site near N'dounga, Niger, of an experiment to quantify the effect of soil fertility on millet growing under Faidherbia albida*: daily rainfall (bars); daily maximum (solid line) and minimum (dashed line) soil temperatures at 3 cm depth at the Kollo–N'dounga station of the Institut national de recherches agronomiques du Niger, 3.5 km from the experimental site.*

data also indicate that soil temperatures in the Sahel can reach 60 °C before the onset of rains but that they drop sharply with rain.

Neither the tree canopy nor fertilizer treatments had shown any effect on seedling survival at 25 days after sowing. This raises a question as to whether there was, as suggested by the earlier ICRISAT study, any beneficial effect of microclimate on seedling establishment, the stage at which plants are most susceptible to high soil temperatures. Although more seeds may germinate and survive under trees, the overall effect of tree canopy on stand establishment could be small. Farmers in the Sahel generally sow millet in hills with 50 to 100 seeds per hill then thin to 4 or 5 seedlings by removing the weak ones 3 weeks after sowing. Sowing in hills is a farmer's strategy to avoid the unfavourable effect of climate; the seedlings within the hill shade each other, reducing the impact of high soil temperature and favouring the survival of an adequate number of seedlings.

Millet canopy temperature under the trees was 1.8 °C lower than the canopy temperature of millet grown in the open, which varied from 30 to 34 °C during the day. The lowered temperature may have had some favourable effect on photosynthesis, as temperatures above 25 °C are higher than optimal for millet growth. Light transmitted through the tree canopy was only 40 to 50% of that in the open area, a factor that may have decreased photosynthesis of the understorey millet by up to 17%. It is possible that the positive effect of the reduced temperature may have offset the negative effect of reduced light transmission under the tree.

At harvest, the effect on total millet biomass production caused by N ($p = 0.006$), P ($p < 0.001$), the *F. albida* tree ($p = 0.024$) and the interaction between tree and N ($p = 0.03$) were significant, while any other effects were not (fig. 35). The total dry matter under the tree was about 1200 kg ha^{-1} (or 36%) higher than in the open. The effect of the tree disappeared with application of N to millet, which clearly indicates that increased N availability was the major contributory factor for higher biomass production of millet under the tree. The importance of higher N availability under a tree was further confirmed by the significantly higher N concentration of millet grown under the tree than in the open (table 36). The P concentration of millet in the open area (0.14%) was close to 0.1%, a concentration

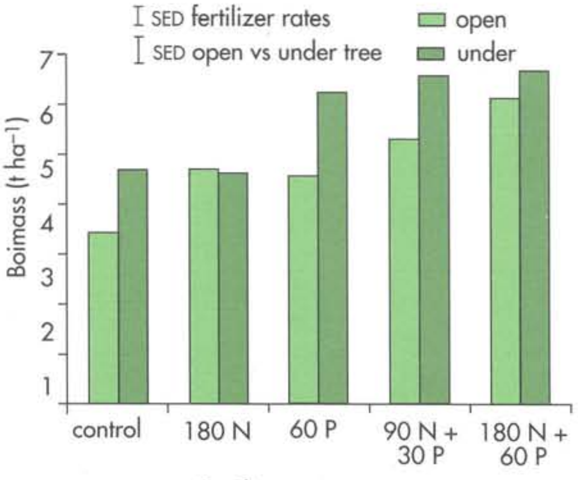


Figure 35. Millet biomass at harvest under Faidherbia albida *trees and in the open at different fertilizer treatments in N'dounga, Niger.*

Table 36. Nutrient concentration (percentage of dry weight) of millet grown without fertilizer in the open and under Faidherbia albida *trees in N'dounga (near Niamey), Niger*

System	N	P	K	Ca	Mg
Open	0.74	0.14	1.95	0.27	0.23
Under *Faidherbia*	1.14	0.18	2.01	0.31	0.25
SED	0.12	0.02	0.17	0.05	0.04

commonly found in millet grown on P-deficient soils, which suggests that phosphorus could be the 2nd most limiting factor for crop growth in the Sahelian environment. The P concentration of millet under *F. albida* was higher than that in the open ($p = 0.062$), indicating the possibilities of increased P availability under trees. However, millet yield under trees was significantly higher than that in the open field, even after 60 kg P ha^{-1} was applied overall (fig. 35), which indicates that factors other than P had a greater influence on yields under trees.

The equations in box 1 show that under natural conditions N availability under *F. albida* trees compared with in the open (54.3 vs 22.7 kg N ha^{-1}) was significantly higher ($p = 0.001$) and the recovery of applied N in the absence of P was lower. Measurements of N mineralization rates in Malawi during the cropping season have confirmed higher nitrogen availability under large *F. albida* trees compared with the open sites (see ICRAF annual report 1992 p 58–60). Similarly,

Box 1. Regression equations for N and P uptake

Regression of N uptake by the crop (N kg ha^{-1}) on N and P fertilizer applications (kg ha^{-1}) and *F. albida* gave the following equations (joint regression $R^2 = 0.799$).

$$\begin{array}{l} \textit{N uptake} \text{ (in open)} = 22.7 + 0.46\,N - 0.00123\,N^2 + 0.061\,P + 0.00156\,NP \qquad [\text{eq. } 1] \\ \qquad\qquad\qquad\qquad \pm 5.0 \pm 0.11 \quad \pm 0.00057 \quad \pm 0.097 \quad \pm 0.00076 \end{array}$$

$$\begin{array}{l} \textit{N uptake} \text{ (under tree)} = 54.3 + 0.35\,N - 0.00123\,N^2 + 0.061\,P + 0.00156\,NP \qquad [\text{eq. } 2] \\ \qquad\qquad\qquad\qquad \pm 7.4 \pm 0.12 \quad \pm 0.00057 \quad \pm 0.097 \quad \pm 0.00076 \end{array}$$

Similarly, regressions between P uptake by crop (P kg ha^{-1}) on N and P fertilizer applications (kg ha^{-1}) and the tree gave the following equations (joint regression $R^2 = 0.520$).

$$\begin{array}{l} \textit{P uptake} \text{ (in open)} = 5.83 + 0.172\,P - 0.00185\,P^2 \qquad [\text{eq. } 3] \\ \qquad\qquad\qquad\qquad \pm 0.57 \pm 0.052 \quad \pm 0.00085 \end{array}$$

$$\begin{array}{l} \textit{P uptake} \text{ (under tree)} = 7.57 + 0.172\,P - 0.00185\,P^2 \qquad [\text{eq. } 4] \\ \qquad\qquad\qquad\qquad \pm 0.84 \pm 0.052 \quad \pm 0.00085 \end{array}$$

Box 2. Equations for Faidherbia albida *effect at final harvest of millet*

$$\text{Log (biomass)} = \underset{\pm 0.14}{6.98} + \underset{\pm 0.047}{0.179} \log \textit{(N uptake)} + \underset{\pm 0.065}{0.390} \log \textit{(P uptake)},\ R^2 = 0.754 \qquad \text{[eq. 5]}$$

The effect of *F. albida* trees on crop production for the use of any 2 different growth resources, say N and P, can be written—

$$\textit{albida effect} = \textit{N effect} + \textit{P effect} + \textit{other effects} + \textit{interaction}\ (\text{N} \times \text{P} \times \textit{other effects}) \qquad \text{[eq. 6]}$$

P availability under *F. albida* compared with the open (7.57 vs 5.83 kg P ha^{-1}) was significantly higher ($p = 0.007$), but the tree had no effect on P recovery. The millet biomass at final harvest was related to N and P uptake as given in box 2.

The 'other effects' (eq. 6) refer to the direct effect of shade, which may reduce the detrimental effect of high temperature or improve the efficiency of photosynthesis. The indirect shade effects brought about by improved soil biological activities and mineralization are taken as part of the N and P effects. Estimation of these various effects is analogous to the estimation of main and interaction effects in a 2^3 factorial experiment. Using the estimated millet biomass production for N and P uptake under natural conditions (based on eq. 5), the components of the albida effect were estimated as follows (see eq. 6):

$$\textit{albida effect} = 664\ \textit{(N effect)} + 435\ \textit{(P effect)} + 0\ \textit{(other effects)} + 0\ (\text{N} \times \text{P} \times \textit{other effects})$$

No positive effect from the shade of *F. albida* canopy was noted, probably because nutrients (N and P) were limiting the growth more than other resources in our study. Therefore, N and P are the major limiting resources for growth in this study, and water is the next most important resource. In the ICRISAT study, nutrients and water did not limit crop growth as the study was conducted for only 6 weeks and with irrigation. It is possible that the shade effect was prominent in that study because of the high soil temperatures encountered during May, which are not common for normal sowings done in late June or early July.

However, these 1-season results need further confirmation by studying the effect of trees and by quantifying in detail the microclimate measurements under contrasting soils and seasons.

The implication of these results is that optimum tree density in parklands depends on the origin of increased N and P fertility under trees. The scope for a higher stand of trees exists only if the increased fertility is due to biological nitrogen fixation, or if the uptake is of deep nutrients unexploited by crops. The P effect of *F. albida* is possible only through the concentration of P under trees from surrounding areas through uptake by lateral roots or mycorrhizae. If fully grown *F. albida* trees are considered, on a conservative estimate, to exploit up to 15 m in all dimensions below ground, then the scope for increasing tree stand in fields already having 20 to 25 trees ha^{-1} is very limited.

CAPACITY BUILDING

Previous surveys and studies conducted in 1994–95 have identified favourable conditions for an agroforestry systems approach to research and development in the Sahelian countries. In addition, technical colleges and universities have shown a great interest in incorporating agroforestry into their curricula.

In this context, we have developed a specific plan of action based on ICRAF's dissemination strategy, which involves the training of trainers for the region, the selection of focal institutions and the strengthening of their capacity to deliver relevant agroforestry courses.

Our dissemination activities have led to a significant increase in the number of scientists committed to agroforestry education, research and development (tables 36 and 37). Given the growing demand for training by NARS, this trend is most likely to continue in the future.

Scientists from the region rarely benefited from ICRAF training activities before the Sahelian AFRENA began in 1989. Since then, the pool of scientists trained in agroforestry has risen sharply.

ICRAF's Sahelian staff have also helped NARS scientists to have access to funding for individual or group research proposals from various sources such as IFS, the African Academy of Sciences and ANAFE.

Activities are undertaken in close collaboration with NARS; the diagnosis and design exercises conducted during the development and implementation phase of the project enhanced the capabilities of national research institutions in the design of agroforestry research. The iterative nature of our collaborative research programme with national partners has also provided opportunities for continuous upgrading of institutional capacity.

Recognizing the fact that technical colleges and universities are the main centres of education in the region and that conventional land-use education is sectorial (agronomy, forestry, livestock science and so forth) we have undertaken activities to develop appropriate mechanisms to institutionalize agroforestry in the region. For example, 11 educational institutions have endorsed ANAFE's programme of work. Two (IPR in Mali and IDR in Burkina Faso) were selected to serve as focal institutions in the region for agroforestry education and training. Both were identified as prime actors in rural development—working with farmers and involved in agroforestry. They are expected to articulate links in agroforestry research, education and extension. ICRAF's Sahelian office has provided them with training and educational materials and with technical and logistical support for organizing training and educational programmes.

Assistance was given to lecturers who played a key role in translating and adapting in French materials produced by ICRAF: 1) agroforestry research for integrated land-use and 2) approaches to agroforestry curriculum development. Consequently, agroforestry is being anchored with a broader approach on land husbandry. In 1996, capturing recent developments in research, agroforestry was incorporated into

Table 36. Number of trainees involved in non-degree training in agroforestry in the Sahelian countries (1983–96)

Theme and organizing institution	No. of trainees per year										
	83	84	88	89	90	91	92	93	94	95	96
Diagnosis & design—ICRAF					20						
AF training course—ICRAF	1	1									
AF research for development—ICRAF			1					20	2		
AF for integrated land use—ICRAF											5
Scientific writing—ICRAF									8	11	
Training materials development—ICRAF											19
Experimental design—ICRAF									1		20
Training of trainers—ICRAF											5
AF in the Sahel—focal institution (IDR)											3
Training of technicians—ICRAF							20				
Datachain application—ICRAF						15					
AF course—Univ. of Nebraska*											1
Information management—ICRAF						12		20			
Total	1	1	1		20	27	20	40	11	11	53

*AF course on windbreak technology

Table 37. Number of trainees involved in degree training in agroforestry in the Sahelian region

Home country	Home institution	Trainees (no.)	Sponsor	Host university	Degree and year of graduation		
					Engineer	MSc	PhD
Burkina	IRBET	2	CIDA	Laval		1 (1996)	1 (ongoing)
Mali	IER	2	CIDA	Laval		1 (1995)	1 (ongoing)
Mali	IPR	4	Sida	IPR†	4 (1996)		
Niger	INRAN	2	CIDA	Laval		1 (ongoing)	1 (ongoing)
Niger	University	1	Sida	Morogoro		1 (1996)	
Niger	University	1	Sida	IDR†		1 (1996)	
Senegal	ISRA	1	CIDA	Laval			1 (ongoing)
Senegal	UCAD	1	Sida	UCAD‡			1 (ongoing)

† IPR (Institut polytechnique rural) and IDR (Institut du développement rural) are the 2 focal institutions in SALWA region

‡ UCAD: Université Cheick Anta Diop, Dakar, Senegal

the curricula of 2 colleges (Centre de formation pratique forestier de Tabakoro, Mali, and Ecole nationale des eaux et forêts, Burkina Faso) and 1 university (Ecole nationale supérieure d'agronomie, Côte d'Ivoire). A consensus has been reached among ICRAF, IER and the University of Mali to develop and implement a full agroforestry postgraduate programme in 1997 with regional focus at the University of Mali.

Since the early 1990s, there has been a big drive to institutionalize agroforestry in the Sahel. The dissemination in the region of agroforestry information through hundreds of brochures, reports and ANAFE newsletters in 1996 has made research and educational institutions, NGOs, policy- and decisionmakers, and donor agencies aware of agroforestry.

As ICRAF no longer publishes *Agroforesterie aujourd'hui*, and given the fact that no agroforestry journal is available as a forum in which NARS can publish their results, we have identified a range of local and regional opportunities for copublishing in French.

TO SUM UP . . .

The AFRENA for the semi-arid lowlands of western Africa focused its work in 1996 on understanding the dynamics of social changes in the region and assessing the potential of an indigenous fodder tree, *Pterocarpus erinaceus*, to help farmers respond to these changes. Results show that *P. erinaceus* fodder banks can make a significant impact by helping to sustain smallholder livestock production, by providing a real opportunity for periurban farmers to earn cash revenues and by reducing the threat to the natural resource base of wild populations of pterocarpus.

Another research topic where significant results were achieved was the parklands. Many parkland trees, such as *Vitellaria paradoxa*, *Parkia biglobosa* and *Adansonia digitata*, have an underrealized economic potential; *P. biglobosa*, for example, can increase a household's annual income by some USD 266—that is, it can double the present income. In addition, biophysical research has shed more light on the *Faidherbia albida* effect: on-farm studies in Niger have revealed that about 60% of the tree's effect on improved biomass production of millet is due to increased N availability and 40% to increased P availability.

Finally, mechanisms and strategies put in place to institutionalize agroforestry in the Sahel achieved significant results in 1996, as 2 focal institutions (IPR in Mali and IDR in Burkina Faso) began to receive training and educational material as well as technical and logistical support to make them operational in linking agroforestry research, education and extension.

Research in 1997 features, in addition to the above directions, work on accelerating impact through live hedges and domestication of agroforestry trees. Furthermore, soil fertility, the lack of which has been identified as a major constraint to food production, will figure prominently in our future plans in collaboration with other institutions in the region.

Southern Africa

THE SOUTHERN AFRICA AGROFORESTRY RESEARCH NETWORK

The Southern Africa Agroforestry Research Network is based in the upland plateau ecoregion, which is characterized by miombo woodland, mean annual rainfall of 800–1200 mm and altitude ranging from 600 to 1200 m. Most countries in the ecoregion are faced with the problems of food and fodder shortage, soil fertility depletion and decreasing supplies of fuelwood. The deteriorating food situation is partly due to the rapidly growing population (average annual growth rate > 3%) and decreasing food production as a result of declining soil fertility and erratic rainfall. The worsening food security situation is underscored by a severalfold increase in maize imports in the last decade accompanied by a projected 3–5% growth in food demand in most of the countries in the ecoregion.

Against this backdrop, the Southern Africa Agroforestry Research Network was launched in 1987, with activities in Malawi, Tanzania, Zambia and Zimbabwe (see ICRAF annual report 1995 p 73–74). Its main focus is to generate agroforestry technologies to address the problems of declining food security and soil fertility, shortage of fodder and fuelwood, and environmental degradation. The network also conducts research on the domestication of indigenous fruit trees whose products have been identified as an important source of food and nutritional security, especially during droughts, and are also marketable and thus have the potential to increase farmers' income.

Four years ago the regional programme started an intensive participatory on-farm evaluation of a range of species and management options associated with priority technologies in each of the 4 network countries. With the new funding by CIDA, which came onstream in March 1996, testing of technologies on farm and dissemination activities are being further expanded and intensified. Towards this end, a technology transfer specialist and 4 national extensionists, 1 per country, are being recruited in 1997, as well as a soil scientist to enhance our work on soil fertility replenishment.

Numerous NGOs and development agencies also collaborate with ICRAF and NARS in evaluating agroforestry technologies and in disseminating information. In fact, disseminating the technologies will receive major emphasis during the next 5 years. Taking steps in this direction, ICRAF has established informal adaptive research and dissemination networks in a few critically selected extension pilot areas in each country (table 38).

The adaptive research and dissemination networks involve ICRAF, national extension networks (NEXs), NGOs, NARS and farmer groups. They are the focal points for participatory evaluation and dissemination of the technologies by farmers and for training farmer groups. The formation of the dissemination networks followed highly consultative extension planning meetings of all stakeholders including farmers and policymakers in each country. These meetings defined the modus operandi for agroforestry extension, including identification of training needs for extension workers, farmers and training institutions.

The network has thus brought a variety of disciplines together in the technology design and development process—forestry and crop, animal and social sciences—to address its 1st objective: to diagnose land-use constraints and design and develop technologies with the participation of farmers at every stage. Farmer participation in the technology development and adoption cycle is an important feature of the research programme.

The countries of the region focus on 1 major problem each. In Malawi, it is domestication of indigenous fruit trees; in Tanzania and Zimbabwe,

Table 38. Pilot areas for technology evaluation and extension impact

Country	Site
Malawi	Lilongwe Agricultural Development Division: Lilongwe East and West Rural Development Projects Machinga Agricultural Development Division: Zomba Rural Development Project Blantyre Agricultural Development Division: Chiradzulu Rural Development Project
Tanzania	Shinyanga Rural District Tabora Rural District Meatu District
Zambia	Chipata, Lundazi and Petauke Katete Chadiza
Zimbabwe	Mashonaland East, Central and West: Chikwaka, Chinamora, Zvimba/Guruve

fodder; and in Zambia, soil fertility. In addition, each country is also responsible for 1 or 2 secondary research issues as may be dictated by local conditions. Thus, in Tanzania work is also being done on fuelwood shortage and soil fertility while in Malawi research also deals with soil fertility, targeted in particular at the densely populated land-use systems of the Shire highlands. The principal research sites are Makoka (Malawi), Chipata (Zambia), Shinyanga (Tanzania) and Domboshawa (Zimbabwe).

The need to strengthen the capacity of the national research systems was highlighted during the diagnosis of the land-use constraints in the ecoregion. Therefore, the 2nd objective of the network is to strengthen and mobilize the local and national capacity for developing appropriate agroforestry systems. This objective is being addressed through a variety of training courses and the dissemination of information. Whereas previously more emphasis was put on formal training of scientists at MSc and PhD levels, in the next 5 years the emphasis will shift to the training of farmers and extension workers and the production of training and extension materials. This shift, however, will not preclude research attachments of scientists and postgraduate students to network research sites. The rationale behind the shift in training emphasis is to enable extension agents and farmers to adapt as well as to adopt new agroforestry systems.

THIS YEAR . . .

In this year's report, we highlight our research on improved fallows in Zambia, with special reference to our on-farm participatory evaluation of this technology. We describe the formation of the adaptive research and dissemination network in Zambia and the output of 2 village-level workshops for impact assessment of improved fallows. In addition, we present preliminary results of a regional trial undertaken in all 4 countries to assess the biophysical limits of improved fallows. We also report results from our on-farm research evaluating improved fodder supply systems for small-scale dairy production in Zimbabwe and Tanzania, our on-farm research evaluating rotational woodlots in Tanzania, and our collections of the indigenous fruit tree *Sclerocarya birrea.*

BURNING WOODY FALLOW BIOMASS—A VIABLE OPTION FOR FARMERS?

In all our improved fallow research with sesbania *(Sesbania sesban)* in Zambia, both on station and with farmers, the wood biomass is removed from the fallow area when the field is cleared, and only the leaf and twig material is incorporated into the soil. This is based on the assumption that the wood will be a valued product for farm families, both as fuel and as light construction material. Indeed, for many farmers this is the case. However, during the 1992–93 season, an exploratory trial indicated that the burning of 9 t ha^{-1} of sesbania wood (valued at USD 7 per tonne) on an adjacent grass fallow area produced an additional 1.5 t ha^{-1} of maize grain when that area was subsequently cropped. This additional grain was valued at USD 63 ha^{-1}.

Based on this observation, a formal trial was designed to evaluate the impact of a range of burning strategies for sesbania and grass fallows on subsequent test-crop yields. Several control treatments were included (table 39). The experiment was established at 2 locations in eastern Zambia in the 1993–94 season: at Msekera Research Station near Chipata (altitude 1020 m) and at Masumba Technology Assessment Site in Luangwa Valley (altitude 490 m). Soils in the Luangwa Valley are more fertile than those on the plateau around Chipata (table 40). In addition, rainfall in the valley area is lower and more erratic (mean 600 mm year^{-1}) than on the plateau (mean 1020 mm year^{-1}). Sorghum is the principal food crop grown in the valley, but farmers prefer maize as the staple crop. For this reason, sorghum and maize were both used as

Table 39. Fallow biomass management options, control treatments and test crop treatments at Msekera and Masumba, Zambia, 1994–96

Treatments year 1 and 2	Treatments year 3[a]
1) 2-yr sesbania fallow, wood removed from plots, litter incorporated	maize (± fertilizer)
2) 2-yr sesbania fallow, all biomass burned on plots	maize (± fertilizer)
3) 2-yr grass fallow, vegetation removed from plots	maize (± fertilizer)
4) 2-yr grass fallow, vegetation burned on plots	maize (± fertilizer)
5) 2-yr grass fallow, grass vegetation + sesbania wood from treatment 1 burned on plots	maize (– fertilizer)
6) 2 yr of maize plus recommended fertilizer	maize (+ fertilizer)
7) 2 yr of maize with no fertilizer applied	maize (– fertilizer)
8) First year with maize, 2nd year with groundnut	maize (– fertilizer)

At Masumba, both maize and sorghum were used as test crops in separate experiments.

[a] In some treatments, the test crop in the 3rd year was evaluated both with and without the recommended fertilizer rate being applied (112 N, 40 P_2O_5, 20 K_2O kg ha^{-1})

Table 40. Selected soil properties of trial locations at Msekera and Masumba, Zambia

	Soil property						
Location and depth interval	Sand (%)	Silt (%)	Clay (%)	Org. C (%)	pH	Avail. P (mg kg^{-1})	Total exch. bases (cmol$_c$ kg^{-1})
Msekera station							
0–15 cm	77	8	14	0.86	5.2	39	6.1
16–30 cm	69	8	22	0.69	5.2	10	7.0
Masumba site							
0–15 cm	75	8	17	1.31	6.9	291	10.6
16–30 cm	78	9	14	1.13	6.8	371	10.5

test crops in separate experiments at Masumba, whereas only maize was used at Msekera.

At both sites, sesbania was established from bare-root seedlings at a density of 10 000 seedlings ha^{-1}, at square spacing. Each treatment was replicated 3 times in plots 15 x 15 m. In the 3rd year, after the fallow had been cleared and biomass management treatments imposed, maize (hybrid, MM604) and sorghum (var. Sima) were grown as test crops, as indicated in table 39.

The years of fallow growth (1994 and 1995) were relatively dry, with 560 and 580 mm rainfall being recorded at Msekera and 638 and 440 mm at Masumba. This adversely affected sesbania growth at Msekera (table 41), and there was only 9.4 t ha^{-1} of total biomass production in the 2-year period. Between 15 and 20 t ha^{-1} is usually recorded under more normal rainfall conditions at this location. In spite of the dry seasons, sesbania growth was remarkable at Masumba, with a 2-year accumulation of 40.7 t ha^{-1} of biomass, the highest we have ever recorded in our research at that site. In addition to this standing biomass, 7.2 t ha^{-1} of litter had also accumulated on the soil surface. Such high biomass production can be partially explained by the relatively fertile soil (see table 40 and control yields, table 42) coupled with the lower altitude, hence warmer mean temperatures than on the plateau. However, the growth is still unusual, given the dry seasons experienced during fallow growth. Sesbania is known to root rapidly to depth, and after 2 years of growth at Msekera it was found to be taking up water from below 6 m. It seems very probable that in the valley bottom, sesbania was able to reach the water table. In contrast to sesbania, the dry-matter production of the grass fallows was very similar and low at both locations (table 41). Unfortunately, differences in composition of grass fallow species (hence biomass quality) were not recorded in this experiment. However, it was observed that the annual species *Sesbania macrantha* was a common component of the natural fallows at Masumba.

In 1996, when the test crop was grown, rainfall was above average and well distributed at

Table 41. Fallow performance and biomass production after 2 years at Msekera and Masumba, Zambia, 1994–95

Fallow type and location	Survival (%)	Height (m)	Biomass (t ha^{-1})		
			Leaf + twig	Wood	Total
Msekera					
S. sesban [a]	67	2.7	0.6	8.8	9.4
Grass [b]	–	–	–	–	6.4
Masumba					
S. sesban [a]	84	6.6	2.2	38.5	40.7
Grass [b]	–	–	–	–	6.5

[a] Results are mean values from treatments 1 and 2 (see table 39 for treatments)

[b] Results are mean values from treatments 3, 4 and 5

both locations, with 1100 and 850 mm at Msekera and Masumba respectively. In treatments where the nutrient supply was not limiting, yields of over 6 t ha^{-1} of maize were recorded at both locations (table 42).

At Msekera, because of poor sesbania fallow growth, none of the fallow management options were able to raise the yields of maize to those achieved with full recommended fertilizer use (6.6 t ha^{-1} in treatment 6, see table 42). However, a standardly managed sesbania fallow (treatment 1) resulted in significantly higher maize yields than those achieved after grass fallows (treatments 3, 4, 5) or other control treatments (treatments 7, 8). Burning all the sesbania biomass on the plots (treatment 2) resulted in a significant decrease in yield below standard management (treatment 1), presumably because of nitrogen loss from the twigs and leaves, which would normally have been incorporated into this N-deficient soil. Yields following a grass fallow were very low (0.85 t ha^{-1}) in both treatments, presumably because both vegetation removal and vegetation burning resulted in negligible addition of nitrogen to the system. However, the burning of 7 t ha^{-1} of sesbania biomass on the grass fallow plots resulted in a significant increase in maize yield, from 0.85 to 1.65 t ha^{-1} (treatment 4 vs treatment 5). Without appropriate soil analysis, the reasons for this increase in yield cannot be confirmed, but it is likely due both to some additional nitrogen being added in spite of the burn and also to about 7 kg ha^{-1} of immediately available P. In simple monetary terms, the wood burned would be valued at USD 5.50 and the additional maize yield at USD 56.50.

At Masumba, maize yields in all unfertilized treatments were substantially greater than those achieved at Msekera. The outstanding performance of the sesbania fallow resulted in maize and

Table 42. The effect of fallow biomass options and control treatments on the grain yield (t ha^{-1}) of maize and sorghum, Zambia, 1996

	Msekera	Masumba	
Treatment	Maize[a]	Maize[a]	Sorghum[a]
1) Sesbania fallow, wood removed	3.10	6.03	8.56
2) Sesbania fallow, wood burned	2.10	6.27	8.26
3) Grass fallow, vegetation removed	0.83	4.53	5.37
4) Grass fallow, vegetation burned	0.85	4.41	6.16
5) Grass fallow + sesbania wood burned	1.65	5.29	6.46
6) Continuous maize or sorghum (+ fertilizer)	6.61	6.52	6.94
7) Continuous maize or sorghum	2.03	3.03	4.52
8) Maize or sorghum and groundnut rotation	1.73	4.10	6.02
SED	0.45	0.85	0.75

[a] Test crop grain yields reported are those that did not receive fertilizer, except treatment 6.

The wood biomass from a sesbania fallow (here a 15-month-old fallow in Zimbabwe) can be harvested and used as fuel or as light construction material. Or it can be burned and the residue incorporated back into the soil. Results of experiments in Zambia are showing marked increase in grain yield in the crops of maize that fallow—with potential economic returns as high or higher than they would be for the wood harvest.

sorghum yields equivalent to or greater than those achieved in a fully fertilized crop (treatment 1 vs treatment 6) and significantly greater than those following a grass fallow (treatments 1 and 2 vs treatments 3 and 4). Burning, as compared with incorporation of litter, had no significant effect on either maize or sorghum yields in any treatment comparison. Certainly, available P in the Masumba soils is high (table 40), and no positive beneficial effect of immediately available P added through burning would be expected. On those generally more fertile soils, the inevitable loss of nitrogen through burning did not have any negative effect on grain yields of either maize or sorghum.

In conclusion, this study confirmed the beneficial effects of sesbania fallows on subsequent maize (or sorghum) yields at both locations compared with grass fallowing, continuous monocropping or rotational cropping. The burning of all sesbania residues within plots upon fallow clearance reduced maize yields at Msekera and had no effect at Masumba. However, the removal of the woody component of the fallow and the burning of that biomass on an adjacent grass fallow area appears to be a practical option for farmers on the plateau to evaluate. They would not only benefit from the area under a standardly managed sesbania fallow but would achieve greater production from adjacent grass fallow areas with little or no extra labour involved.

ON-FARM RESEARCH ON IMPROVED FALLOWS IN EASTERN ZAMBIA

The processes involved in the adoption of natural resource management research such as agroforestry are not well understood. We report our documented experience with on-farm trials in this section as well as the personal experience of farmers, to gather basic information towards a predictive understanding of the adoption process. The next section describes the actual dissemination methods used by our partners.

During the 1995–96 season, the number of farmers participating in on-farm experimentation on improved fallows increased from 205 to over 1000, reflecting the enthusiasm farmers have for the technology. The number of researcher-designed, farmer-managed trials increased from 158 to 205, to permit researchers and farmers to assess performance when planting in different seasons. In some of these trials, at least a third of the experimenting farmers have been women. Farmer-designed, farmer-managed trials are much less expensive to implement, because farmers plant and manage the trials as they wish, and over 800 of these were added. Here we present some findings from these trials and report on 2 other innovations in Zambia: village workshops for impact assessment, and development of an adaptive research and dissemination network.

RESEARCHER-DESIGNED, FARMER-MANAGED TRIALS

In the researcher-designed, farmer-managed trials, farmers select 1 of 6 improved fallow technologies and compare it with continuously cropped maize, both with and without nitrogen fertilizer. The 6 technologies they choose from are improved fallows with sesbania *(Sesbania sesban),* tephrosia *(Tephrosia vogelii),* or pigeonpea *(Cajanus cajan),* or those same species intercropped with maize while the fallow is established in year 1 and then allowed to grow into a pure stand in year 2. Sesbania was planted using bare-root seedlings, and tephrosia and pigeonpea were planted by direct seeding. Bare-root seedlings were inoculated with rhizobia from the already established stands of sesbania at the farmer training centres or on farm. Tephrosia and pigeonpea were not inoculated.

In last year's report we described the enthusiasm of the farmers in these trials, despite the poor rainfall of 1994–95, which adversely affected tree and maize performance. The 1995–96 rainy season was much better; trees and crops performed better and farmer enthusiasm increased. Here we report on 2 surveys to assess farmers' progress and feedback: 1) 130 farmers who planted in 1994–95, interviewed 1 year after planting, and 2) 35 farmers who planted in 1995–96, visited 6 months after planting. The 1st survey was actually composed of 2 separate ones: a survey of farmers who had survival rates of over 60%, 3 months after planting, and another of those with lower rates. Most of those with low rates (38% of farmers with pure-stand fallows and 73% with intercropped fallows) were not expected to have adequate stands for obtaining a good yield response after the fallow period.

FARMERS PLANTING IN 1994–95 WITH SURVIVAL RATES OVER 60%

The mean survival rates for all fallows were significantly reduced following the longer-than-normal dry season in 1995 (March to November), which was characterized by temperatures of about 28 °C and uncontrolled fires and communal grazing. A paired comparison of survival rates 3 months and 1 year after planting showed that sesbania ranked highest in its ability to withstand the dry season. On 19 farms that had high survival rates on pure

An ICRAF technician and a camp extension officer hold a village meeting with farmers at Feni Camp in eastern Zambia to discuss the successes the farmers have had with improved fallows and how they have managed them.

stands, survival dropped from 81% at 3 months to 63% after 1 year. Tephrosia survival dropped from 91 to 51% and pigeonpea from 72 to 21%. The differences in the reduction in survival rates among the species were significant at $p = 0.01$.

Table 43. Problems cited by farmers that affected establishment and growth of Sesbania sesban, Tephrosia vogelii *and* Cajanus cajan *in improved fallows during the first 12 months after establishment*

Problem	Farmers who mentioned the problem (%)		
	S. sesban	*T. vogelii*	*C. cajan*
Beetles	80	0	0
Drought	68	80	72
Termites	48	32	50
Browsing by livestock	16	36	78
Poor seed	0	20	33
Other	28	8	12
No. of cases	25	25	18

Percentages do not sum to 100 as each farmer could mention more than 1 problem.

The dry season had a greater negative impact on species when intercropped than when planted in pure stand. For example, whereas the survival rate of tephrosia in pure stand declined by 44% between 6 and 12 months, intercropped tephrosia declined by 59%. Trees planted in pure stand grew more vigorously because of the lack of competition for resources by maize and were thus better able to develop a deep rooting system, necessary to withstand the long dry season. Moreover, intercropped trees are more susceptible to trampling by livestock, which feed on the crop residues remaining after harvest.

The main problems experienced by the farmers who planted sesbania were an outbreak of a sesbania leaf-defoliating beetle, *Mesoplatys ochroptera* (reported by 80% of sesbania growers), and drought (68%) (table 43). About 48% of the farmers who had an outbreak of *M. ochroptera* sprayed their fields, usually with Decis, a chemical used to spray cotton. Our observations indicate that in most cases, trees were able to recover fully after a beetle attack, even without being sprayed.

For farmers who planted tephrosia, drought was the main problem; next were browsing by livestock and termites. Browsing, drought and poor seed were the major problems for the farmers who planted pigeonpea. Browsing is primarily a problem during the dry season; once food crops have been removed from the field, the animals are let loose to graze on crop residues.

We expect yield responses after the fallow periods to be variable, depending on the technology used. Browsing destroyed most of the pigeonpea stands; we thus decided to stop distributing seed in researcher-designed trials, although some farmers are continuing to plant it on their own. On the other hand, nearly all surveyed farmers who planted sesbania and tephrosia in pure stands are expected to achieve a good yield response after the fallow period. Yield responses following stands established through intercropping are expected to be variable. Farmer experimentation is thus helping researchers and farmers alike to understand the advantages and disadvantages of different improved fallow practices.

Farmers expressed a strong interest in continuing to experiment with improved fallows; over 70%

plan to plant an improved fallow during the 1996–97 season and 67% wanted to plant sesbania.

FARMERS PLANTING IN 1994–95 WITH SURVIVAL RATES LESS THAN 60%

By 6 months after they had established their fallows, some farmers had survival rates of less than 60%; of those farmers, 39% had designed and were managing their own trials. Farmers had discontinued 60% of the total number of trials with survival rates of less than 60%. Most of those whose trials failed had grown *C. cajan* as a fallow species, and it was heavily browsed by livestock. Commonly in the survey area, soon after the crops have been harvested, the animals are left to roam freely in the fields, and thus they caused a lot of damage to young plants. Other fallow species failed mainly because the farmers managed them poorly or because of drought. In a few instances, failure was attributed to the defoliation caused by *M. ochroptera.*

It is encouraging to note that the majority of those farmers whose trials failed in 1994–95 established new farmer-designed, farmer-managed trials in the 1995–96 season. They preferred sesbania and tephrosia for their fallow species, which is not surprising, given their previous failure with pigeonpea.

FARMERS PLANTING IN 1995–96

Survival rates averaged 75% for sesbania, as compared with 58% the previous year. The higher rates are probably a result of higher rainfall and improved management of nurseries and transplanting as farmers gain experience with the technology. Survival rates for tephrosia were 77%. Beetles were seen as a problem by 75% of the sesbania growers, but they had little effect on survival. Most tephrosia growers claimed that there were no problems affecting growth of their trees. About 10% mentioned each of the following: drought, termites, waterlogging, weeds and late planting. Farmers overwhelmingly preferred sesbania over tephrosia and pigeonpea. Of the 35 farmers surveyed, 34 plan to plant an improved fallow during 1996–97; 67% plan to plant sesbania in pure stand, 25% plan to intercrop sesbania, and 15% want to plant tephrosia.

FARMER-DESIGNED, FARMER-MANAGED TRIALS

In 1993–94, 5 farmers established farmer-designed, farmer-managed trials, using sesbania seed or bare-root seedlings obtained from researchers and extension staff. The farmers visited research trials to learn about the technology but were not given an experimental plan to follow; rather, they were encouraged to experiment with the technology as they wished. The objective of the trials was to assess farmers' experiences with the technology and how they modified it, and to provide feedback to research. In 1996, following their 1st postfallow harvest, the farmers, 3 men and 2 women, were interviewed concerning their experiences. Here, we recount the experience of Ms Zelina Mwanza, head of a household in Kalichero camp, and summarize the results of the other farmers.

Ms Mwanza learned about improved fallows through her camp officer in the 1993–94 season,

Discussing the potential of tephrosia to improve the soil, these women of Feni Village are part of the Chipata South (Zambia) research and dissemination network on improved fallows. Mama Mphanza, the woman on the left, who owns the fields where they are standing, in which maize did not do well, has planted tephrosia to renew soil fertility.

shortly after the officer had attended a field day at Msekera Research Station. In January 1994, project staff planted a trial in Kalichero that they had designed and managed, and Mwanza was able to collect 620 sesbania seedlings. She removed the seedlings from the polythene bags and carried them in a washbasin on her head to her field, 6 km away. It took her 2 trips to complete the task. She then used the seedlings to establish a trial she designed and managed herself, with an improved fallow of 528 m^2. Shortly thereafter, Mwanza herself attended a field day at Msekera and visited other farmers who had planted improved fallows. At the start of the 1994–95 season, she used naturally regenerated seedlings from her 1-year fallow plot to fill gaps in her field and to establish a 2nd, smaller improved fallow. She also tried to plant an improved fallow of *C. cajan* but failed, because of drought in the early part of the season.

In late 1995, Zelina Mwanza cut down her 2-year-old sesbania trees and incorporated the leafy biomass into the soil. She used the firewood for cooking meals in the field—firewood that she says she would have had to collect from about 5 km away had she not had the sesbania firewood. She was very pleased with her maize yield after the

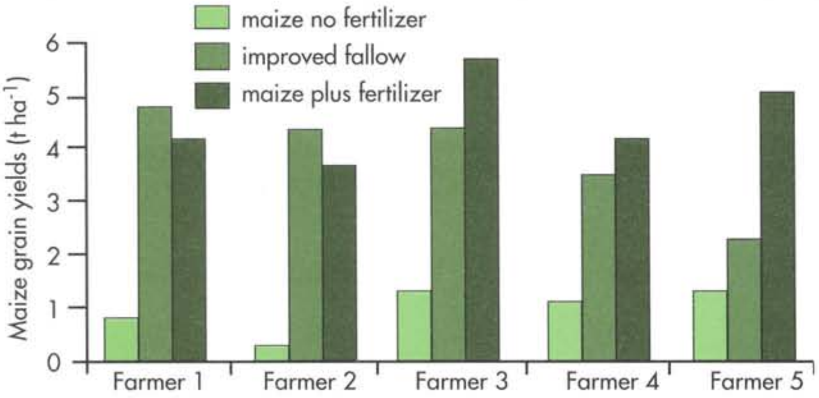


Figure 36. Maize yields following 2-year sesbania fallows in farmer-designed, farmer-managed trials; individual farmers' results, Kalichero camp, eastern Zambia.

fallow period—she harvested 232 kg from the plot (4.4 t ha^{-1}) (fig. 36). Her biggest problem associated with the fallows was the work involved in cutting the trees. She and her oldest child cut them with axes. In the 1996–97 cropping season she plans to plant a sesbania improved fallow of 2500 m^2.

The 5 farmers in the trial planted a total of 17 improved fallows over the period 1993 to 1996. All have used planting material from their own farms to plant new fallows, taking care to maintain a broad base by collecting seed from more than 30 trees. All are experimenting with the technology, testing such practices as—

- intercropping with different crops (maize, sunflower, cowpeas, or groundnuts) during the year of establishment
- intercropping with maize during the 2nd year after establishment
- varying the time of planting of the intercrop with respect to that of the trees
- weeding during the 1st year after establishment

In 1996, the 5 harvested their 1st crop of maize following a sesbania fallow; 4 had fallowed for 2 years and 1 for 3 years. The results were extremely promising on 4 of the farms (fig. 36): maize yields increased between 1 and 4 t ha^{-1} as compared with maize continuously cropped without fertilizer. Maize yields after the fallow exceeded those of fertilized maize on 2 of the farms. On the 5th farm, where the fallow had lasted 3 years, maize yields after the fallow period were only 77% higher than those of continuously cropped maize without fertilizer. Here, 2 problems were responsible for poor performance of the fallow: failure to weed and fire. Although fire is common in the area, it does not usually affect improved fallows; nevertheless, protection against it is essential.

Three of the 5 farmers have distributed seed to a total of 28 other farmers. We are continuing to monitor their experimentation and their progress in expanding their fallows. All 5 planned to plant new improved fallows during the 1996–97 season.

THE DISSEMINATION PROCESS IN IMPROVED FALLOWS IN EASTERN ZAMBIA

INFORMAL NETWORK

The Zambia–ICRAF project has helped facilitate the establishment of an informal network to conduct adaptive research and facilitate dissemination of improved fallows (fig. 37). The network has 2 functions: to provide coordinated and analytical mechanisms for participatory monitoring and evaluation of on-farm research on improved fallows and to act as a catalytic and action-oriented group for the widespread dissemination of the technology in pilot areas. The network began when the project started supplying planting material and information to extension services, development projects, NGOs and farmer groups that wanted to help their members test improved fallows. In exchange, these

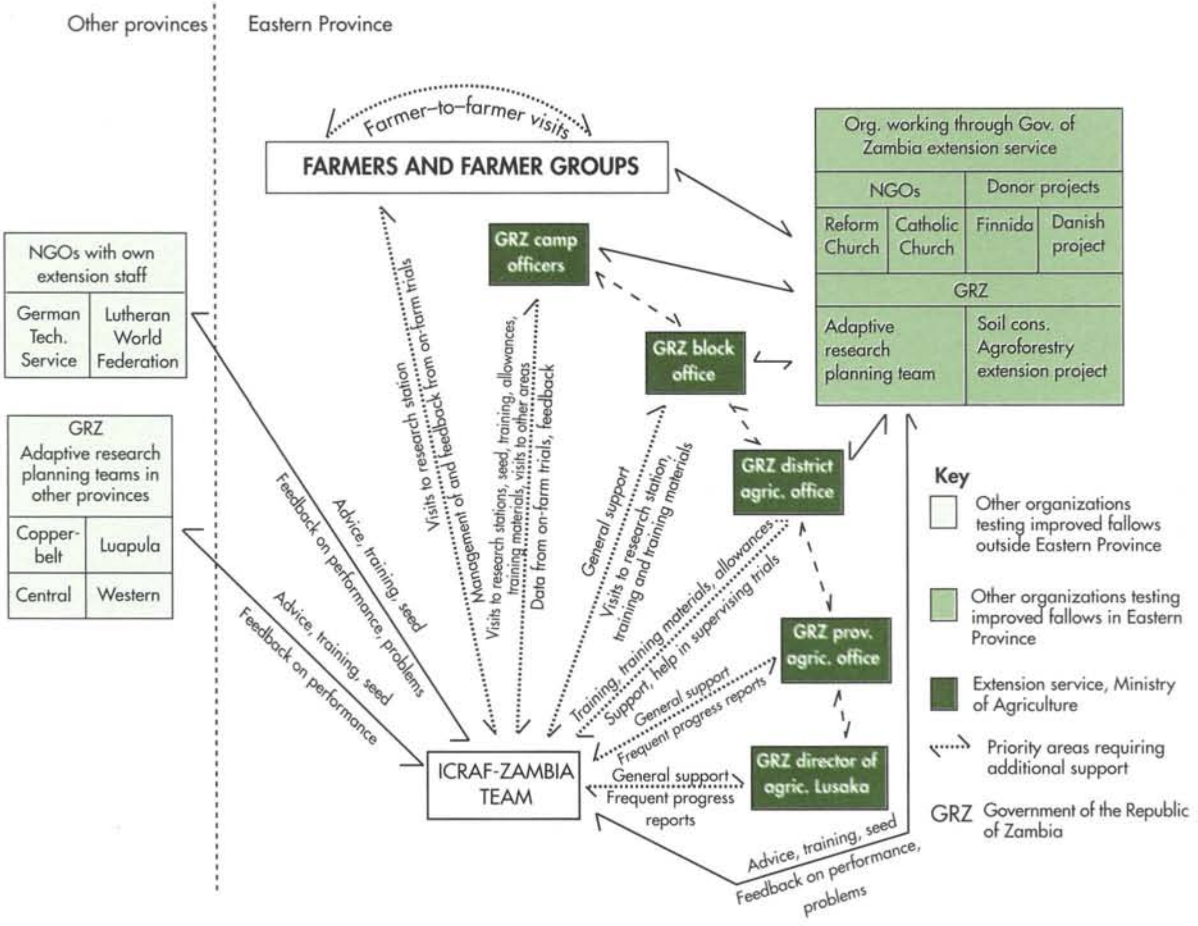


Figure 37. Institutional links between the ICRAF–Zambia team, farmers and other organizations testing improved fallows.

organizations provided the project with feedback on the performance of the technology.

The network is based on the principle that adaptive research and extension are really 2 sides of the same coin. Once on-farm research has confirmed that a technology has adoption potential, extension can begin. But researchers need to be involved to obtain feedback on problems and to identify researchable issues. Moreover, the more extension and NGO staff become involved in on-farm research, the more knowledgeable and enthusiastic they will be in extending the practice. Their involvement can save scarce reseach resources and improve the feedback to research.

The extension service in Zambia is a full partner in on-farm research. In fact, about half of the trials were laid out by extension staff in the absence of researchers. Extension staff are also playing an important role in supporting the village nurseries and in monitoring the trials. They view the trials as joint research–extension work. Relations are excellent also at higher levels. Throughout the system, managing on-farm trials is seen as a normal duty of extension and NGO staff rather than a burden imposed on them from outside.

The Zambia–ICRAF project has also developed ties with many other organizations, such as government agencies, donor-financed development projects, and NGOs. These organizations are now assisting farmers to test improved fallows. In addition, strong links have been developed with the numerous farmer groups operating in the area. These groups (often called clubs) are generally composed of farmers in a single village; sometimes they are limited to a specific group such as women or youths. Most have several different self-help activities but some were formed specifically to promote improved fallows. The groups manage nurseries, distribute seed and seedlings, and exchange knowledge and experience on improved fallows.

The 1st meeting of the network was hosted by the Zambia–ICRAF project in April 1996 and was attended by 75 representatives of extension services, projects, NGOs, and farmer groups. Participants met in Chipata to plan for the wider testing of improved fallows, to review the state of knowledge about them, and to develop a draft extension manual. The 2nd meeting was held in Chipata in October 1996 as part of a workshop on integrated soil fertility management. It was attended by 90 representatives of 17 organizations. Representatives of extension and NGOs presented the progress they had made and problems encountered in helping farmers test improved fallows and other soil fertility-enhancing technologies. Several farmers presented their experiences, and researchers reported on the results of on-station and on-farm trials. Other issues discussed included the supply of planting material, nursery development and plans for increasing on-farm testing. Participants forecast that the number of farmers planting improved fallows in Eastern Province would increase to 3400 in 1996–97. Representatives also agreed that they would meet twice a year, in March and October, to plan research and extension activities and review progress made.

VILLAGE WORKSHOPS FOR IMPACT ASSESSMENT

Impact assessment is an important feature of every research and development project. But there are often uncertainty and lack of consensus among researchers over which impact indicators to monitor. Moreover, farmers are seldom involved in the process of determining and planning for the measurement of the indicators. In 1996, we conducted 2 village workshops in eastern Zambia to obtain community and farmer views on the impact indicators that they think are important with respect to the improved fallow practices they are testing. We also wanted to know what they expected in the way of increased yields and what constraints they anticipated in achieving these new levels. We wanted to develop a general strategy for monitoring impact, not only in these villages but in others as well.

The workshops were held in 2 of the 4 pilot villages that the Zambia–ICRAF team has selected for monitoring village-level impacts of improved fallows. The workshops lasted 1 day and each involved about 50 farmers, of whom about 35% were women. All the farmers had seen improved fallows and many were testing the technology. The introductory session included songs, a play about improved fallows, a farmer's presentation on the technology, discussion of workshop objectives, and a question-and-answer session. Then participants split into working groups to identify economic, social and ecological impact indicators. At the 2nd workshop, there was time for a 2nd set of working group sessions dealing with special topics, such as farmers' plans for laying out improved fallows, their plans for conducting experiments, and likely changes in farming activities if maize yields increased. Agricultural extension officers and camp officers in the village acted as rapporteurs for the working groups.

The working groups identified impact indicators at different scales: plot, household and village (box 3). At the plot level, most of the indicators concerned improvements in soil structure, fertility and moisture availability. Farmers also expected that improved fallows would reduce striga infestation, act as windbreaks, improve moisture retention and reduce soil erosion. At the household and farm level, several impacts emerged of which researchers were not previously aware. For example, if improved fallows raise maize yield, many farmers plan to reduce their area under maize and increase the area devoted to cash crops, which are more profitable and easier to market. Some farmers have found that sesbania poles are useful for fencing and for constructing storage bins. More fuelwood production from the fallow plots may reduce the time people spend collecting wood, but there was some dispute as to whether sesbania wood could substitute for fuelwood normally collected from the miombo woodlands.

At the village level, many felt that free grazing and uncontrolled fires would damage improved fallows during the dry season. Therefore, they felt that the community would have to regulate the grazing and setting of fires. They also noted that more stover would be available for feeding to livestock and that the increase in available firewood from improved fallows could help conserve forests and wildlife.

Farmers also discussed the main factors affecting adoption and constraints that may militate against it. These constraints included characteristics of the technology (for example, the fallow period may be too long for some farmers who are short of land), *Box 3. Selected indicators of the impact of improved fallows as identified by farmers in village workshops*

On the plot

Soil fertility will improve
Soil structure will improve
Rainfall infiltration will improve
Less erosion will occur in plots
More moisture will be held in the soil
Better maize seedlings will emerge
Maize yields will be higher (compared with other plots)
Sesbania will control striga
Sesbania will act as a windbreak
Sesbania will provide shade for rest periods (where other trees are absent)

On the farm or in the household

Increased harvest will mean increased food supply
More firewood will be available
More time will be available for other activities because of reduced time spent collecting fuelwood;* for example, extra time could be spent growing vegetables, looking after the family, cooking
More cash will be available (earnings from maize and savings from buying no or less fertilizer)
Standard of living and nutrition will improve
Sesbania poles will be available for building storage bins and for fencing
More maize stover will be available for cattle fodder
Pesticide effect from tephrosia can be used to protect harvested grain
More labour will be needed—for work in nurseries, for transplanting and weeding—but less for cropping
More time will be needed for herding in dry season to ensure animals do not damage fallows*

In the village

Indigenous trees, forests, and wildlife will be saved as fuelwood collection declines*
Food security will increase
Grazing area will be reduced*
Community spirit of working together will be enhanced through group nurseries
Need will be greater for community regulation of grazing and fires

* Indicates there was lack of agreement among farmers

field characteristics (for example, the technology will perform especially well where striga is present), household characteristics (lack of access to water will limit many farmers' abilities to establish nurseries), and community characteristics (the less available fuelwood becomes, the more interested farmers will be in sesbania fallows).

This information helped researchers, community leaders and farmers develop a strategy for monitoring impact. Researchers and leaders will develop methods for monitoring the main impacts and leaders will assist in collecting data. Monitoring will begin with a brief census of all households in each village and some of their main characteristics. Information on factors affecting adoption is useful for developing recommendations and planning research. In addition, the workshops had several other beneficial spin-offs—bringing farmers together with other stakeholders in the research and dissemination process, exchanging information with farmers, and generating a team approach to research and development.

PERIURBAN ON-FARM FODDER RESEARCH

. . . IN ZIMBABWE

Milk consumption is growing rapidly in the cities and towns of southern

Africa, and there is a concomitant increase in the number of improved-breed dairy cows to help meet the demand. Shortage of high-quality feed is a major constraint to increasing milk production in the smallholder sector; high-protein fodder trees can play an important role in improving feed supplies, especially during the long dry season. Other livestock, including goats and cattle for beef and draught, can also benefit. On-station research in Zimbabwe has confirmed that several fodder tree species perform well in contour hedges (ICRAF annual report 1994 p 138–140); here we report on the testing of fodder trees on farm.

On-farm testing began during the 1994–95 season at 2 contrasting sites in communal areas of northern Zimbabwe. Chikwakwa, 50 km east of Harare, is in an area of poor, sandy Alfisols, while Guruve, 150 km north of Harare, has more fertile, clayey Alfisols. Both areas receive an

A farm couple (centre) on their smallholder dairy farm in Zambia explain to other farmers and extension staff on a field day how harvest from this tree fodder bank (left) is incorporated with napier grass fodder. Farmers appreciate a number of advantages of growing and using trees for fodder.

annual rainfall of 800–1000 mm, and the dry season lasts 7–8 months. In Chikwakwa, frost is a common problem between June and July; in Guruve, frost is less common. Farm size averages 2 ha in both areas, and main crops include maize, cotton, sunflower and groundnuts. Most farmers in both areas own local breed cattle for beef and draught; 7% in Chikwakwa and 1% in Guruve also have dairy cows. Grazing provides the base of the cattle diet; dairy cows are also often fed on napier grass, silage and hay. Dairy cows are fed purchased concentrates throughout the year, but the quantities vary, dropping when cash is short. Marketing infrastructure is more developed in Chikwakwa, and projects have assisted low- and middle-income smallholder farmers to buy dairy cows. In Guruve, the infrastructure is less developed, and the owners of dairy cows tend to be higher income smallholder farmers.

Surveys have shown that farmers are acutely aware of feed shortages and are eager to test new fodder species.

Farmer fodder bank trial

A fodder bank trial was started in 1994–95 involving 12 farmers in the 2 locations, each farmer planting 4 species *(Acacia angustissima, Calliandra calothyrsus, Cajanus cajan* and *Leucaena leucocephala)* in fodder banks. The trial was researcher designed and farmer managed, with each farmer planting 100 trees of each species in hedges 4 rows wide along the contour. Farmers established the trees using potted seedlings provided by the researchers. Spacing was 0.5 x 0.5 m. Survival was variable; poor survival was attributed to browsing by goats and poor soils.

In 1995–96, 28 farmers were added, 9 of whom were women. The new trials were farmer designed and farmer managed, that is, farmers were encouraged to plant and manage the trees as they wished. Several new species were introduced *(L. esculenta, L. shannoni, Sesbania sesban* and *L. pallida)* in addition to those mentioned already. Each farmer planted an average of 600 seedlings, using 1 to 6 species, depending on interest and seedling availability.

The farmers planted in a range of niches: 15 planted trees in their fodder grass plots, which consist mostly of napier grass *(Pennisetum purpureum)*; 8 planted in pure stand, 4 intercropped with maize and grasses, and 2 intercropped with maize (1 farmer planted in 2 niches). Nearly all were planted in existing fodder banks or in paddocks because these fields were already fenced. Other reasons for planting in fodder banks were that no extra land is taken up by the trees, and management, for example weeding, is easy. Most of the farmers—25 of the 28—planted their trees in rows. There was a wide range in spacing; some farmers varied their spacing to compare its effect on the growth of adjacent trees, crops and fodder grasses.

Farmers have experienced some problems growing the trees but overall their performance is very encouraging. The biggest problem is browsing by goats, which have free access during the dry season. Heavy dry-season browsing reduces leafy biomass production during the following rainy season by roughly 25%. Frost is the 2nd most important problem—it can damage or kill newly planted trees. Farmers have found that early planting, at the beginning of the rainy season, is an effective measure against frost, which occurs during the dry season.

Few differences have thus far emerged between farmers in the 2 zones. Guruve farmers tend to plant more frequently in paddocks because they want their cattle to browse the trees. Chikwakwa farmers are more interested in cutting and carrying or in drying and storing the tree leaves for use in the dry season.

Cutting and feeding begins in the 2nd or 3rd year; of the 12 farmers who planted at the beginning of the 1994–95 rainy season, 9 pruned their trees and fed the cuttings to their animals in 1996, after the 1995–96 rains. Informally, 4 of these farmers were interviewed about their feeding practices; 3 of the 4, Mr Gwara, Ms Mudzivare and Ms Muronzi, have dairy cows, and the other, Mr Guzha, has local cattle used for draught and for sale as beef cattle.

The dairy farmers practise cut-and-carry whereas Mr Guzha allows his animals to browse the trees after a day's grazing. He likes this system because it requires less labour than the cut-and-carry system and because browsing promotes the growth of many shoots and increases leaf production. Ms Muronzi dislikes letting her cows browse because the animals trample the trees and sometimes browse to ground level, which inhibits growth.

Those practising cut-and-carry mix the tree leaves with other feeds. They explained that there were 2 reasons: 1st, to help the cows get accustomed to the new feed, and 2nd, because it is easier to grind feeds at the same time rather than separately. Tree leaves are fed during or after milking, that is, before the cows go out to graze.

The farmers were also conducting their own experiments to assess the effectiveness of the tree leaves as a feed. Ms Muronzi tested the leaf material by alternating among 3 diets, 2 'controls'—concentrates + silage and concentrates + napier grass—and 1 'test treatment'—concentrates + a mixture of leaves of 4 tree species *(L. leucocephala, C. calothyrsus, A. angustissima, L. esculenta).* She found that with the tree leaves, she obtained 1 litre of milk a day more than with either of the other 2 treatments. She also found that the milk was creamier, probably reflecting a higher butterfat content.

Ms Mudzivare and 2 other farmers are testing the tree leaves as a substitute for purchased concentrates. Ms Mudzivare mixes the leaves of 5 fodder tree species: *C. cajan, Gliricidia sepium, A. angustissima, L. leucocephala, S. sesban).* First she fed the tree leaves instead of concentrate, but the effect on milk production was negative. Now she is feeding both but has cut back on the amount of concentrate. None of the 3 farmers have yet arrived at a conclusion concerning the effectiveness of substituting tree leaves for concentrates.

Ms Muronzi, who has also experimented with using the leaves to make silage, has found that tree leaves improve the palatability of silage. The farmers generally felt that a mixture of leaves was best for their cattle, to provide them with a balanced diet. Leucaena and acacia leaves were the most palatable and calliandra and pigeonpea the least, but the cattle accepted eating all species.

In the future, farmers hope to use leaves as a substitute for purchased concentrates, which are expensive for them. The trees are especially important for maintaining the quality of the animals during the dry season, when green feed is lacking. The farmers, who are also interested in reducing the amount of grazing their animals do, see fodder trees as part of a way to move toward a minimum- or zero-grazing system. Also, 3 of the farmers appreciated the fuelwood obtained from the trees and 2 used leaves that their animals did not eat as green manure in their vegetable gardens. Farmers felt that growing the trees was easy and that their only drawback was that they had to be fenced to prevent their being browsed by free-grazing animals. All planned to expand their acreage in fodder trees in the 1996–97 season.

The wide variation in trial conditions has helped confirm the hypothesis that the trees grow well under a wide range of conditions. Farmers' initial experiences in feeding leaves are also encouraging. The demand for fodder trees is high, and the team plans to assist about 100 farmers to plant during the 1996–97 season. Instead of providing seedlings, the team is assisting farmers to establish their own nurseries. Future work will emphasize—

- conducting research to make the technology more appropriate and more effective—on-farm trials planned for this year focus on establishment, live fences, mixed stands, and feeding
- continued monitoring of the on-farm trials, especially to assess farmers' expansion of plantings, feeding strategies, and feedback on problems
- expanding the testing of fodder trees to new geographical areas and involving a broad range of organizations—governmental, NGOs, and farmer organizations—in the testing and dissemination of fodder trees

. . . AND IN TANZANIA

Research on the potential of fodder trees is under way also in Shinyanga and Tabora, Tanzania, where milk is one of the essential components of the diets of the Sukuma people. Traditionally, farming households in the rural areas maintain a small stock of local milking cows to supply essential domestic needs. In more recent times, as urban settlements have expanded and milk markets developed, both urban and periurban milk production has increased in importance.

To help focus our research, a survey of current dairy-management strategies was undertaken; it involved 24 farmers in periurban and urban areas of Shinyanga. The results of this survey highlighted several important factors. Milk yields are generally very low, ranging from 5 to 10 litres day^{-1} per cow in the wet season and dropping even further, to below 3 litres day^{-1}, during the dry season. In general, farmers try to overcome this low production level by increasing their animal numbers. The average dairy herd recorded in this initial survey was 13 milking cows per dairy household, with a range of 2–30.

Free grazing of the dairy cattle in communal lands ('ngitiris') and fallow areas provided the dominant source of feed for 22 of the 24 farmers. This means that not only do cattle have to move long distances in search of fodder, an average of 10 km daily, but also the quality of the grazing lands is poor, even during the rainy season. Eleven communal grazing areas were sampled for species composition and quality. Dry- matter production ranged from 0.2 to 2.0 t ha^{-1}, crude protein from 62 to 107 g kg^{-1}, digestibility (48-h degradability) from 62 to 71 g kg^{-1}, and metabolizable energy from 8.5 to 10.4 MJ kg^{-1}.

While these rainy season values for fodder quality are adequate to meet maintenance requirements of animals, they are not sufficient to support high levels of milk production. Although commercial fodder supplements are available (cottonseed cake), few farmers can afford to purchase them, and the lack of affordable and quality feed was the single greatest constraint identified by all the farmers interviewed. Other important constraints mentioned were poor extension services (95%), lack of veterinary supplies and services (88%), poor housing for dairy cattle (88%) and lack of capital to invest in the dairy enterprise (85%). Farmers clearly recognized that a poor feed supply was far more critical in the dry season, and in addition, many of them (63%) had dry-season problems with water supply for their cattle.

Concerned about feed quality, 12 of the farmers interviewed were keen to participate in a feed supplementation trial using *Leucaena leucocephala* during the rainy season of 1996. For the trial, 25 cows were selected from the participating farmers. Cows were in their 1st to 3rd month of lactation. Animals were selected regardless of breed, as breeding lines were hard to establish. However, Friesian crosses appeared to dominate. The 25 cows were divided into 5 groups of 5 cows per group and assigned to 5 treatments. The mean milk yield of each is given in litres per day:

1) Free grazing—no leucaena or concentrate	4.9^{a}
2) Free grazing plus 1 kg leucaena and concentrate	6.2^{b}
3) Free grazing plus 2 kg leucaena and concentrate	9.9^{c}
4) Free grazing plus 3 kg leucaena and concentrate	10.0^{cd}
5) Free grazing plus 4 kg leucaena and concentrate	10.2^{d}

(Means with the same letter are not significantly different—$p < 0.05$.)

The daily supplement was offered in 2 equal amounts, in the morning and the evening during and after milking. In addition, animals were given a uniform amount of 150 g d^{-1} of mineral mix. All animals were preconditioned for 7 days to get them adapted to the leucaena diets.

Milk yields were recorded for each animal at each milking period for 21 days. Mean milk yields (l d^{-1}) over the 21-day trial period were significantly affected by the feeding regimes imposed. The inclusion of concentrate plus 1 kg of leucaena significantly increased milk yields from 4.9 to 6.2 l d^{-1}. Increasing the leucaena supplement from 1 kg to 2 kg d^{-1} resulted in a further significant increase from 6.2 to 9.9 l d^{-1}; supplementation at 4 kg d^{-1} resulted in a further significant but small increase in milk yield. These results are in line with results achieved in Kenya (Embu) and Zimbabwe.

Research in Shinyanga is now addressing 2 areas. We are working with 30 dairy farmers to refine improved feeding rations based on leucaena. In this study, we are providing the leucaena material, as farmers have yet to develop their own supply. In a 2nd study, we have assisted 15 women farmers to establish leucaena fodder banks (400 seedlings farm^{-1}, spaced at 1 x 1 m). We will monitor establishment, growth and productivity of these fodder banks and farmers' reactions to them.

In Tabora, we have also established a similar leucaena fodder bank with 70 periurban milk producers. In this location, 600 seedlings farm^{-1} were provided and similar monitoring is being undertaken.

ON-FARM TESTING OF ROTATIONAL WOODLOTS IN SHINYANGA

Deforestation is widespread in the Shinyanga area of Tanzania. This has happened partly as a result of population increase and partly because of the programmes to eradicate the quelea bird and the tsetse fly. Fuelwood is thus extremely scarce, and the use of alternative fuels such as cow dung is increasing, which means this resource cannot be used for crop manure.

Rotational woodlots are one of the technologies that researchers and farmers are testing to alleviate the fuelwood problem (ICRAF annual report 1994 p 135–138). The woodlots have 4 phases: 1) establishment—2 years during which crops may be grown between the trees, 2) tree growth—2–3 years during which prunings may be used for fodder or

Rotational woodlots in Tanzania are helping alleviate the fuelwood shortage which has been brought about in part by an earlier deforestation programme to curb the tsetse fly. Farmers and researchers around Shinyanga are working together to test the survival rates and growth patterns of 5 species considered as possibilities for these woodlots.

fuelwood, 3) harvest for fuelwood, and 4) cropping, during which resprouts are used for fodder or green manure and decomposing roots and litter may improve soil fertility. The on-station trial results of this technology have been described in the ICRAF annual report 1994 135-138; here we report on farmers' experiences testing the technology.

Farmers and researchers established researcher-designed, farmer-managed trials on 20 farms in 4 villages during the 1994–95 season; 15 farms were added during the 1995–96 season. The objectives were to 1) assess crop and tree growth in the rotational woodlots under farmers' conditions and management, 2) have farmers assess the technology and the different tree species and determine their adoption potential, and 3) assess the costs and returns of the technology. Farmers planted 5 species, neem *(Azadirachta indica), Leucaena leucocephala, Acacia polyacantha, Senna siamea* and *Albizia lebbeck,* and intercropped maize between the trees. There was also a control plot of maize in pure stand.

Field plots were laid out in a randomized block design with a plot size of 596 m^2. Each farm was treated as a replicate. Trees were spaced at 4 x 4 m. Biophysical parameters monitored included tree growth and maize yield; socioeconomic parameters included labour, costs and returns, farmer preferences among the species, and problems the farmers encountered.

In the 1994–95 season, survival rates for all species were over 85%, measured 6 months after planting (table 44). At 18 months after establishment, average height ranged from 156 to 213 cm and root collar diameter from 37 to 62 cm. *S. siamea* had the greatest height and ranked 2nd in root collar diameter, after acacia. *S. siamea* was less frequently attacked by termites or browsed by livestock than were the other species. *Acacia polyacantha* had the least growth in height and *Albizia lebbeck* the smallest root collar diameter.

In the 2nd season, maize yields averaged 2.3 t ha^{-1} in trials established on Vertisols but only 0.8 t ha^{-1} in trials on an Alfisol, which has a much lower inherent fertility. On the Vertisols, the percentage of reduction in maize yields ranged from 24% for neem to 59% for *Acacia polyacantha.* On the Oxisols, only *Acacia polyacantha* and

Table 44. Survival rates and growth parameters for species in a series of researcher-designed, farmer-managed trials, planted in 1994–95 (n = 20 farmers)

Species	Survival 6 mo after planting (%)	Height 18 mo after planting (cm)	Root collar diameter 18 mo after planting (mm)
Acacia polyacantha	90	156	62
Albizia lebbeck	91	170	37
Azadirachta indica	92	163	55
Leucaena leucocephala	86	183	42
Senna siamea	88	213	58
SED	6	20	10

S. siamea appeared to affect maize yields, reducing them by 39% and 35% respectively. The main difficulties experienced by the farmers in establishing the woodlots included insufficient rainfall (34% of the farmers reporting), insect infestation (29%), browsing (18%) and lack of labour for weeding and pruning (13%).

Neem was the species preferred by most of the farmers, selected as 1st by 61% (table 45) even though it ranked 4th in height and root collar diameter. Farmers preferred it because of its medicinal qualities; the bark is used to treat malaria and stomach ailments, and the dried and crushed leaves are used to control insect pests in stored maize. *L. leucocephala* was the 1st choice for 21%, probably because of its uses as fodder, fuelwood and poles. More farmers ranked *S. siamea* in 2nd place than any other species; it was preferred because it produces many branches and thus much firewood, and because of its rapid growth and tolerance to drought. Other important criteria mentioned by farmers include low competition with crops and lack of attraction to insect pests, livestock and wild animals.

Table 45. Species most preferred as ranked by farmers who planted a researcher-designed, farmer-managed trial in 1994–95 (n = 18 farmers)

	Percentage of farmers		
Species	First	Second	Third
Azadirachta indica	61	17	11
Leucaena leucocephala	21	11	34
Acacia polyacantha	6	17	22
Senna siamea	6	33	22
Albizia lebbeck	6	22	11

Most of the farmers (89%) were willing to establish new woodlots on their own. They proposed several changes in the technology: 37% wanted to plant a crop other than maize, 16% wanted to change the tree species, and 10% wanted to change the spacing between trees.

Asked about the adoption potential of the technology in their communities, most (71%) thought that their neighbours would be willing to test the technology. But 25% pointed out that many people were afraid that the government would use the trees to nationalize their land. In fact, farmers are uncertain as to their rights to harvest trees on their own land. Land shortage was also viewed by 25% of the farmers as a constraint to adoption.

As farmers were able to successfully establish the rotational woodlots in these researcher-designed, farmer-managed trials, researchers decided to include the woodlots in a farmer-designed, farmer-managed trial in 1995–96. In this trial, 120 farmers from all 4 districts of Shinyanga were given the option of planting either rotational woodlots or boundary plantings. In addition to the 5 species tested in the researcher-designed trial, 10 other species were added: *Grevillea robusta, Melia azedarach, Acacia nilotica, Acacia tortilis, Parkinsonia aculeata, Eucalyptus camaldulensis, Jacaranda mimosifolia, Gmelina arborea, Ziziphus* spp and *Delonix regia.* Farmers planted the trees and crops as they wished, using whatever spacing, intercrops and management they thought were best. The objectives of the trial were to 1) assess how farmers adapt and modify the technology and 2) evaluate socioeconomic factors that influence adoption.

About 56% of the farmers chose to plant woodlots; the percentage varied between 20 and 80% depending on the district. The percentage was highest in the 2 districts in which farmers had had the most exposure to the technology. Farmers also chose the size of the area that they wanted to plant, which ranged from 0.3 ha in Shinyanga to 0.6 ha in Meatu. The size of the woodlot is associated with the availability of land; farm size is greater in Meatu than in Shinyanga. Survival rates in the woodlots, measured at 5 months after planting, were satisfactory, averaging 73%. *M. azedarach* had the highest rate—over 90% in all 4 districts. All species achieved rates higher than 60% in each location except for *A. indica* in Meatu (55%), *Ziziphus* spp in Meatu (29%), *L. leucocephala* in Shinyanga (45%), and *G. robusta* in Shinyanga (55%). Farmers planting on the boundaries had slightly lower survival rates, 63%.

The strong enthusiasm of farmers in Shinyanga for rotational woodlots and boundary planting reflects the high demand for fuelwood, the possibility of planting crops between the trees during the 1st 2 years, the availability of prunings for fodder, and the potential to improve their soil fertility. Future research should focus on monitoring performance of the technology, farmer assessment of it, economic analysis and assessing which farmers are able to adopt the technology.

FRUITS OF FORTUNE

The miombo woodlands provide tree products to millions of rural dwellers in southern Africa. ICRAF's focus has primarily been on indigenous fruit trees, as the miombo woodlands contain more than 50 species that provide food and nutritional security as well as opportunities to generate income. Traditionally, fruit trees are not cut when miombo woodland is cleared for agriculture, and so the trees are used extensively. The popularity of these fruits is reflected by the plethora of local names for each kind of tree. Such is the high regard for some species, as for *Sclerocarya birrea* in Namibia, that farmers even give names to individual trees. Today, the fame of the plum-sized fruit of marula *(S. birrea)* has spread beyond the region because of the rapidly growing international demand for the liqueur Amarula.

Given the popularity and importance of these fruit trees, it is somewhat paradoxical that the fruits are not more commonly seen in local markets. Various socioeconomic studies point to the competition that they face from domesticated exotic fruits, such as mangoes. Exotic fruits are generally larger and often sweeter and come to the market at the same time. A clear message, then, that came out of a regional meeting on miombo fruit trees held in Swaziland 1995 was that the indigenous trees should be more systematically domesticated, and various organizations encouraged ICRAF to coordinate the collection and evaluation of priority fruit trees. With funding support from the SADC Tree Seed Centre Network, ICRAF, together with its national partners, organized regional collections of *Uapaca kirkiana* in 1995, and in 1996 germplasm from the next most important tree, *S. birrea,* was collected.

S. birrea is a close relative of the cashew (Anarcardiaceae), and it is used more for juices and brewing alcoholic beverages than it is eaten fresh. In some areas, however, the nuts are extracted and eaten or marketed.

S. birrea is unusual in that the species is dioecious, with separate male and female trees. Indeed, this is a bit of a problem in farmlands where non-fruiting trees (that is, the males) are selectively removed, leading to poor pollination and hence poor fruit set. The fruits fall off before ripening and after falling quickly begin to ferment, and these are relished by elephants. Indeed, if there are only a few fruits underneath a marula tree elephants will shake the tree with their tusks, often damaging it in the process. Ethnobotanic surveys revealed that the species is also used for pestles and mortars, boat building, wood carving and fuelwood, and the bark is used to treat diarrhoea. The appreciation of the tree is not, however, ubiquitous across the region, as in parts of Malawi it is not eaten at all.

The wild prototypes of domesticated varieties of *S. birrea* that are found in the forest are hidden within a wide range of diversity. Enormous differences are evident in fruit size, time of fruiting, fruit load per tree, pulp-to-seed ratio, sweetness, colour and taste. The collecting mission sampled as much variation as possible. Because standardized collection procedures were used in all countries, this initiative also served as a training exercise for national partners.

The FAO Code of Conduct for Germplasm Collection was followed throughout the exercise, and in keeping with ICRAF's guideline 'Intellectual Property Rights', the source and the identity of individual trees were documented so that it will be possible to share the benefits derived from improved germplasm with the farmers who helped identify the trees. This was not an easy task, considering that in several countries more than 10 tonnes of fruit were collected.

In total, 30 populations of *S. birrea* were collected in 1996 in Botswana, Malawi, Namibia, Zambia and Zimbabwe. Collections were also planned for Mozambique and Swaziland; however, flooding in Mozambique and a poor fruit crop in Swaziland meant that making these collections had to be pushed forward to 1997. At each of the national Tree Seed Centres, seeds were extracted and will be stored for a short time before nurseries are established for field trials.

Domestication is all about providing choice to farmers. For *S. birrea*, this is being done not only through rangewide collection of seeds but also through vegetative propagation of desirable types. Investigations into the most appropriate methods such as air-layering, rooted cuttings or grafts are under way in Malawi. In this way, a wide range of cultivars can be tested with farmers, and along with market information, the most productive ones can be disseminated more widely to enhance the fortunes of small-scale farmers in the region.

CAPACITY BUILDING

Malawi extension agents in areas around Lilongwe and Salima participated in a pilot study on the amount and the quality of agroforestry information that was reaching farmers. The study, which also included Uganda, was conducted by ANAFE, which was interested in learning the role of the training institutions that extensionists had attended—how and where had they learned about agroforestry. For more details of this survey, see p 286–288.

Participants from NARS in the southern African countries of Lesotho, Malawi, Mauritius, Mozambique and Tanzania attended a training course in Ethiopia on managing information services (see p 278–279).

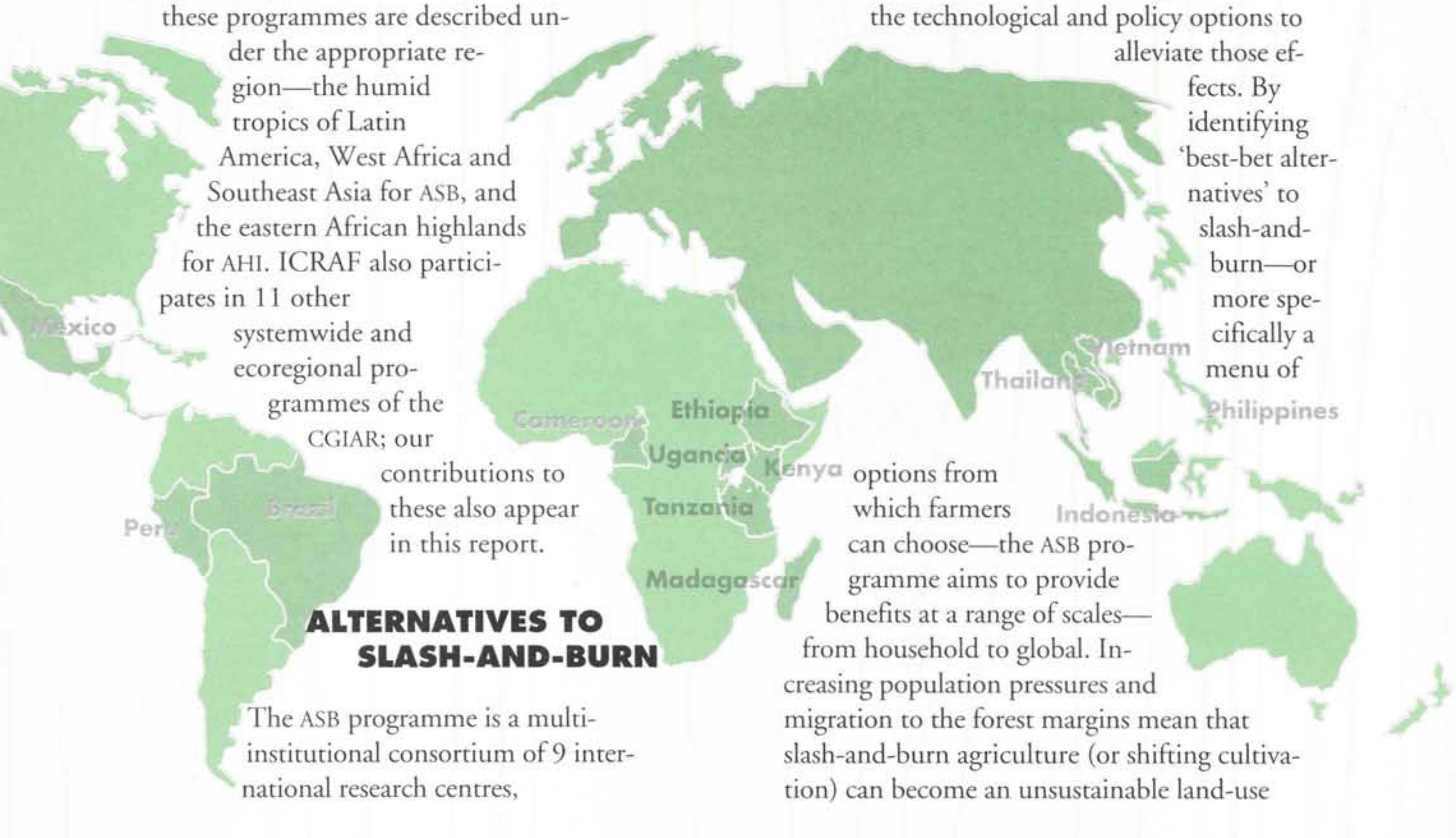
TO SUM UP . . .

The region has been in the forefront in disseminating new agroforestry technologies—especially improved fallows. The adaptive research and dissemination networks are serving as a vital and effective means of getting information about them out to the farmers. The information these networks spread is solidly backed up by research, both on farm and on station. The village workshops that were held in Zambia to assess the impact of the improved fallows technology carried the collaborative approach a step further. Working in groups, the farmers themselves set their own criteria for monitoring impact and adoption of the technology.

Also in the region, efforts are going toward improving the economic lot of small-scale farmers by, directly or indirectly, turning agroforestry products into profits—through fodder banks that can increase the milk production of dairy cows, through growing and harvesting rotation woodlots for fuelwood, and through cultivating indigenous and saleable fruits.

Systemwide and ecoregional programmes

The activities of 2 CGIAR systemwide programmes, both of which ICRAF convenes, are described here: Alternatives to Slash-and-Burn (ASB) and the African Highlands Initiative (AHI). Our specific research contributions to these programmes are described under the appropriate region—the humid tropics of Latin America, West Africa and Southeast Asia for ASB, and the eastern African highlands for AHI. ICRAF also participates in 11 other systemwide and ecoregional programmes of the CGIAR; our contributions to these also appear in this report.



ALTERNATIVES TO SLASH-AND-BURN

The ASB programme is a multi-institutional consortium of 9 international research centres, 39 national research institutes, 18 universities in collaborating countries, 43 non-governmental organizations and 10 advanced research institutes. It is built around 2 issues—the global environmental effects of slash-and-burn agriculture and the technological and policy options to alleviate those effects. By identifying 'best-bet alternatives' to slash-and-burn—or more specifically a menu of options from which farmers can choose—the ASB programme aims to provide benefits at a range of scales—from household to global. Increasing population pressures and migration to the forest margins mean that slash-and-burn agriculture (or shifting cultivation) can become an unsustainable land-use system. The consequences of this in terms of climate change, soil erosion and degradation, watershed degradation, and loss of biodiversity are potentially devastating. For example, the ASB Programme estimates that 200 million tonnes of carbon were lost from primary forest in southern Cameroon between 1973 and 1988, at an annual deforestation rate of 1340 km^2 per year.

The ASB Programme aims to provide farmers and policymakers with alternatives to unsustainable slash-and-burn practices by developing forest-based livelihoods. Removing some of the major policy distortions that encourage inappropriate forest conversion will have further major positive effects on the rate of deforestation. The ASB Programme also aims at building national capacity to ensure that identified alternatives are sustainable and that policy options are developed that will facilitate the adoption of these alternatives.

Phase 1 of the ASB Programme was strongly linked to a GEF (Global Environment Facility) grant, but ASB now has a broader base, and its links connect all of ICRAF's work in the humid tropics and the work of other CGIAR centres, NARS and NGOs (see box 4). In 1995–96 the ASB Programme suffered a major funding gap. During this difficult period without funds, research activities were interrupted, and the programme suffered serious setbacks. However, after GEF again provided funding, the ASB Programme entered its 2nd phase. The hiatus in funding became the catalyst for forming the ASB Donor Support Group (DSG)—set up in 1995 with DANIDA as the leading organization. The DSG had 3 meetings in 1996—in February (Kampala), May (Jakarta) and October (Washington). The programme has now secured funding beyond GEF and has developed a clear funding strategy to the year 2000 (see 'Strategy and Funding Requirements 1997–2000'). Australia, Denmark, France, the Netherlands, Norway, Spain, USAID, DFID,

Box 4. Main partners of the ASB Consortium

AARD	Agency for Agricultural Research and Development, Indonesia
CIAT	Centro Internacional de Agricultura Tropical, Colombia
CIFOR	Centre for International Forestry Research, Indonesia
CIRAD	Centre de coopération international de recherche agronomique pour le développement, France
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária, Brazil
ICRAF	International Centre for Research in Agroforestry, Kenya
IFDC	International Fertilizer Development Center, USA
IFPRI	International Food Policy Research Institute, USA
IITA	International Institute of Tropical Agriculture, Nigeria
INIA	Instituto Nacional de Investigación Agraria, Peru
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico
IRAD	Institut de la recherche agronomique pour le développement, Cameroon
MAC	Ministry of Agriculture and Cooperatives, Thailand
MARD	Ministry of Agriculture and Rural Development, Vietnam
ORSTOM	Institut française de recherche scientifique pour le développement en coopération, France
PCARRD	Philippine Council for Agricultural Resources and Research, Philippines
TSBF	Tropical Soil Biology and Fertility Programme, Kenya

EU, IADB, IDRC, ADB and the Ford Foundation have already committed funds for work in 1997.

Originally based in 3 benchmark countries—Brazil, Indonesia and Cameroon—the ASB Programme has now expanded and is active in various ways in an additional 5 countries—Peru, Thailand, the Philippines, Mexico and Vietnam. In Indonesia, the Philippines and Vietnam, NARS are now raising money for their own contribution towards the programme, and there are indications that the others will do likewise in the future. This year we report on the driving forces of deforestation, remote-sensing research and the identification of best-bet alternatives and ways to assess them.

DRIVING FORCES OF DEFORESTATION

The work carried out during phase 1 has identified a broad range of driving forces behind deforestation at the benchmark sites (see box 5). Identifying these forces has shown that alternative land-use technologies may be a *necessary* condition, but they are definitely not *sufficient* in themselves to solve the environmental problems entailed in tropical deforestation. Road infrastructure, human migration, tenure security and effectiveness of local forest resource management institutions are at least as important as a lack of adequate land-use technologies. Thus during phase 1, it became apparent how important it is to integrate policy into the ASB agenda along with other conditions that are necessary for intensifying agricultural production.

ANALYSIS OF LAND-USE DYNAMICS AT ASB SITES

Most of the ASB characterization activities in 1996 were undertaken by a collaborative CIRAD-CA/ICRAF project; they focused on analysing remotely sensed data for the ASB sites in Brazil, Cameroon and Peru.

Monitoring deforestation in the Congo Basin

Global scale. Low-resolution satellite data (AVHRR NDVI, 7.4-km resolution) were obtained from 1981 to 1991 for 2 sites within the humid tropical forests of the Congo Basin. One is the ASB benchmark site in Cameroon, the other, chosen for comparison, is in the Democratic Republic of Congo. This site lies at the same latitude as the ASB site but is farther inland and consists largely of primary forest.

At this low level of resolution, no significant degradation of the forest canopy was observed at either site over the 10-year period. The deforestation that took place was thus not sufficiently substantial to be detected at this global scale.

Regional scale. The 1993 AVHRR satellite data at 1-km resolution enabled us to map forests and agroforestry areas (mainly cocoa plantations) in south Cameroon with accuracy and to determine whether deforestation could be observed at this higher level of resolution. A comparison of the classification and interpretation of these 1993 data with a 1973 vegetation map did identify large areas that were deforested through logging and rural migration over the period 1973–93. However, narrow bands of land cultivated along the roads in some remote regions cannot be detected on the image, and AVHRR data thus overestimate total forests area in such cases.

It is interesting to note that the distribution pattern of non-forested areas through the landscape can be directly related to access to roads and markets. In 1993, forest cover still represented a large percentage of the land area—about 80% in the Cameroon benchmark area.

Community scale. The map obtained from classified 1995 Spot images for the Cameroon benchmark site gives quantitative information relevant to the analysis of the deforestation proc-

Box 5. Some of the driving forces of forest conversion identified by the research consortium in phase 1of the ASB Programme

Indonesia	Brazil	Cameroon
• Road development and good prices for rubber, attracting migrants to forest areas	• Migration into the forest and farm-level deforestation stimulated by subsidies and policies related to road building, colonization, livestock, timber and land speculation	• Liberalization of cocoa and coffee and an overvalued local currency leading to disinvestment in perennial crops and increase in annual food crops
• Expansion into forest areas as means of ensuring food security and improving living conditions for indigenous communities	• Need of the colonists to produce food and livestock	• Increasing commercial demand for both food production and fuelwood, combined with improved rural-to-market infrastructure
• Market-oriented farming leading to the conversion of forest lands	• Declining income from extractive reserves (such as rubber and brazil nut) means that they are less likely to be maintained	• Slow growth in factor productivity because of a lack of effective agricultural services and research —increases in production only from increased use of land and labour
• Unfavourable policy instruments preventing marketing of old rubberwood—increasing pressure on natural forests	• Decline in the overall economy leading to reverse urban-to-rural migration	• Increasing population leading to a possible increase in urban-to-rural migration
• Unclear forest boundaries	• High inflation rates making cattle an attractive investment—with forest conversion as a safe strategy for increasing value of the land	

ess at the community scale. The site encompasses a gradient of vegetation types, from primary forest in the south to savanna in the north. Our analysis of the data confirms that a main force behind deforestation is access to markets, which translates to proximity to towns and roads. Roads are important in determining land cover throughout the landscape in both the north and the south of the benchmark area.

The highest land-use intensity, which is defined here as the ratio of cultivated land area to the total land area, is generally found near the towns. But in the provinces that have the lowest population density (such as Nyong, So and Ntem), land is cultivated relatively far from towns—over 20 km. So the impact of towns and markets on land-use intensity varies depending on the region (fig. 38) and in particular relates to population density.

Conclusion. Deforestation processes in the Cameroon benchmark site are not significant at a global scale of 1 : 5 000 000, but they become visible at a regional scale of 1 : 1 000 000. At this scale, deforestation patterns appear along the corridors that follow roads and surround the main towns. This deforestation is, however, accompanied by regrowth of secondary forest, which partly explains the apparent absence of significant net deforestation at the global scale.

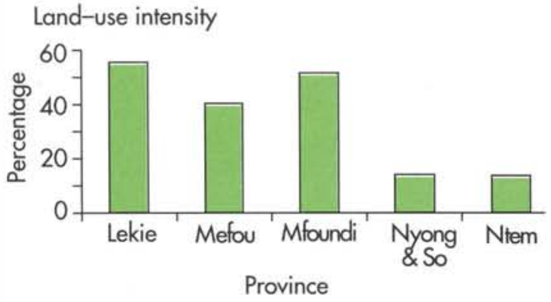


Figure 38. Agricultural land-use intensity in the different regions.

The effects on the landscape of the principal driving forces of deforestation identified at the regional scale—transport and market infrastructure—can be quantified at a yet finer community scale of 1 : 100 000. Such a quantification is a prerequisite for completing the modelling of deforestation processes at the different ASB sites—the next step in the ASB characterization. Such an analysis will also illustrate the local variability of both land-use and agroecosystem dynamics, which can be understood only at a fine scale.

Monitoring deforestation in the Amazon Basin

Regional scale. There are 4 ASB benchmark sites in the Amazon Basin. Deforestation is more widespread at Theobroma than at the other sites. Furthermore, the large Mato Grosso area contiguous to Theobroma is also almost entirely deforested. Deforestation in the other 3 sites is much more patchy, in small pockets, a pattern more typical of the Amazon Basin forests. From the satellite images, it is possible to predict that future land-use changes in Theobroma will not involve much additional deforestation; however, they are likely to involve further resource degradation. The 3 other sites, by contrast, are much more likely to represent agricultural frontiers

Access to the market is a critical factor in determining what land will be deforested. Here produce arrives at the market in Yurimaguas, Peru. About 70% of the cropping area in the vicinity is located within 3 km of a river.

where deforestation rates will become substantial in the near future.

Community scale: Yurimaguas, Peru. The major components of the deforestation process in the benchmark site of Yurimaguas were identified by interpreting land-cover patterns on 2 Spot satellite images, in 1989 and 1995; these are the town of Yurimaguas and the large rivers. This interpretation from satellite data was then confirmed through the quantitative analysis of land cover within linear buffers or corridors around the town of Yurimaguas and along the rivers (fig. 39). About 70% of the total cropping area around Yurimaguas is located at less than 3 km from a river.

Soil quality is also one of the factors affecting the deforestation process. The best soils are cultivated first, starting with alluvial soils along the main river, but with time it is possible to observe that soils with low fertility or with a high probability of being eroded are also being extensively cultivated. In these cases, the main driving forces are land accessibility, its availability and low cost, and the need to hide illegal crops (such as coca) in remote areas.

A ground study undertaken to verify the interpretation of the satellite images reported in ICRAF's annual report of 1995

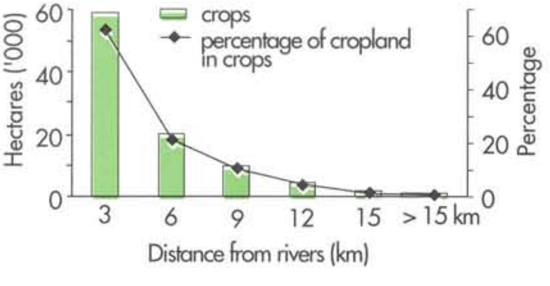


Figure 39. Agricultural land-use intensity as a function of distance from rivers, Yurimaguas, 1995.

(p 128–129) shows that 4 major farming systems dominate the landscape in Yurimaguas (fig. 40). The cropping system in figure 40d is practised far from the town on the poorest soils by the poorest farmers (mostly 'colonos', or migrants from the high sierra). It is therefore important to focus future research on alternatives to slash-and-burn farming in the area these farmers are cultivating. Another priority area for future research could be the region between the Shanusi and the Paranapura rivers. This area, in which are found the oldest croplands of the region, has low soil fertility and a pasture system that is unsustainable without improvement.

Deforestation within this small region remains low (0.6% a year). This is due to rapid forest regrowth on fallow or abandoned croplands and to a lack of infrastructure and access to significant markets—factors that hamper further development in agricultural production. The impact of deforestation on biodiversity could be significant here, even though the forest is highly resil-

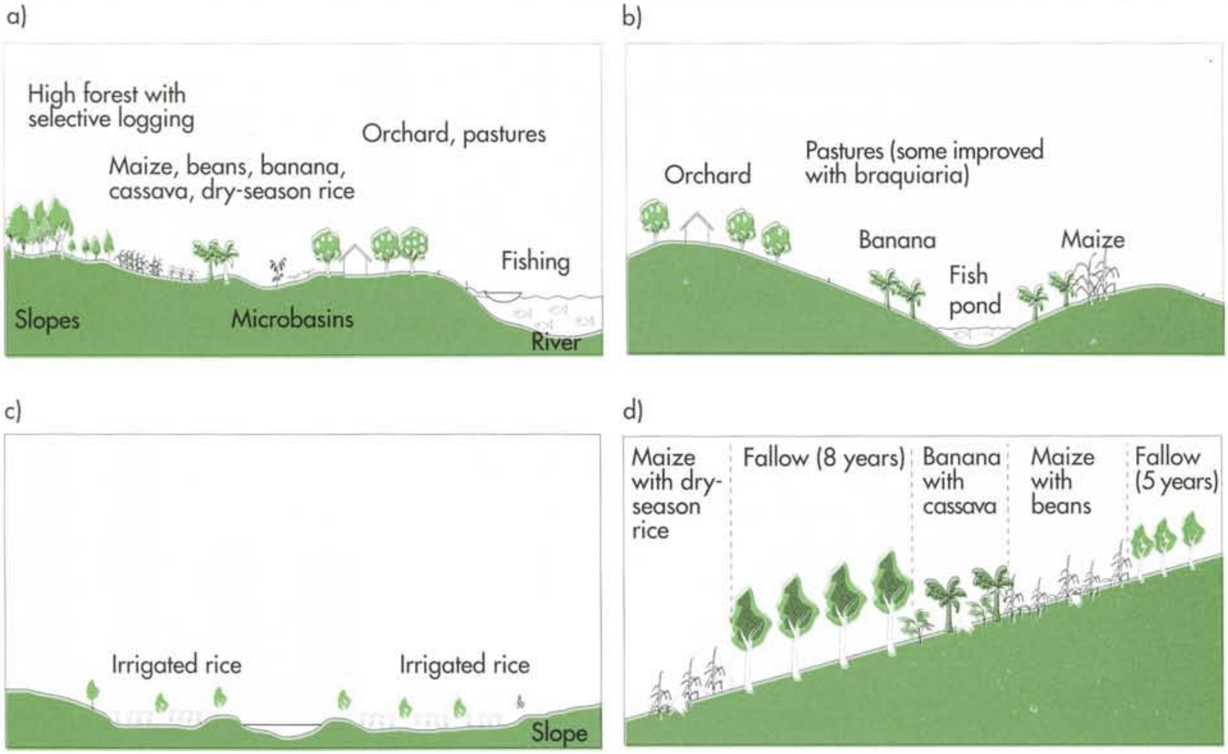


Figure 40. Four major farming systems in Yurimaguas, Peru: a) along the Huallaga River, b) between the Shanusi and the Paranapura rivers, c) the lowland between the Huallaga and the Shanusi rivers, d) on the slopes of the forest margin.

ient and the loss of forest cover is not great, as the region has one of the highest levels of biodiversity in the world.

Community scale: Pedro Peixoto, Brazil. Using Spot and Landsat images from 1984, 1987, 1992 and 1996, the CIRAD-CA/ICRAF collaborative project showed a significant increase in deforestation rates in recent years (fig. 41), with a strong relationship between the presence of roads and land-use intensity (fig. 42). In 1992, for example, 40% of all cultivated land was located less than 300 m from a road, whereas 5% was located between 1200 and 1500 m from roads. Roads, in effect, open up forested areas to deforestation. Furthermore, the data indicate that in 1984, farmer strategy was to clear the boundaries of their plots, sometimes far from a road. For example, 55% of the croplands were farther than 1500 m from a road. By 1992 farmer strategy was to clear land for cultivation within the farm plots and as near as possible to roads. By then, only 20% of the croplands were located farther than 1500 m from a road.

Community scale: Theobroma, Brazil. Monitoring land-use changes in Theobroma has enabled us to identify a huge increase in deforestation rates during 1995 and 1996—amounting to about 4% of the total area per year and an increase from the previous rate of about 2.5% (fig. 41). Again the presence of roads is a major cause (fig. 43). Land-use intensity decreases as the distance from a road increases: 29% of the cultivated areas is less than 300 m from a road, and only 7% is 1200–1500 m away.

Conclusion. Satellite images obtained over time can generate a rich information base about 1) the driving forces of deforestation, 2) their impact on the landscape, and 3) farmers' land-clearing

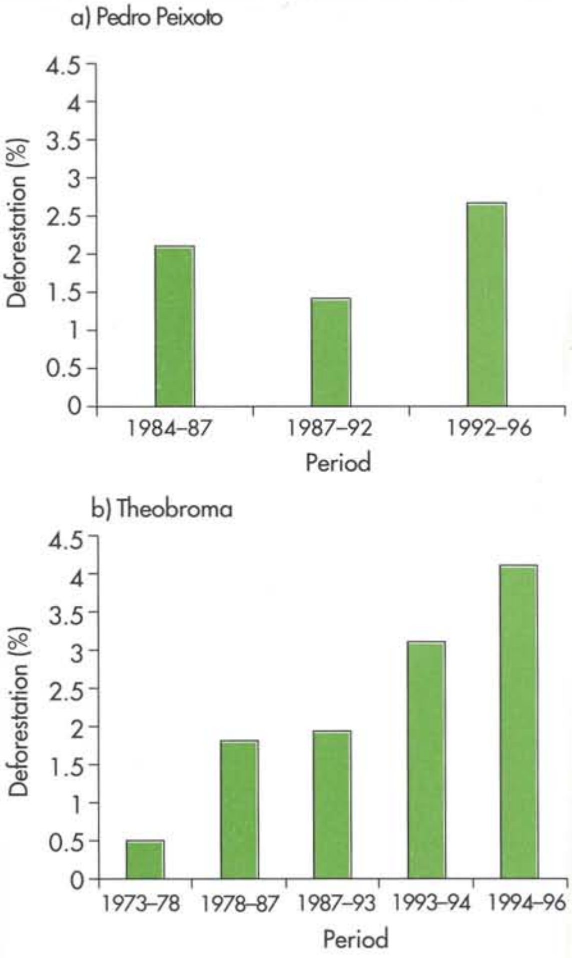


Figure 41. Rates of deforestation in Pedro Peixoto, Acre, and Theobroma, Rondonia, Brazil, 1973–96.

strategies. The results show that 1 specific driving force is common to all sites—the presence of transportation networks such as roads and rivers. However, the impact of these networks and of the specific land-clearing strategies used by farmers differs significantly between benchmark sites. This is because socioeconomic conditions vary substantially, including national agricultural and economic policies, and farmers' access to international markets.

A comparison of the data obtained at all the benchmark sites suggests that in the near future, the greatest land-use changes (including deforestation) will take place in Pedro Peixoto (Brazil) and Pucallpa (Peru). This is because these 2 sites are now linked to substantial urban centres—Pedro Peixoto to the towns of Cuiaba and Goiani, and Pucallpa to Lima. The other 2 sites still have large forested areas.

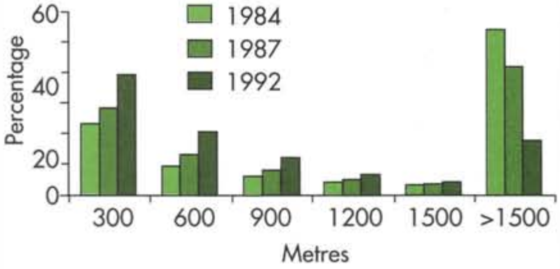


Figure 42. Agricultural land-use intensity as a function of distance from roads, Pedro Peixoto, Acre, Brazil, 1984–92.

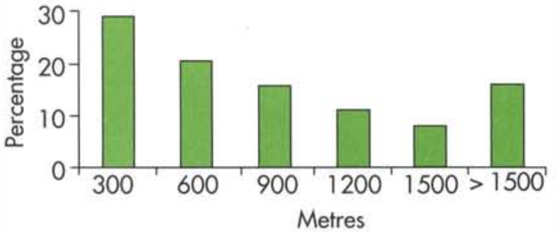


Figure 43. Agricultural land-use intensity as a function of distance from roads, Theobroma, Rondonia, Brazil, 1994.

Monitoring with middle-infrared and microwave data

Classifying the data obtained with Spot-HRVIR or Landsat TM sensors entails some ambiguities in distinguishing land-cover classes. The acquisition of new information such as MIR or C and L radar signals could improve mapping and monitoring of the deforestation process. Results obtained using these new data show the usefulness of the 1.55–1.75 mm MIR TM band, which improves both mapping and statistical accuracy. The new MIR band at 1.58–1.75 mm from the Spot 4 satellite should be even more helpful when it becomes available in 1998.

The ERS-C radar band, however, is less useful. By itself, it gives fairly accurate information on pasturelands, but it cannot clearly distinguish agroforests from forests. Moreover, adding the C band did not improve the land-use classification. So the C band does not appear well suited to distinguishing complex land-use practices. In this case it would be better to use the JRS-L band, which penetrates the canopy more deeply. The

Roads such as this, cut in Amazonas, Pará, Brazil, open up access to the market, and thus open up forested areas to deforestation.

JRS-L radar band is much more sensitive than the ERS-C band in the sense that differences appear between land uses that were confused when ERS was used. However, using only 1 JRS image is not sufficient for good land-use classification, although the characterization of the roughness of the terrain undoubtedly adds new information that is very helpful for classification.

To obtain adequate accuracy in land-use mapping, TM bands are still necessary. They give good information on vegetation cover, particularly with the red, near-infrared and middle-infrared bands. Thus combining these 2 factors, vegetation cover and terrain roughness, provides an efficient means of improving land-use classification. Interestingly, for Theobroma, which is already severely deforested, combining these 2 data sets gave sufficient accuracy for mapping land use. The recently slashed forest plots appeared clearly when the L band was added. These plots had been burned late, at the end of August or the beginning of September.

The forest, pasture and crop classification was substantially improved when the MIR band or the L radar band was added to the optical bands. The accuracy of mapping and monitoring the deforestation was significantly improved. The addition of the L radar band was interesting in this case; it provided good data, even under cloudy conditions, although fallows were still not easily distinguished from crops and forests. This is the main source of error at the moment in developing this classification, and it will be very difficult to overcome this inaccuracy in the near future.

IDENTIFYING AND ASSESSING BEST-BET ALTERNATIVES

Food security does not have to be based on local food production as long as there is income security—from high-value cash crops, good infrastructure and a reliable market for staple foods. For example, the development of rubber agroforests in Sumatra in the beginning of this century, as an alternative to food-based slash-and-burn agriculture, was facilitated by good prices for rubber and large imports of rice to the area.

The best-bet alternatives

The identification of 'best-bet' options has been built on the analysis of driving forces and the wider context of land-use change in the countries involved. During the 5th Global Steering Group meeting (3–5 October 1996, Nairobi), representatives from each of the participating countries presented a range of the best-bet alternatives (see table 46). Best bets were chosen with a number of criteria in mind—household income and welfare, adoptability, readiness for extension, sustainability, and the objectives of national leaders, decisionmakers and global environmentalists.

A prime best-bet alternative to slash-and-burn agriculture is the complex agroforest, such as this damar forest in Indonesia, where farmers here relax after collecting fruit and resin.

Methodologies for assessing best-bet alternatives

The best-bet alternatives are now being evaluated under several criteria (table 47). This evaluation will provide an understanding of the incremental environmental benefits of land-use practices alternative to slash-and-burn agriculture at the tropical forest margins.

Carbon stocks have already been measured in a range of land-use systems at the benchmark sites. Tree-based systems—such as the Cameroonian cacao agroforests—have been shown to sequester more than twice the carbon of traditional cropping systems. However, the gap in ASB funding meant that much of the work related to assessing the environmental benefits of the best-bet alternatives was suspended during the 1st half of 1996. These measurements resumed in August 1996 with the 2nd phase of funding, and the results are being presented at the 6th Global Steering Group meeting in Bogor, Indonesia (August 1997).

The ASB Programme has also developed protocols for the rapid assessment of the functional attributes of below-ground and vegetational above-ground biodiversity. Restoring biodiversity through alternatives to slash-and-burn involves

Table 46. Best-bet alternatives identified under ASB

Best bets	Brazil	Cameroon	Indonesia	Mexico
Complex agroforests	brazil nut, peach palm, cupuacu	cocoa & coffee plantations	jungle rubber (Jambi), mixed fruits (Lampung)	homegardens
Simple agroforests	coffee plantations, cocoa plantations	homegarden, cocoa & coffee plantations	rubber (Jambi), oil palm (Jambi), tree plantation (Lampung)	high-value timber (mahogany, cedar)
Improved pastures	*Brachiaria brizantha* + kudzu			legume-based systems
Improved fallows	rice–maize–kudzu	calliandra, pueraria	eupatorium (West Sumatra)	leucaena
Community-managed forests	Acre	along topo-sequence (Ebolowa)	Jambi	high-value chicle (ejidos Xaben)
Wetland systems			rainfed wetland (Jambi, Lampung)	

identifying options that will sustain system productivity while maintaining the resource base in a degraded natural ecosystem. The rubber agroforests of Sumatra, for example, retain a significant proportion of the biodiversity of the primary forest. And a study of plant diversity in the Brazilian sites has shown that although overall diversity was much higher in the forest, plant diversity was often relatively high in cropping systems and fallows but low in pastures. However, when cropping persisted for more than 2 years, diversity decreased significantly. Data from the Yurimaguas site in Peru confirmed the low level of both above- and below-ground diversity in pastures—but plant diversity increased significantly in 2 years after crops or pastures were abandoned.

These assessments have also provided an understanding of the social parameters and constraints within which farmers operate—and thus the alternatives that are practicable for them.

Improving nutritional security and increasing household welfare are among the overall objectives of the ASB Programme. By identifying the economic benefits of alternative land-use options in the other benchmark sites, it is possible to provide best-bet alternatives that produce high-value products for sale in the short term, as well as meet the subsistence needs of farmers. During this current phase, the ASB Programme is

Peru	Philippines	Thailand	Vietnam
multistrata with 4–5 species	indigenous fruit base	jungle tea (Miang), mixed high-value fruits, enriched natural forest	indigenous fruit base
camu-camu, peach palm, oil palm	tree plant (Mindanao), bamboo plantation (Luzon)	fruit orchards, contour alley crops	rubber, coffee & cashew systems
Brachiaria and *Desmodium*	Luzon		improved pastures for cows, water buffaloes, goats
Inga edulis	Cebu	legumes	
Von Humboldt forest, Pucallpa		watershed forest community woodlots	highland mountain areas
rainfed rice, Yurimaguas		irrigated paddy rainfed paddy	irrigated paddy (MK Delta, Red Delta), rainfed paddy (mountain)

Table 47. Measurable global and household criteria for selecting best-bet alternatives (with initial impressions of relative biophysical values)

	Global benefits		
Best bets	Global warming		Biodiversity
	GHG	C	
Agroforests			
complex, multistrata	++	++	++
Tree crops			
simple, multistrata	+	++	++
Pasture			
improved	?	+	–
Fallows			
improved	0	+	0
Community-managed forest	+++	+++	+++
Indicator	N_2O, CH_4, CO_2 flux summed by nrf	total carbon (time-averaged over system lifespan)	plot-level indigenous spp relative to natural forest (α diversity)
Measure	Σ nrf area^{-1} time^{-1}	C_{total} area^{-1}	Σ *R group* $div_i * w_i$ (w_i = constant weight related to importance or abundance)

GHG = greenhouse gases; nrf = net radiative forcing

addressing the problem of adoption as differentiated from adoptability—the actual event rather than the potential for adoption—and the need to analyse the process of adoption.

CAPACITY BUILDING

Phase 2 has addressed the gaps in local capacity to assess the environmental impact of a range of land-use systems. Training workshops on the methodologies used to assess carbon stocks, greenhouse gas emissions and biodiversity levels

			Household			
Agronomic sustainability				Adoptability		
Soil quality	Pests and diseases	Profitability	Food	Labour use security	Institutional endowment	Policy distortions
+	next phase					
+	next phase					
+	next phase					
+	next phase					
+++	next phase					
D soil quality as indicator of future soil productivity		expected net present value of production	risk of food entitlement failure	labour requirement (do gender and age matter?)	qualitative assessment of institutions	difference in profitability at domestic versus world prices
threshold minimum of— • soil water (compaction) • erosion (susceptibility) • nutrients (exports/imports) • organic matter (% C deficit)		expected present discounted value at domestic prices	price risk (food + non-food) + production risk (food + non-food)	person-days ha^{-1} $year^{-1}$	institutional effects on— • land • labour • capital • markets • information	profitability at domestic prices minus profitability at world prices

have been held at all of the benchmark sites. As well as training participants in how to measure and analyse biophysical factors, members of the ASB consortium have conducted workshops in Brazil on socioeconomic data collection methods—including questionnaire design and enumeration. In addition, EMBRAPA scientists visited IFPRI and received training in advanced research methods. Phase 2 has also identified where backup help is needed—and these needs will continue to be addressed in phase 3. As more countries join the programme, ASB will continue to transfer skills to new partners, enabling a wider implementation of its aims and goals.

VISION FOR THE FUTURE

As the ASB Programme evolves, it becomes clear that the driving forces for deforestation differ in the various benchmark sites, as do the alternative options available to farmers. Within its conceptual framework that is common to all sites and with a sound scientific basis for its best-bet alternatives, the ASB Programme aims to help national governments to develop local solutions. The lessons learned and the methodologies developed during phases 1 and 2 mean that countries have a clear set of criteria with which to evaluate their own sites and identify the range of land-use systems and policies that are appropriate in their own situations. The challenge for ASB is to provide guidelines and analytical tools to governments and development agencies, thus facilitating the integration of global environmental benefits and human welfare benefits into both national and global action plans. Phase 3 will progress by implementing the best-bet alternatives, discussing and outlining with policymakers the range options, and continuing the public awareness exercise.

AFRICAN HIGHLANDS INITIATIVE ECOREGIONAL PROGRAMME

Decades of agricultural research in the high-potential and densely populated eastern and central African highlands have not achieved major results in improved and sustainable land productivity. As the available land continues to be subdivided to accommodate the growing population, land productivity has declined markedly. Concerned with this situation, the NARS and the IARCs of the region formed the African Highlands Initiative (AHI). The initiative has now become an ecoregional programme, focusing on natural resource management (NRM) within the eastern and central African (ECA) highlands region. AHI is a programme of the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA). It also forms the eastern African ecoregional component of the Global Mountains Initiative of the CGIAR, a programme coordinated by CIP. It is thus a priority programme of both ASARECA and the CGIAR, and ICRAF is coordinating the development and implementation of the programme on behalf of both.

AHI offers a fresh approach to research, combining the objectives of NRM and agricultural production. It means collaboration and joint action by institutions working on different NRM components. It means new links and partnerships between research and development organizations, and it means stronger involvement of farmers in NRM research and development. AHI is now practising this new approach and creating a framework within which NRM research can be conducted in an integrated, holistic and participatory way.

The year 1996 was a busy and significant one for AHI: research activities were launched at the various benchmark locations, and an external review was conducted mid-year, which led to structural and programmatic shifts. Following is a report on major activities undertaken within the various thematic components, along with insight into the report of the AHI review and its outcomes.

PARTNERSHIPS

AHI is concentrating considerable energy on strengthening partnerships to address issues regarding agroecosystems and natural resource management more efficiently through research and development. Overall, AHI is under the umbrella of ASARECA. ASARECA brings together national research institutes in the region, and it provides policy and management guidance to regional programmes such as AHI. Partnership links are of several types (see box 6): between IARCs, including other systemwide initiatives; between IARCs and NARS; within the countries with benchmark locations—this involves NARS, NGOs, universities, extension services, district administrators, farmer group representatives, cooperative leaders, business people and individuals. Through many bilateral and regional projects there are also links within a given level as well as between levels.

Box 6. Main partners of the AHI Consortium

Organizations		**Members**	**Function**
ASARECA	Directors of Research		regional research umbrella
NARS	Ethiopia:	IAR, Awassa Agricultural College	agricultural & agroforestry research
	Kenya:	KARI, KEFRI, University of Nairobi, Egerton University College	
	Madagascar:	FOFIFA	
	Tanzania:	MOA, Sokoine University of Agriculture	
	Uganda:	NARO FORI, Makerere University	
Extension services		Ministries of Agriculture	extension at national, district, subdistrict & village levels
NGOs	Ethiopia:	Farm Africa, Red Barna, Catholic Church	research, development, extension
	Kenya:	CARE, OMMN, KWAP	
	Madagascar:	FIFAMANOR, FAFIALA, LOVASOA	
	Tanzania:	SECAP	
	Uganda:	CARE	
IARCs and other research organizations	CIAT	beans	support of strategic & adaptive research, & technology dissemination on specific commodities
	CIMMYT	maize & wheat	
	CIP	potatoes & sweet potatoes	
	ICIPE	entomology	
	ICRAF	agroforestry	
	IFPRI	policy research	
	IITA	bananas & root potatoes	
	ILRI	livestock	
	IPGRI	genetic resources	
	ISNAR	research management	
	TSBF	soils	
Regional commodity networks	AFRENA	agroforestry (ICRAF)	associated IARC support & work on research & technology dissemination
	BARNESA	bananas (IITA)	
	EARRNET	root crops (IITA)	
	ECABREN	beans (CIAT)	
	PRAPACE	potatoes (CIP)	
SWIs and ecoregional programmes	GMI	mountain research (CIP)	convened by associated IARCs, support of research & technology dissemination globally
	SLP	livestock (ILRI)	
	SWNM	water & nutrient management (TSBF)	

Farmers' organizations, cooperatives and other government administrative departments are not listed, although they are involved at the various benchmark locations.

CHARACTERIZATION AND DIAGNOSIS

Progress was made in the characterization and diagnosis (C&D) work in the 4 countries in team building and in specific research findings in selected benchmark locations.

Land use and agroecosystem changes

Table 48 provides an overview of the AHI benchmark locations. It illustrates the variability one finds in the eastern African highlands and points to some common issues: interactions between land tenure and natural resource management, competition between agriculture and livestock or disappearance of livestock from the system, lack of market integration in many of the sites and poor input delivery systems. Better understanding and quantification of these issues and their impact on poverty and resource degradation is the challenge now facing AHI.

Changing land use and soil productivity at 2 benchmark sites: Mt Kenya, Kenya, and Kabale, Uganda

In eastern and central Africa, the high-potential areas are found mainly in the cool tropical highlands ranging in altitude from 1000 to 3000 m. These subhumid lands are centres of high population density and population growth, occupying only a small area of the region compared with the arid and semi-arid lands. The adjacent semi-arid lowlands are an outlet for population migrations, and thus strong links exist between these 2 areas.

As part of the C&D research activities, a number of studies were undertaken to analyse land-use change and soil productivity in 2 benchmark sites: Mt Kenya (Embu) in Kenya and Kabale in Uganda. In Mt Kenya, land-use practices and dynamics were studied in the semi-arid lowlands and high-potential highlands. This study, which was a collaborative project between CIRAD-CA and ICRAF, characterized changes in these land-use systems over the past 40 years, by using aerial photos and satellite imagery.

The Mt Kenya highlands

The Mt Kenya highlands comprise various agroecological zones: the tea and coffee zone, ranging from altitudes of 1400 to 2000 m with an annual rainfall of 1000–2000 mm, and the cotton and food-crops zone, ranging from 1000 to 1200 m altitude with rainfall of about 650 mm. A transition zone lies between them, at altitudes of 1200 to 1400 m.

The land-cover gradient is shown in figure 44, a photo interpretation of a Spot image. The image covers about 360 000 ha, which can be considered representative of the landscapes of the southern part of Mt Kenya. The areas under different types of land cover in 1995 are shown in table 49.

The perennial crop zone covers 14% of the total area. The food-crops zone in the semi-arid lands covers 45%. The semi-arid zone thus covers 3 times as much area as the subhumid zone.

Most of the urban centres (fig. 44) are located in the subhumid zone. According to the government of Kenya census of 1989, the population of Embu was then 421171, with an annual growth

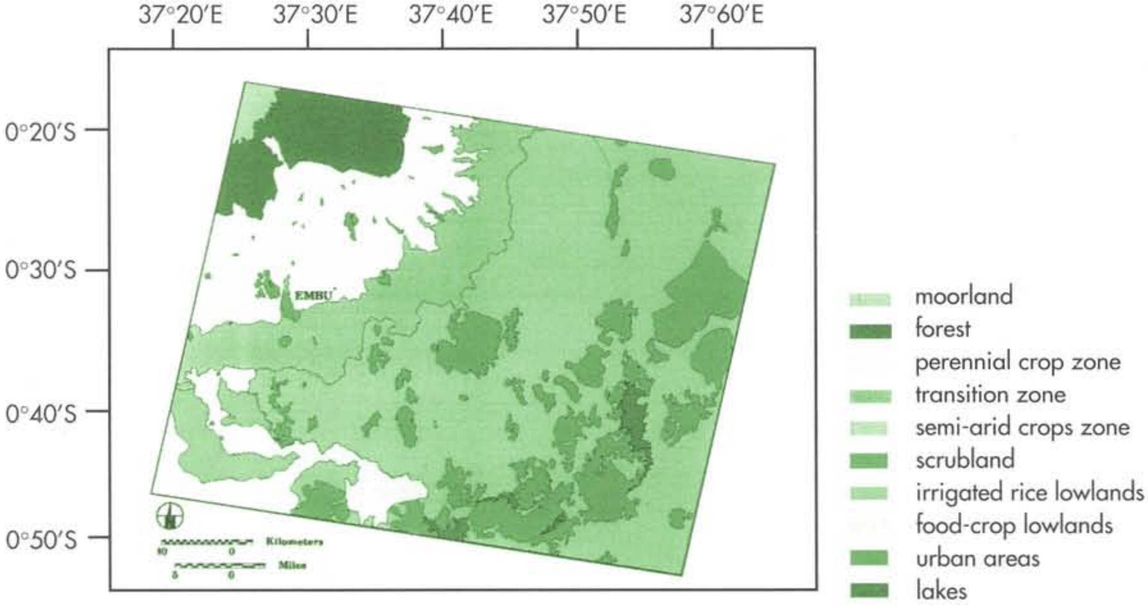


Figure 44. Land cover of Embu region (Spot image of 23 August 1995).

rate estimated at 4.2%. More than 50% of the Embu District population live on about 16% of the land. In the subhumid zone, population densities can reach 800 people per square kilometre. In the semi-arid zone, the population density drops to 50 people or fewer. This huge disparity in the population distribution, coupled with very high population growth, will lead to fluxes of population and goods between the upper (tea and coffee) and the lower zone (food crop).

Data used to map the land-use changes were a set of 1958 aerial photos and a set of 1985 aerial photos, both from the Kenya National Survey, and a 1995 Spot image.

Land-use dynamics in upper Embu

The land-use maps we produced on upper Embu for 1958, 1985 and 1995 are shown in figure 45. Beyond the differences in the quality of these maps because of the quality of the original data, the following major observations can be made.

First, in 1958 there were many large settlements in the area. These villages, settlements created by the British authorities during the Kenyan revolt for independence, were laid out in geometrical designs. None of these now remain. The current villages are in different locations.

Second, between 1958 and 1985 the spatial distribution of population changed from these

Table 48. Overview of African Highlands Initiative benchmark locations.

	Ethiopia		Kenya	
Site attributes	Areka	Ginchi	Kakamega	Mt Kenya
Altitude (m)	1800–2600	> 2200	1500–1700	1400–2000[†]
Popul'n density (km^2)	400–600	100–200	600–1200	400–700
Land form	rolling	steep mtn with catchments and expansive plateau & valley	rolling with small catchment areas	steep mtn gradient with catchments
General land use	enset, wheat, maize, barley, sorghum, sweet & Irish potato, bean, faba bean, pea, some grazing in small areas, horticulture	hillsides—wheat, barley, pulses, oilseeds, tef, dry-season grazing; Vertisols—tef, legumes, grazing	maize, beans, vegetable crops, some coffee, tea, sugarcane, some intensive and semi-intensive dairy	maize, coffee, tea, bean, vegetable crops, intensive dairy
Livestock trends	small number intensively managed; not enough	high numbers of cattle, sheep and goats	low but stable ?	stable
Land distribution and tenure issues affecting NRM	land owned by state; very small 'micro' farm size	land owned by state	small land size	small land size; 60% own or rent land in lowlands
Soil productivity status	fertility low as indicated by yield levels; erosion problem, acidic Nitosols in most areas	hillsides reported to have erosion problems; fertility ?	general low fertility as indicated by low yields; erosion in 1 area but otherwise not a big problem	moderate fertility with P deficiency; medium yields; high erosion risk; acidity increases with altitude
Trees	tree planting common	few & decreasing	many but not enough for population	many but not enough for population
Cash opportunities and market access	limited; some off-farm opportunities	medium	medium to good	very good & diverse but poor infrastructure
Inorganic fertilizer	low use and not available	some use but less than recommended	available but little used	available but dependent on markets; used especially for cash crops

Rainfall in all sites is greater than 1000 mm per annum; there are differences in rainfall pattern and distribution.
?—information uncertain or not known to C&D coordinator at this time
†—where interaction with lowlands is identified, survey work will look at NRM-related issues

	Madagascar		Uganda
Antsirabe	Finarantsoa	Tana	Kabale
1600	1200–1300	1200–1300	1500–2700
100–300	100–200	400–600	100–300
steep mtns with broad valley	steep mtns with narrow valley bottoms	steep mtns with moderate valleys	steep mtns with varying valley
upland—trees, grazing; hillsides—cassava other root crops; valleys—rice, vegetables & potato alternate seasons	upland—trees, grazing; hillsides—cassava, pulses; valleys—rice, vegetables & potato in alternate seasons	upland—trees and grazing; hillsides—cassava, root crops, pulses, some cereals; valley—rice, vegetables, potato	upland—sorghum, pulses, some bananas, other cereals; valley—dairy, vegetable crops, potato
decreasing, with no small ruminants	decreasing, with no small ruminants	decreasing, with no small ruminants	decreasing
small-size valley & suitable hillside areas, ownership of hillsides ?	small-size valleys and suitable hillside areas, ownership of hillsides ?	complicated situation of renters & absentee owners	fragmentation, small farm sizes, absentee ownership
low P, hillside acidity severe, grass cover poor on hillsides, yields very low, erosion in some areas	low P, hillside acidity severe, grass cover of hillsides poor, yields very low; erosion in some areas	low P, hillside acidity severe with some micro element problems in some areas; erosion in some areas	decreasing fertility as indicated by low yields and crop shifts; soil movement downhill (human); erosion low
few & decreasing	few & decreasing	few & decreasing	few & decreasing
medium to good	poor	good	poor
some used & available	almost nil, not available	some used & available	almost nil, not available

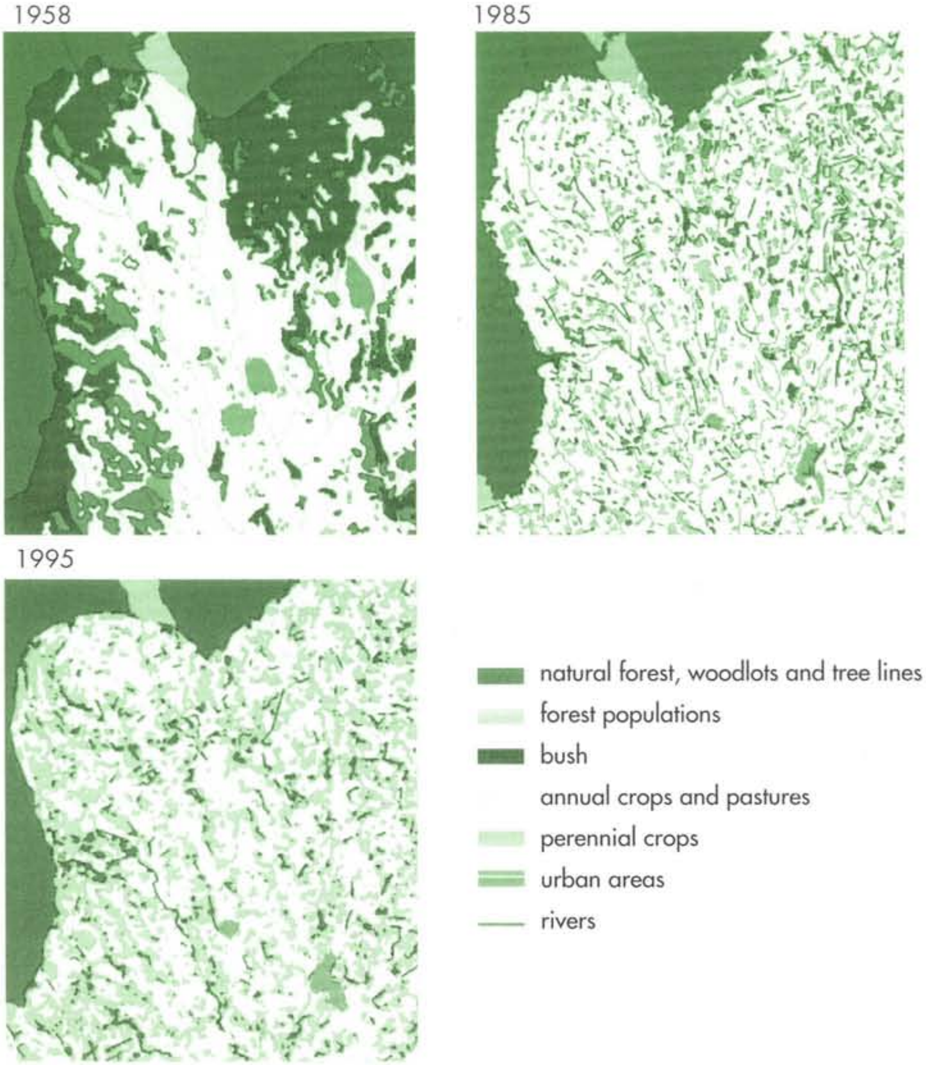


Figure 45. Land use in upper Embu, 1958, 1985, 1995.

large settlements to a fragmented distribution where farms were dispersed everywhere in the landscape. Furthermore, during this same period, bushland disappeared. This type of land cover was quite substantial in 1958. This implies that there was an old agricultural system in place and the forest was by then already cut. This system was based mainly on food crops, but the large extent of bush indicates that some shifting cultivation was still being practised. Today, bushland has been totally converted to land for food crops and perennial crops.

Third, in 1985 the landscape became very fragmented, with small plots of perennial crops (coffee and tea) of less than 1 acre and many tree lines as boundaries. This indicates that land tenure boundaries were confirmed through tree planting.

Finally, between 1985 and 1995 the major change in land use was the increase of perennial crops on land previously under annual crops. Comparing statistics on a common area of 5000 ha for the 3 data sets, we can observe these changes in terms of proportion of the total area (table 50).

Total tree cover including forest, woodlots, tree lines and tree plantations did not change over time. However, the composition of this tree cover changed in the cultivated area.

Table 49. Land use in the Embu side of Mt Kenya, from a P-Spot satellite image, August 1995 (types are listed in order of descending altitude)

Land-use type	Area (ha)	Proportion (%)
Moorland	2 600	0.7
Forest	21 000	5.8
Perennial crops zone	50 100	14.0
Transition zone	37 800	10.5
Food crops lowlands	20 700	5.8
Irrigated rice lowlands	9 700	2.7
Dry food-crop zone	161 000	44.7
Scrub	51 000	14.2
Lakes	4 600	1.3
Urban areas	1 500	0.4
Total	360 000	100.01

The highlands around Mt Kenya are diverse, comprising many agroecological zones, some of them quite rich and high in agricultural potential.

Table 50. Land use in upper Embu, 1958, 1985, 1995

Land use	1958 (%)	1985 (%)	1995 (%)
Annual crops	45	59	42
Perennial crops	1	10	33
Tree cover	26	28	24
Bush	25	1	0
Other	3	2	1

For example, *Grevillea robusta* and *Eucalyptus* spp now dominate the landscape in linear tree plantings, whereas before 1985 natural bush vegetation was dominant. The area under annual food crops had increased noticeably between 1958 and 1985, from 45 to 59%, probably because of population increases. At the same time, the bush disappeared (25 to 1%). Finally, perennial cash crops, which were rare in 1958 (1%), started appearing before 1985 (10%) and then developed substantially during the following 10 years (33%), replacing annual food crops to some extent.

If we look in greater detail at the tree cover change in the area, we can observe that the forest cover remained the same (14–16%); the protected Mt Kenya forest has been respected. Tree plantations remained unchanged; there are no new plantations and their extent is still small (less than 1%). Woodlots have decreased significantly, from 10 to 2%. The former woodlots mainly comprised old forest patches on steep slopes along rivers and on top of hills, and this type of tree cover has almost disappeared. Linear boundary plantings were made between 1958 and 1985, but there have not been appreciable changes during the last 10 years. The mean length of tree lines is now 31.6 m ha^{-1} for the cultivated area (about 120 km in 3750 ha).

Land-use dynamics in lower Embu

The land-use maps developed for lower Embu in 1958, 1985 and 1995 are presented in figure 46. Their analysis leads to the following results.

Between 1958 and 1985 no significant change occurred. In both years, bush cover predominated. The large areas of cultivated land were unchanged even if some local shifts can be observed. In both periods shifting agriculture was extensive.

In 1958 there were almost no urban areas. But they appeared in 1985 and grew significantly until 1995. Between 1985 and 1995 the land was quickly occupied by farms, and a large part of bush cover (50%) disappeared to be replaced by food crops.

The statistics on a common area of 7700 ha (table 51) indicate that no noteworthy change took place between 1958 and 1985. Annual crops and bush cover remained respectively at about 41 and 50% of the total area. Between 1985 and 1995, however, a significant change occurred as

Table 51. Land use in lower Embu, 1958, 1985, 1995

Land use	1958 (%)	1985 (%)	1995 (%)
Annual crops	41	41	73
Bush	49	45	22
Scrub	8	12	2
Other	2	2	1

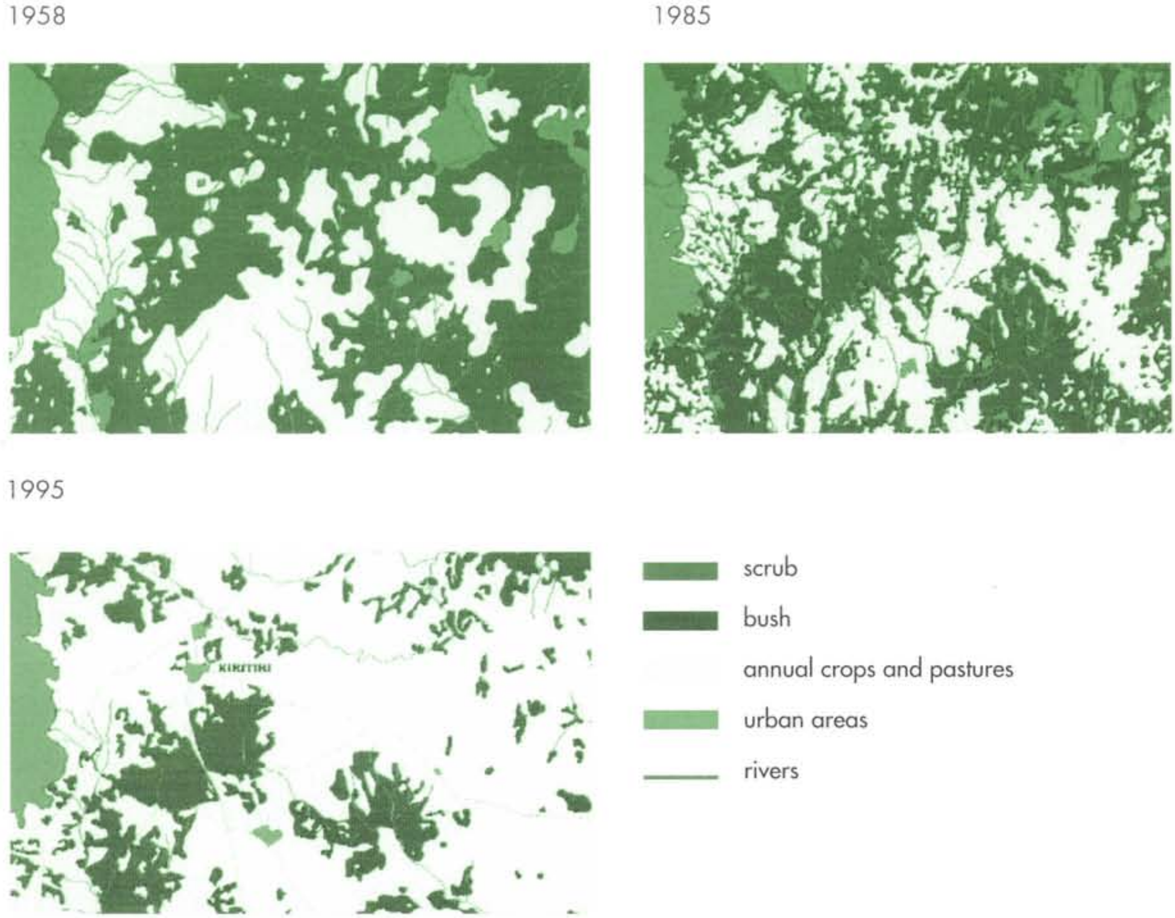


Figure 46. Land use in lower Embu, 1958, 1985, 1995.

cropland increased from 41 to 73% of the total land area, replacing bush and scrub cover.

The big picture

In upper Embu the history of land-use change was essentially written by 1985. Since then, there have been few changes indeed. We conclude, on the basis of the analysis of the changes reported here and the results of our work on impact assessment in the same area (reported in the 1995 annual report), that there is now little room for change in the existing land-use systems of upper Embu that emphasize tea or coffee production and are highly intensified and integrated in the market mechanism.

Because these lands were high in potential, they were cultivated before 1958, largely through a shifting cultivation system. Since that time, tea and coffee have had an enormous impact on the land-use system and on trade with other regions. As a consequence, every piece of land is now intensely cultivated, and no further land is available. The cash-crop boom was followed by linear tree plantations, which shape the current landscape. Purchasing food, hiring labour, and selling fuelwood and manure also became frequent activities between upper and lower Embu. Now the landscape of upper Embu is saturated, its population dense, the cash-crop system intensified, and farmers well integrated into the national market economy and the international market. However, there is still an option to diversify the type and species of trees used.

Compared with 1958, when bush and shifting cultivation were dominant, the situation has improved substantially. The aerial photos in figure 46 show the dramatic change in landscape that has occurred. The fertility of the soils in upper Embu has improved over time through both a reduction of erosion and the application of manure and fertilizers on cash crops.

In lower Embu the history of land-use change is still being written. While no significant changes occurred between 1958 and 1985, the dynamics of the last 10 years have been rapid. Cultivated lands have increased during this period to more than 75% of the total land area. Natural vegetation is thus disappearing, and so is shifting cultivation. This area, with low, erratic rainfall and poorer soils (classified as Ferrasols, Acrisols and Luvisols), has much lower potential than does upper Embu, both in water-holding capacity and in soil nutrients. The fact that croplands now cover more land area than does the bush (mostly fallows) indicates that fallow length has decreased, and very likely so has soil fertility, as there are no cash crops to warrant the use of fertilizers. These dynamics indicate that most land-use changes in the near future will occur in lower Embu. Given the population growth in upper Embu and the saturation of the humid highlands, population migrations down to these semi-arid areas will increase. If no effort is made to improve land-use systems, natural resource degradation will increase significantly in lower Embu in the near future.

Changing land use and soil productivity

The land-use changes that have been occurring in the past 30 years in the African highlands have been profound, reflecting the major political, economic and social events of the period. These events have radically altered farmers' management of their soils and therefore the soils' productivity. In some cases, the changes have led to an impressive intensification of agricultural production that has been accompanied by increases in the use of nutrient inputs, both chemical and organic, and widespread use of erosion control techniques. In other cases, events have led to increased pressure on the land, but farmers have been unable to accompany the pressures with the necessary intensified management strategies such as additional soil inputs, effective soil protection mechanisms or other investments to maintain soil productivity.

This contrast between areas that are apparently successful in not only maintaining but even increasing the productivity of their soil and other areas that appear to be losing it is stark but only part of the story. Individual farmers in each area have been more or less successful in increasing the productivity of their soil, depending upon their family and individual resources and their willingness to experiment with different methods. The differences between families in ownership of agricultural resources, such as the quality of land or the number of animals, in combination with non-farm earnings, appear to be crucial in explaining the differences between families' soil-management strategies and in their relative ability to maintain soil productivity.

Using time-series remote sensing data, we have found a link between broader land-use changes, visible on aerial photographs and satellite imagery, and agricultural practices at the farm and field level that have an impact on soil productivity. The information on changing agricultural practices came from household and field surveys, group and key informant interviews, and hillside transects that were conducted at the end of 1995 and in 1996, while the pattern and distribution of crop mixes and soil conservation measures are being analysed in a high-resolution GIS. This varied collection of land-use, management and other socioeconomic information is being integrated with soil-testing results, elevation, slope, soil type, water runoff modeling and several other types of environmental data. An important objective is, therefore, to examine the study's research questions at different scales using varied data types. Integration of the findings will require a sound conceptual framework and appropriate analytical methodologies. The usefulness of this approach will be measured in an improved understanding of the social and environmental processes affecting the agricultural system and the soil. This understanding will help identify the driving forces and their regional indicators—critical elements for extrapolating site findings to the region and for charting future trends.

In Kabale . . . Land-use changes identified at the landscape scale through aerial photography reflect processes leading to increased soil degradation in Kabale. Areas that had been considered too marginal for cultivation, such as very steep slopes, rocky hilltops and flooded valleys, have been cleared and are now under near-continuous cultivation of seasonal crops. Information concerning the ubiquitous terraces on the hillsides is showing that, although almost all cropped fields are terraced, farmers usually keep the height of

Although the land near Kabale in Uganda is terraced, the terraces are often not adequate to handle the steep slopes, and the land is becoming severely degraded.

the terraces quite low to prevent terrace collapse and to maintain good relations with their neighbours. The width of the field between terraces varies as farmers have moved terraces or consolidated fields, but almost all field areas between terraces are now wider than that recommended to minimize erosion. The full potential of the terraces to prevent erosion is, therefore, not being met. Farmers are aware of the effect of 'terrace scouring', where soil on the upper half of the terrace is shallow and poor, and attribute it to erosion and to pulling down soil as they hoe. They often place whatever nutrient inputs they have onto the upper half of the field to compensate. The use of these inputs, usually household or crop residues and sometimes animal manure, is fairly infrequent by the standards of Rwanda or Kenya.

One of the reasons for the infrequent use is the long distance farmers must carry inputs because of the extreme fragmentation of farms. An uphill walk of 30 to 40 minutes from the house to 1 of several small fields is common. Fallowing, which was until 30 years ago the sole method of maintaining soil fertility, at 1st glance appears to remain a common practice. A closer examination reveals, however, that most of the land under fallow is owned by large-scale landowners and is found predominately on the steepest slopes. In general, intensified soil maintenance in Kabale appears to face many social and environmental hurdles.

. . . and in Embu. Upper Embu, near the Mt Kenya forest, was already intensely cultivated in the 1950s. Since then, the pattern of habitation has moved from people grouped in villages, with family fields fragmented, to the current situation of each nuclear family living on its own consolidated, titled farm. Along with this change, a large increase in labour invested in soil fertility has occurred, with most fields receiving animal or green manure, or both, plus commonly, chemical fertilizers and pesticides. Most fields are also protected by soil-conservation measures. This intense soil management reflects not only the government's extension efforts but also the high economic value of the crops and the degree of involvement in the national and international economy. On average, between a third and a half of the land is covered by tea or coffee, both crops served by marketing boards supplying (for a price) fertilizers and pesticides. Families typically use the proceeds of these cash crops to buy food imported from the semi-arid zones. The rosy picture of upper Embu is nuanced, however, by the trend of young families experiencing increasing difficulty in surviving on very small amounts of land, without the necessary land or animals to support themselves or to maintain their soil's productivity.

The semi-arid region of lower Embu, now Mbeere District, is the area of the study that is experiencing the greatest—and the most risky—land-use change. Over the past 10 to 15 years, the area has been adjudicated, which means that the land has changed from being communally managed by the clan—a good structure for the former shifting cultivation and herding system—to being parcelled out to individual families, who now must confine themselves to small holdings. With this change, reliance on long fallowing for soil replenishment is no longer possible, and farmers are experiencing problems in maintaining their soil productivity in the face of near-continuous cultivation of seasonal crops. They do not have the advantage of growing high-value, perennial crops, as in upper Embu, and must contend with unreliable and severe rainstorms. Erosion is, therefore, worse here than in the high-rainfall area of upper Embu. Also, farmers neither earn the cash with which to buy chemical fertilizers and pesticides nor are they supplied with them. The experience of upper Embu in using nutrient inputs does not exist in this area. This has led farmers to now experiment widely with different, labour-intensive methods of management such as gathering and spreading manure, harvesting water, controlling erosion and planting trees.

The implications. The findings of the study are providing an understanding of the forces behind changes in soil management. The reflection of some of these forces on the landscape is clearly visible through the interpretation of aerial photographs and satellite imagery, and the forces are described by farmers in discussions with them in their fields and their communities. The impact of the changes in management on the soil and in soil properties is as impressive in the unsuccessful cases as in the successful ones. The understanding we are now gaining will be crucial in identifying the constraints of current improvements in soil management and the potential of future ones.

As we continue to analyse the data and return to sites to confirm findings and discuss their research and development implications, certain overriding questions gain increasing importance:

- What are the driving forces behind the changes in soil management, and how are the changes affecting different groups of people in their soil management strategies?
- What is the link between changes in management and changes in the soil?
- What are the social and economic constraints to intensified soil management?
- What are the trends for the future in soil management? and how can we help?

In addition, methodological questions will be examined to provide a source of reference for future studies of the changing agricultural system, both for the African Highlands Initiative and for characterization and diagnosis activities of ICRAF:

- How can studies be designed and conducted to take advantage of varied types of information, and information from different scales?
- How can research be designed so that site-level findings may be extrapolated to the region?
- How can the link between information gathered at different scales be made to create a whole larger than the individual parts?

NATURAL RESOURCE MANAGEMENT RESEARCH

The key natural resources of relevance to AHI are soil, water and vegetation. In the implementation of AHI's integrated NRM research, however, priority focus has been placed on soil fertility. Water, vegetation—as well as the effects of intervention and interaction by people and livestock, and the policy environment—are all studied in relation to this central theme of soil fertility replenishment. Biodiversity and integrated pest management are seen as subcomponents of the vegetation theme.

In 1995, AHI initiated a regional synthesis study on soil productivity research. The specific objective was to synthesize existing regional information, so as to provide an integrated view on existing knowledge and to identify gaps that would guide future research. This work was a collaborative effort among experts from—

- national institutions in Ethiopia, Kenya, Madagascar and Uganda
- the DLO Winand Staring Centre, in Wageningen, the Netherlands
- the AHI Soil Productivity and Resource Inventory groups

During 1996, the collected data were entered into a GIS database; the analysis of the collected information was completed and the 1st complete draft report published for initial review. The final report of this regional synthesis, complete with maps and other GIS information, will be published in 1997 for wide distribution in the region. This will be an important input into the soil and natural resource research agenda for the countries of the region.

SOIL PRODUCTIVITY RESEARCH

Soil fertility and productivity research in AHI focuses on exploring ways to use organic resources and appropriate cultural practices to regenerate and maintain the fertility of agricultural land. It is believed that the appropriate use of organic resources can reduce the need for inorganic fertilizers—and in most cases reduce the overall cost to smallholder farmers of replenishing soil fertility.

During 1995 and 1996, a number of research projects were initiated under AHI's small grants scheme, in Ethiopia, Kenya and Uganda. These projects fall into 4 categories:

- specific literature reviews and synthesis of research done in benchmark locations
- targeted surveys and characterization
- screening of herbaceous and woody vegetation for use as soil fertility regenerators in smallholder systems
- management options and technologies for soil fertility and productivity maintenance

These research programmes were developed according to the constraints and potentials of the farming systems in various benchmark areas. The research is being conducted by teams of national and international scientists and NGO partners and is funded jointly by AHI (through the small grants scheme) and institutional partners.

The tithonia story

Tithonia *(Tithonia diversifolia)* is a shrub that commonly grows wild along roadsides and farm boundaries in medium-altitude areas (1000–1600 m) of the eastern African highlands. Research undertaken by ICRAF and its partners in western Kenya has now shown that tithonia foliage, used as green manure in a biomass transfer system, has great potential to supply nutrients and improve crop yields significantly.

The tithonia trials, described on pages 136–146 of this report, showed great consistency in the potential of tithonia as a resource of soil fertility, and farmers have been excited with their results. Consequently, many are already incorporating tithonia into their farming systems on their own initative. We need further research to enhance the production of tithonia and its integration with farming systems and to demonstrate its economic feasibility. We also need more process-oriented research to understand how tithonia regenerates soil fertility.

INTEGRATED PEST MANAGEMENT RESEARCH

The integrated pest management (IPM) research is seen in the context of AHI's principal theme of soil productivity. Research is focused on particular pests and diseases known to have a direct relationship with the fertility status of soils and to be associated with the intensification of agricultural systems. The research aims at controlling these pests through integrated pest and crop management approaches. The 4 crop-pest complexes identified for research during phase 1 are –

Tithonia grows wild in western Kenya and is often cultivated as a boundary hedge. Plentiful and available, it can help turn around phosphorus deficiency in the area.

- bean: bean stem maggots *(Ophiomyia* spp*)* and root rots (caused by *Pythium* spp, *Rhizoctonia solani, Fusarium solani* f sp *phaseoli; Sclerotium rolfsii)*
- potato: bacterial wilt (caused by *Pseudomonas solanacearum)*
- banana: weevils *(Cosmopolites sordidus, Temnoschoita nigroplagiata, T. basipennis, T. erudiata)*
- maize and sorghum: striga *(Striga hermonthica)*

Research activities on all 4 crop–pest complexes were initiated in mid-1995. During 1996, various research projects were undertaken to study the relationship between these pests and soil fertility. A technical synthesis and literature review on each of these pest complexes has been published as an AHI technical report.

Field research activities undertaken so far are helping to provide some insight into these crop–pest complexes and their possible control. This research is being done in direct collaboration with farmers, and it is therefore helping to reveal control strategies of direct relevance to them.

The IPM projects described above are alike in 4 respects:

- They all involve a link with soil fertility and soil degradation.
- They all focus on practical and simple strategies based on cultural practices and field sanitation rather than on the use of pesticides.
- They are all development oriented.
- They all involve partnership of an IARC, a NARS, an NGO and farmer groups.

AHI has placed a regional research fellow in each of these projects to catalyse operations and promote partnerships. This model of operation has been found to be very effective and successful in creating a focus and a drive for this multi institutional partnership programme.

CAPACITY BUILDING AND RESEARCH SUPPORT

The Capacity Building and Research Support component of AHI has 2 main themes: training in natural resource management, and information and communication support.

Training

The following training activities were carried out in 1995–96:

- training workshop, 'Characterization and diagnosis'
- training course, 'Integrated pest management'
- training materials development in support of these 2 group training activities
- detailed AHI training needs assessment study in the eastern African region

A summary of these activities follows.

Training workshop, 'Characterization and diagnosis'. One of the early steps in organizing the regional and national characterization and diagnosis research activities was developing national, multidisciplinary core teams of scientists. A 2-week training workshop, aimed at strengthening these core teams by upgrading their knowledge and skills in characterizing land use and agroecosystems and in diagnosing farming households was held at ICRAF headquarters in Nairobi, 15–26 April 1996. It brought together 17 scientists from the 4 participating countries. As a result, working teams of scientists can now conduct characterization and diagnosis work in their respective countries and have formulated detailed work plans to implement this work. The final outcome of the workshop was an agreed programme of work for characterization and diagnosis research in the highlands of Ethiopia, Kenya, Madagascar and Uganda.

Training course, 'Integrated pest management'. The control of key agricultural pests and diseases of major food and cash crops in eastern Africa is another important research theme for the systemwide African Highlands Initiative. Decreases in soil fertility, as well as reductions in crop rotations and fallow periods, combined with changes in agroecological conditions, have led to the build-up of pest and disease complexes such as striga, potato bacterial wilt, bean stem maggot and root rot, banana weevil and nematodes. The main objective of the research in this area is to develop integrated pest management strategies for these problems. With this in mind, ICRAF organized a collaborative training course on the subject for researchers and senior technicians conducting research in this area.

The main purpose of the training course was to review important concepts and principles related to integrated pest management and to develop a unified research strategy and methodology in this area that would allow cross-site comparison of results and their integration in other research and development themes related to the African Highlands Initiative. The course, which took place at the KARI regional agricultural research station in Kakamega, Kenya, 6–17 May 1996, brought together 24 scientists and senior technicians active in AHI-related integrated pest management research.

Training materials development. The characterization and diagnosis workshop led to the production of training materials: a workshop outline and 9 lecture notes and session summaries. This workshop was important because it provided new knowledge based on ICRAF's research on land-use characterization and diagnosis. Major improvements over the previous diagnosis and design approach are refined sampling methods as well as a more quantified and qualified analysis of the data and information obtained.

Materials developed in support of the 'Integrated pest management' course consist of a series of 17 lecture notes and 5 practical exercises on integrated pest management concepts and principles, on some major pests and diseases of potatoes, beans and bananas, and on striga. These materials will be compiled in a more formal document in 1997.

Information on both training and training materials has been included in the multimedia AHI CD-ROM, which will be finalized in 1997.

Training needs assessment study. Because of changes in resource people, this activity had to be postponed again to the 1st half of 1997. Some progress has been made in developing a methodology and a questionnaire, to be used for this study. The results are now available.

Information and communication support

The information component of AHI aims to provide comprehensive and integrated information on natural resource management to different user groups, including researchers, extension workers, farmers and decisionmakers.

The cooperative bibliographic database of NRM literature developed last year has been installed at the various AHI benchmark sites and documentation centres—3 in Ethiopia, 5 in Kenya, 2 in Madagascar and 4 in Uganda. A user manual was provided with each copy of the database.

In addition to making the AHI database accessible locally at 14 sites in the 4 countries, direct information support in the form of database searches and selective dissemination of information (SDI) is being provided to AHI partners. ICRAF took the responsibility for providing these services to AHI, and several copies of literature search and SDI request forms were distributed to potential beneficiaries.

To facilitate information exchange among AHI partners and beneficiaries, a quarterly newsletter—*AHI Updates*—was initiated in 1995 and currently reaches some 500 readers. These updates provide information on the progress in research and training activities, schedules of upcoming events, and lists of publications and reports.

Email connections have been provided to AHI partners in Nazret, Holetta and Addis Ababa in Ethiopia; Maseno, Embu and Kakamega in Kenya; Antananarivo in Madagascar; and Entebbe, Kabale and Kampala in Uganda.

To facilitate farmer-to-farmer exchange of information, AHI sponsored a group of 22 farmers and 2 extension officers from its Ntungamo site in Mbarara, Uganda, to visit—and see for themselves—technologies that other farmers are successfully using, such as bunds to reduce erosion on steep hillsides and compost manure to fight banana weevil. Follow-up observations in 1997 are to assess the impact these visits make on farmers' use of these approaches.

During the year, a draft of an AHI CD-ROM was produced. This new multimedia support will be developed further in 1997 to incorporate different types of information generated by AHI Technical Advisory Panels (TAPs) for use by researchers and decisionmakers.

AHI UNDERGOES EXTERNAL REVIEW

An external review for AHI was held in April 1996. The overall impression of the reviewers, as summarized in their report, was positive. The report acknowledged the complexity of the AHI assignment and the fact that it involves several institutional partners, generally with different priorities, perceptions and approaches to natural resource management. The reviewers commended AHI for having taken the challenge and recommended extension of phase 1.

A number of issues were raised in the report:

Research. There should be—

- more clarity and sensitization on the common vision
- increased focus on methodology development in integrated NRM approaches

- more focus on catchment, zonal and regional dimensions in research implementation and analysis
- more integration among AHI themes for a true NRM approach

Management and coordination. Recommendations in this area were—

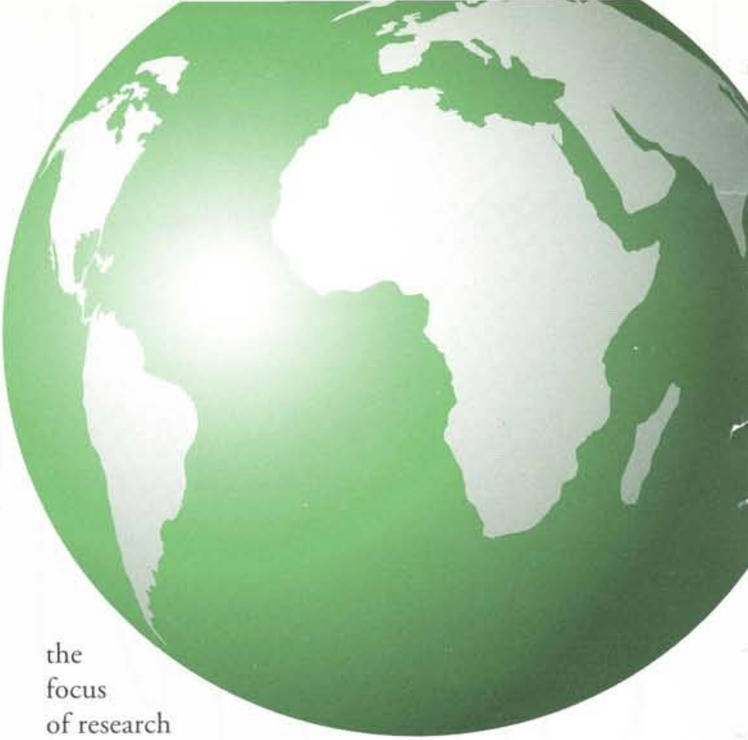
- to have a full-time coordinator, as the present part-time coordination is inadequate
- to develop and strengthen country-level coordination
- to strengthen country representation on AHI committees
- to simplify fund-flow mechanisms

These observations and recommendations were endorsed by the AHI Task Force, and steps have already been taken to effect operational changes. The major changes being effected are—

- An integrated Scientific Advisory Panel (SAP) will provide technical leadership and direction to the programme. It will therefore take on responsibilities currently being held by the 5 independent TAPs. The SAP will be able to provide a more integrated focus on NRM rather than on specific themes.
- Country teams should have increased responsibility for planning, managing and implementing AHI projects in their respective countries. This approach also provides a framework for integrated planning and research development across all of AHI's thematic interests.
- In line with the increased focus and responsibility given to country teams, budgeting in AHI is now to be allocated by country rather than by themes. This approach makes it feasible to develop a programme of work within the framework of available resources.
- There should be a full-time AHI coordinator for phase 2. Country and site coordinators have also been appointed for respective countries, to provide national leadership and direction for AHI activities.
- Phase 1 of AHI, originally planned for 1995–96, has been extended until December 1997. Review of phase 1 activities is being done in June 1997, and is being followed immediately by the development of the proposal for phase 2, which will then begin in 1998.

TO SUM UP . . .

The year 1996 has been eventful and successful for AHI. The challenge of implementing research while making structural changes in management and operation of the programme has not been easy. The programme has, nevertheless, continued to progress, mainly because of the commitment and support of the various partners. The year 1997 is to be a transition year for AHI, as phase 1 draws to a close and phase 2 plans and preparations begin. With the progress made thus far, and the continued support of all institutional partners and donors, the future for AHI looks bright, though the challenge is no less daunting.



Global activities

Here we describe research and dissemination activities that are global in nature. They include basic strategic research on tree–crop interactions, the new tree seed directory, the Germplasm Resource Unit, and capacity building in the form of training, education and information work.

STRATEGIC RESEARCH AT MACHAKOS

Since 1981, ICRAF has maintained a research station at Machakos, 75 km southeast of Nairobi in Kenya. Located at an elevation of 1600 m and with an annual rainfall of 750 mm in 2 rainy seasons, Machakos has a transitional climate between subhumid and semi-arid; it thus represents the drier end of the bimodal highlands. The soils at the site are Kandic Rhodustalfs; they are usually 1 to 2 m deep on the crest of the hills but are shallow and of varying depth (0.3 to 1.0 m) on the hill slopes. The soils have moderate fertility without any major nutrient deficiencies. Limited and variable rainfall and soil erosion on sloping lands are the major constraints for crop production at this site.

Strategic research of global relevance has been under way at the station since 1990 on simultaneous agroforestry technologies. Taking advantage of the biophysical constraints at the site, the focus of research has been on tree–crop competition for water; soil and water conservation on sloping lands by trees in comparison with competition for water; the relationship between competition and tree growth characteristics, particularly root architecture, root growth and root density; and modeling water balance and soil erosion. The emphasis in recent years has been on inter- and intraspecies differences for above- and below-ground competition, on methods for quantifying water use by trees and crops, and on rooting patterns. Evaluation of a few *Leucaena* species, provenances and interspecies hybrids for resistance to leucaena psyllid *(Heteropsylla cubana)* was also taken up, but this work has been expanded further by establishing a series of trials with a rangewide collection of different leucaena species. Some highlights of our research on interspecies competition for water, comparison of legumes for soil fertility, and screening of *Leucaena* species for resistance to psyllid are described in the following sections.

The research at the station involves a number of collaborators from advanced research institutions in developed countries and universities throughout the world, through thesis research of graduate students. ICRAF's soil and plant analysis laboratory is moving from Machakos to the new research division building in Nairobi in 1997. Besides facilitating soil fertility research by ICRAF scientists, it also offers analytical services to collaborators in east and southern Africa. The activities at the station and in the laboratory provide an opportunity for short-term practical training for a number of polytechnic and undergraduate students from Kenyan institutions as part of their curriculum.

INTERSPECIFIC COMPETITION FOR WATER

The best known and most widely practised traditional agroforestry systems are the scattered trees in the Sahel, commonly known as 'parklands' (see Semi-arid lowlands of West Africa, p 179–187. In such environments, nutrients and water are the most limiting factors for net primary productivity. This has been clearly demonstrated by failed attempts to increase tree populations in agroforestry systems in semi-arid areas because few of the trees survive and because the trees compete with the crop for water (ICRAF annual report 1995 p 207–209). To some extent this is surprising, since water balance studies have confirmed that crops are unable to fully utilize the soil water that remains after crop harvest (ICRAF annual report 1995 p 213–214).

Alternative systems are now being considered by ICRAF. In the drylands of Kenya, farmers have also developed parkland systems with such trees as *Melia volkensii*, which they consider to be the most compatible with crops. Information on water use by rows of upperstorey trees intercropped with maize was therefore collected to test the hypothesis that such systems exploit water in the soil profile more efficiently than annual cropping systems. Information on the root distribution of trees and crops was also collected to explore the extent of spatial complementarity.

The experiment consisted of 8 tree species to represent a range of competitiveness and growth rates, and trees were grown along a central row to represent a boundary planting arrangement. Each plot was 18 x 18 m, and each treatment was replicated 4 times. Further methodology details are given in the ICRAF 1995 annual report (p 209–212). Measurements included final crop yield and weekly soil moisture content with distances from the tree rows, hourly tree transpiration using a combination of heat balance and heat pulse techniques (ICRAF annual report 1995 p 219–222), microclimate and root distributions using both non-destructive (minirhizotron, ICRAF annual report 1995 p 78), and destructive root coring and root trenching techniques.

Crop yield in the long rains of 1996 was similar to the trend reported from the previous short rains. Contrary to reports from farmers' fields, the greatest crop competition was with fast-growing species like *M. volkensii*, which reduced crop yield at distances even beyond 8 m (fig. 47). In general, with the exception of *Grevillea robusta* and *Gliricidia sepium,* the least competitive trees were also the slowest growing, such as *Croton megalocarpus.*

Grevillea robusta, *popular in the eastern African highlands around Embu in Kenya, is prominent in the landscape. As it is not highly competitive with crops for water, it is a valued species, planted on bunds and as boundaries.*

Sapflow measurements of tree transpiration during the long rains showed considerable variation in daily transpiration rates. They ranged from 5.7 to 11.6 l day^{-1} in *C. megalocarpus* and *M. volkensii*, respectively; the rates for *Gliricidia sepium* and *G. robusta* were intermediate (fig. 48). These values amounted to 30 to 63 mm of transpiration during the whole season, which represented about 12 to 25% of the total seasonal rainfall (250 mm). Although this amount appears small, each millimetre of water transpired by the trees resulted in a loss of 9.7 kg in maize

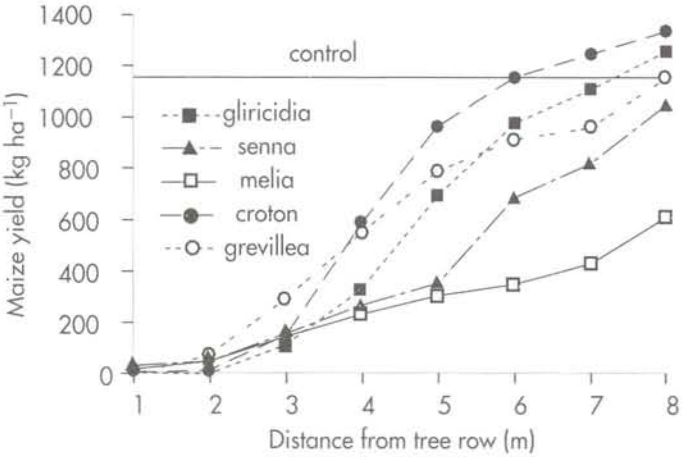


Figure 47. Maize yield in association with different tree species measured at various distances from tree rows in the 1996 long rains at Machakos, Kenya.

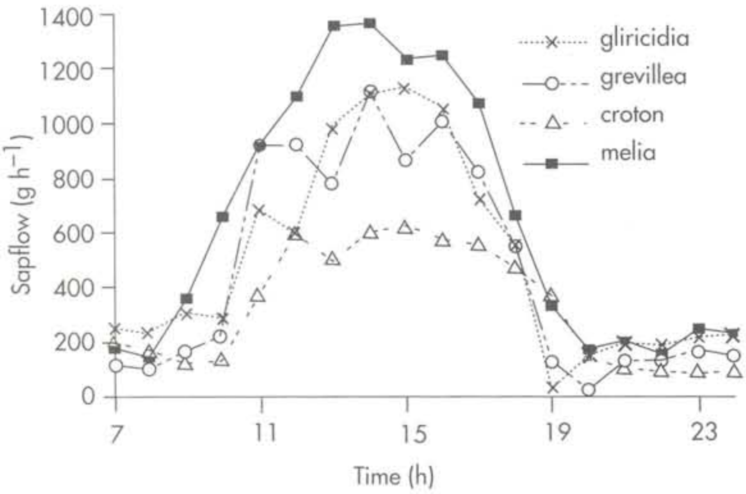


Figure 48. Daily sapflow of 4 tree species during the 1996 long rains at Machakos, Kenya.

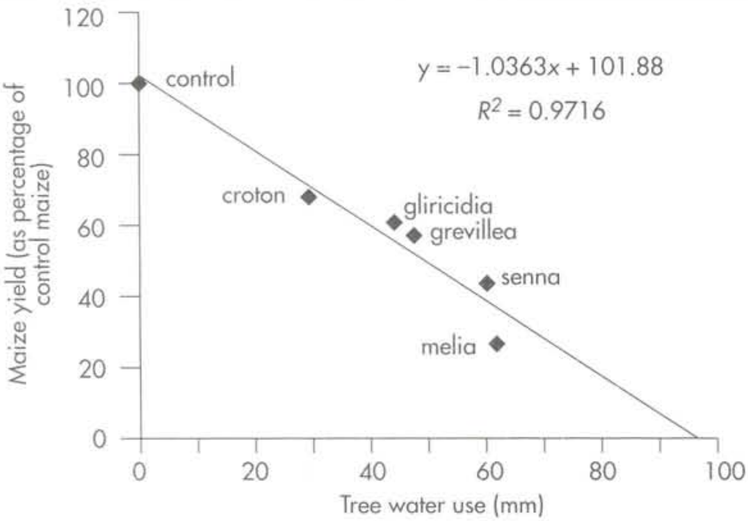


Figure 49. Regression of water use by trees and maize yield in the 1996 long rains at Machakos, Kenya.

yield (fig. 49), implying that both trees and crops were utilizing soil water from the same part of the soil profile. The regression line in figure 49 explains 97% of the variation in maize yield among the 5 tree species that were measured, with *M. volkensii* as the most water demanding and *C. megalocarpus* the least. It indicates that there was little or no complementarity in water use between trees and maize during this season of low rainfall (250 mm). Previous studies at this site with *G. robusta* showed that about 42 to 58% of seasonal rainfall was lost as soil evaporation. Thus if tree populations are increased or if trees exploit about 100 mm per season, there will be complete crop failure. For instance, results from a nearby 4-year-old *G. robusta*–maize trial with 646 trees ha^{-1} have shown that complete crop failure occurred when seasonal rainfall fell below 220 mm, and even when rainfall increased to 570 mm, the maize yield was reduced by 60%.

Analysis of soil water data shows that at the onset of the 1996 long rains there was a significant difference between the soil water content of the top 35 cm of soil in the maize-only control and the various tree treatments (fig. 50), which was closely related to their competitiveness with crops (fig. 47). The water content of the soil increased with the distance from the tree rows in most tree treatments (data not shown), but it was still relatively dry in the *M. volkensii* treatment even at 6 m from the trees. This result is most surprising, as farmers in this region regard *M. volkensii* as a non-competitive tree. The profile of water in the soil indicates (data not shown) that none of the tree species fully utilized the significant quantity of water stored (18%) below 1 m, suggesting that root development of these relatively young 3-year-old trees was still insufficient to extract soil water below that depth. These results imply that great care should be taken before introducing such fast-growing trees into croplands, as intense competition of trees with crops can be expected with boundary planting. However, the trees could be planted in the unexploited niches of farms such as next to footpaths and farm boundaries, as is done with *G. robusta* in central Kenya (ICRAF annual report 1995 p 55–59). The reasons for the apparent contradiction between farmers' assessment of tree competitiveness and our present results are not known but we are investigating them. In addition, we will examine the practices that farmers have developed for tree management to control competition for water under such circumstances.

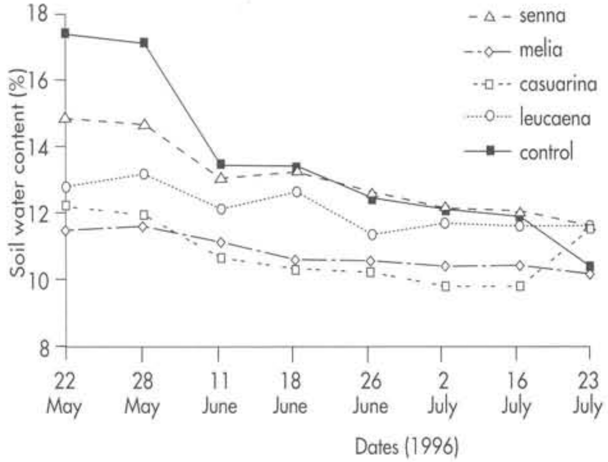


Figure 50. Soil water content at 35 cm soil depth at 1 m distance from tree rows during the 1996 long rains at Machakos, Kenya.

ROOT PROFILES AND DYNAMICS

Root studies are needed to determine the extent of complementarity—or competition—in the utilization of below-ground resources by trees and crops. Previous studies of 2 *Senna* species in hedgerow intercropping at Machakos have indicated that the leaf area of the trees, rather than their root systems, largely determines the trees' competition with crops for water, when they both appear to exploit the same soil profile (ICRAF annual report 1995 p 206–209). In collaboration with the Institute of Terrestrial Ecology, Edinburgh, we have been testing the hypothesis that tree root architecture and root functioning are closely related. We have been using simple but novel techniques for root measurement, such as the fractal branching index (ICRAF annual report 1994 p 97–98) and the heat pulse method (ICRAF annual report 1995 p 220–221), and conventional root coring and trenching techniques. Initial root measurements were made on 3 species with contrasting phenologies and competitiveness: *Senna spectabilis*—a relatively less competitive species; *Gliricidia sepium*—a competitive species; and *Grevillea robusta*—a less competitive one.

Grevillea robusta trees have deep roots, which are complementary to the root systems of maize and cowpea (ICRAF annual report 1993 p 70–73). Recent measurements in Machakos on *Gliricidia sepium* also indicate that about 70% of the water was derived from below the crop root zone, yet *Gliricidia sepium* is one of the most competitive species tested. Root profiles of *S. spectabilis* and *Gliricidia sepium* were studied by conventional root trenching at distances of 1.5, 3 and 4.5 m from tree rows to determine the spatial distribution of tree and crop roots during the 1996 long rains. The root profiles showed that even at a distance of 1.5 to 3 m, root densities of maize greatly exceeded those of the trees but that maize roots were confined to the top 80 cm of the soil profile (fig. 51). The tree roots reached 1.4 m depth, and the 2 tree species had similar rooting profiles with 68 to 74% of their roots in the same rooting zone as the maize. The density of maize roots intercropped with trees was reduced by 26 to 40% in the top 20 cm of the soil as compared with those of the sole-maize

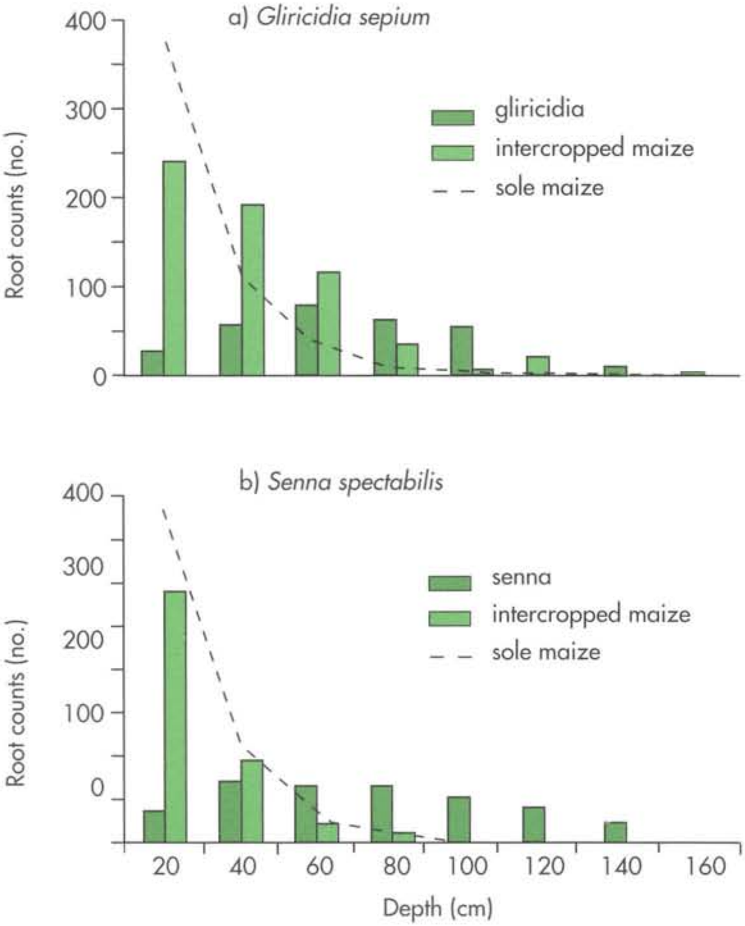


Figure 51. Root profiles of sole maize and maize and trees in boundary plantings at 1.5 to 3 m distance from tree rows during the 1996 long rains at Machakos, Kenya.

control. Thus, during a low-rainfall season, like the long rains of 1996, it is inevitable that even such deep-rooted trees will compete with the crops for water. However, the root profiles suggest that spatial complementarity in rooting is considerably better with unpruned trees in boundary plantings than in alley cropping using *S. spectabilis* (see ICRAF annual report 1995 p 210–211).

We are currently using the fractal root branching method to explore the functions of 8 contrasting tree species in Machakos. Next year, in collaboration with ITE and KEFRI, we shall extend the same approach to determine the prospects for intraspecific differences in root architecture in valuable tree species, such as *M. volkensii*.

POTENTIAL FOR EXPLOITING DEEP SOIL WATER BY TREE ROOTS

Replacing native vegetation containing a mixture of perennial and annual plants—that is, both plants with deep roots and those with shallow—with a monoculture of shallow-rooted annual crops causes substantial changes to soil and microclimate. These changes, often deleterious, can lead to such problems as high wind and soil erosion, loss of soil fertility, secondary salinity and deterioration of the physical structure of the soil. In April 1996 we started a collaborative activity with a consortium of Australian institutes (Commonwealth Scientific and Industrial Research Organisation, University of Western Australia, Agriculture Western Australia, and Department of Conservation and Land Management) to provide information on the potential of deep-rooted trees to mitigate land degradation in the wheat belt of western Australia and the drylands of Kenya. Although these regions face different environmental problems they share in common the possibility that introducing deep-rooted trees can help solve their land-use problems.

In Kenya, as in many other African countries, deforestation (outside the high-potential highlands) has reached such an alarming stage that forest reserves now represent only 2% of the total land area. Two socioeconomic needs contribute to the progressive disappearance of trees from the landscape. The first is the need to put increasingly large areas of land under cultivation, to feed an ever-increasing population; 80% of Kenyans inhabit regions with the highest potential for agriculture—and which also contain most of the country's forests and woodlands, although recent data show that tree cover in the high-potential area of upper Embu has not undergone change. Second, tree products are much sought after by rural Kenyan families for such diverse uses as fuelwood, construction, charcoal production, tool handles and medicine. Currently, Kenya's population of around 28 million demands 14.8 million cubic metres of timber a year for fuelwood alone. Wood resources yield 71% of the energy that Kenya consumes, and rural areas are almost solely dependent on woodfuels.

In western Australia, existing farming systems in the wheat belt are often highly productive, but half a million hectares of agricultural lands are now affected by creeping and insidious salinization following the widespread removal of native trees. At the current rate, it has been predicted that up to 50% of the arable land in the susceptible areas will be lost.

The objective of the present collaboration with the Australian institutions is to develop common approaches to assess the potential of deep-rooted trees to lower the water table, to reduce the competitive effects of trees on neighbouring crops, and to model their impact on the hydrology of the whole catchment or landscape. Substantial progress has been made in the 1st phase (1996–97), which is to test the utility of the low-cost heat-pulse probes (ICRAF annual report 1995 p 220–222) for measuring the contribution of individual tree roots to total tree transpiration during the dry and the wet seasons. The first step is to determine whether the combined uptake of the individual tree roots equals that of the trunk. This was successfully tested on a 5-year-old *G. robusta* tree in which heat-pulse probes were attached to all major roots and the trunk to provide simultaneous sapflow rates; the values were virtually identical for both trunk and the combined root uptake (fig. 52).

Two improvements were made this year to the heat-pulse technique. The 1st is the use of a simple potometer to allow calibration of the heat-pulse technique to measure very low sapflow rates on existing trees in the field. Exposed roots were cut under water, and the cut end was attached to a potometer consisting of a bicycle tube filled with water and a burette with an accuracy of 0.1 cm^3 to measure actual uptake by roots. Tests showed that the correlation between the water flow measured by heat pulse and the potometer was very high ($r^2 = 0.82$). The 2nd is a further improvement in the sensitivity of the heat pulse to detect very low sapflow rates by placing the thermocouples at an equal distance (6 mm) from the heater source. This approach is useful for detecting the possibility of reverse flow or 'hydraulic lift' in the root system, when water is supplied from the taproot to the upper lateral roots, which are in very dry soils (4–8% water content). Figure 53 illustrates the trend in diurnal sapflow of a large lateral root (6 cm in diameter) of

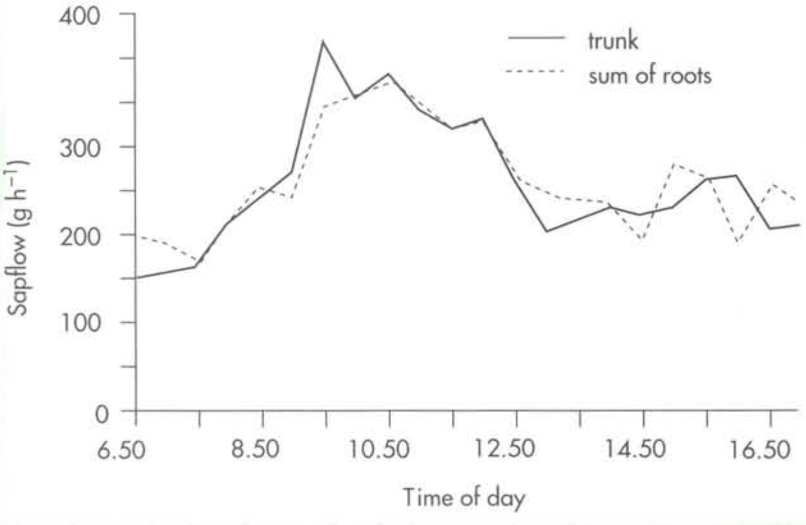


Figure 52. Comparison of sapflow in trunk and all roots of Grevillea robusta *trees during the 1996 long rains at Machakos, Kenya.*

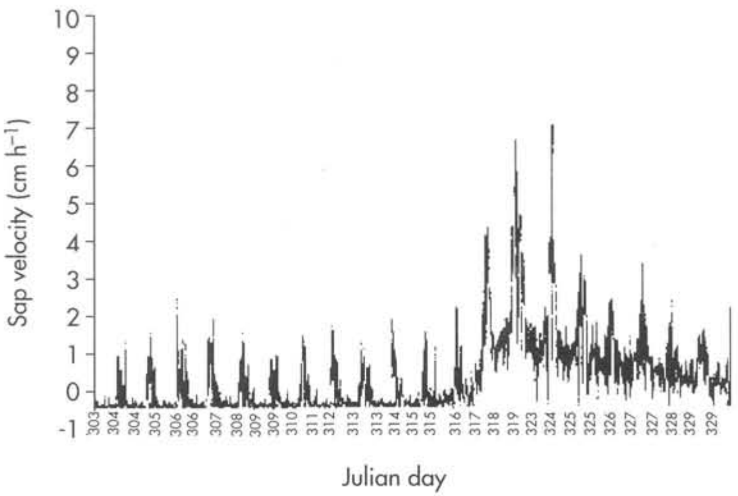


Figure 53. Sapflow velocity of lateral roots of Grevillea robusta *during the 1996 long rains at Machakos, Kenya.*

a 5-year-old *G. robusta* before and after the onset of the rainy season (short rains 1996–97), measured using the equal distance method. The results showed that water was moving backwards into the lateral root for most of the day before the rains but the direction was reversed after the rains (45 mm over 2 consecutive days). Preliminary analysis indicates that the total amount of the reverse flow accounted for 4–7% of the mean daily tree transpiration of 1.5 litres during the dry season. Although this is a small amount for tree growth, it might be very important for the activity of soil microorganisms close to the trees. We are currently testing how sensitive this method is to the high gradients in surface soil temperature, which are commonly found in the dry season, when hydraulic lift is expected.

Assessment of the contribution of deep water uptake was determined by measuring the difference between the tree transpiration and the combined uptake from the lateral roots. This method was used to avoid the need for extensive excavation to attach the heat-pulse probes directly onto the taproot, which is usually located beneath the lateral roots. The excavation may cause mechanical damage to adjacent roots and disturb their normal functioning. Primary lateral roots are usually located 5 to 10 cm below the soil surface in species like *G. robusta*; therefore only superficial excavation is needed to install the heat-pulse probes. Usually the lateral roots were excavated after 3 weeks of continuous sapflow measurements to determine their rooting depth. For deeper rooted species like *G. sepium,* the lateral roots are usually located at 30 to 40 cm depth. Sapflow measurements of *G. robusta* during the long dry season (fig. 54) showed that deep uptake accounted for almost all the daily transpiration when soil-water content in the top 30 cm (determined using time-domain reflectometry) was between 5 and 8%, and water content at 1.5 to 2.0 m depth was between 18 and 20%. When the top soil (40 cm) was rewetted (to 18–25%) by rains, the lateral roots responded rapidly, within 24 hours, and they accounted for about 80% of the daily transpiration within 3 days. Minirhizotron observations over this period did not indicate any production of new roots, which im-

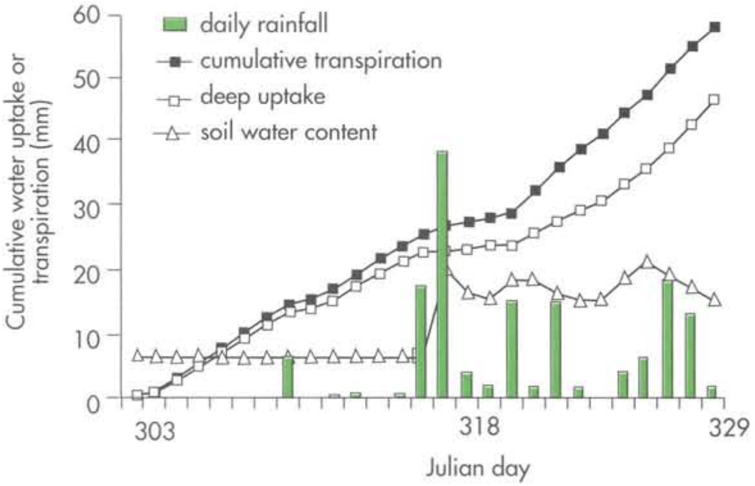


Figure 54. Contribution of deep uptake by taproots to tree transpiration of Grevillea robusta *during the 1996 long rains at Machakos, Kenya.*

plies that surface roots remained active even after 2–3 months in dry soil. This finding suggests that competition with crops for water by lateral roots of *G. robusta* could commence at the onset of rains and that deep uptake is important only during the dry season.

We are currently using this technique to explore the interspecific variation in deep-water uptake of Australian tree species in western Australia and, in collaboration with the Institute of Terrestrial Ecology, to examine the competitiveness of 8 tree species at Machakos. In phase 2 of this project we will be exploring how such information can be used in conjunction with hydrological models to determine the impact of trees on whole catchments or watersheds.

SCREENING FOR RESISTANCE TO THE LEUCAENA PSYLLID

Since its appearance at the Kenya coast in 1992, the leucaena psyllid (*Heteropsylla cubana* Crawford) has spread to almost all countries in eastern, central and southern Africa. It has caused extensive damage to leucaena *(Leucaena leucocephala)* wherever it has occurred, curbing the enthusiasm of extensionists and farmers for planting it. The best options by which the psyllid problem can be tackled are through identification of psyllid-tolerant *Leucaena* species and biological control through efficient parasites and predators. Ever since the global threat of the psyllid was recognized in the late 1980s, efforts have been made to identify psyllid-tolerant leucaenas. A number of species such as *L. diversifolia* (diploid and tetraploid), *L. collinsii, L. pallida* (synonymous with *L. esculenta* ssp *paniculata*), *L. retusa* and *L. esculenta* were found to be tolerant to the psyllid, and within each species considerable variation exists for selecting superior material for psyllid tolerance as well as for agronomic characters. Leucaena germplasm collected by the Oxford Forestry Institute (OFI) is being widely tested in the tropics, and preliminary results of screening trials conducted by ICRAF in southern Africa were reported earlier (see ICRAF annual report 1995 p 93–97). The University of Hawaii, under the leadership of Prof JL Brewbaker, has undertaken an interspecies hybridization programme and has coordinated multilocation testing of different *Leucaena* species and the breeding material throughout the tropics wherever the psyllid has become a pest. Results of a number of these tests were published in the university's Leucaena Research Reports. ICRAF obtained a set of material in 1993 from the University of Hawaii, to evaluate and identify psyllid-tolerant leucaena suitable for African conditions. The results are described here.

The leucaena psyllid, which has spread throughout eastern, central and southern Africa, causes extensive damage to its host plant, Leucaena *species. Control seems most feasible through introducing tolerant or resistant* Leucaena *species and insect parasites or predators.*

Exploiting host-plant resistance

At Machakos, we evaluated 17 accessions representing 4 *Leucaena* species and their hybrids, 7 of them replicated 3 times, 5 replicated twice and 5 only once (table 52). Unequal replication was because the quantity of seed was insufficient. Six-week-old seedlings of the test material, raised in polybags, were transplanted in the field at a spacing of 1 m between rows and 0.25 m within the rows. Each plot contained 2 rows 2.5 m in length. The trial was established in November 1993, and the plants were first pruned in June 1994 at

Table 2. Psyllid damage ratings of 17 leucaena accessions at Machakos, Kenya

Accession	Replications	Dec 1994	Aug 1995	May 1996
L. pallida K 806	1	1.0	1.0	1.0
L. pallida K 376	3	1.0 e	1.0 d	1.0 e
L. pallida K 824	3	1.0 e	1.0 d	1.0 e
L. pallida K 953	2	1.0 e	1.0 d	1.0 e
L. pallida K 748	2	1.0 e	1.0 d	1.0 e
L. esculenta K 948	3	1.0 e	1.0 d	1.0 e
L. diversifolia ssp *diversifolia* (4n) K 784	3	1.0 e	1.0 d	1.0 e
L. diversifolia ssp *diversifolia* (4n) K 156	3	1.2 e	1.0 d	1.2 e
L. pallida K376 x *L. diversifolia* K 156 (F3) KX 1	2	1.5 de	1.0 d	1.0 e
L. pallida K376 x *L. leucocephala* K8 (F3), KX 2	1	2.0	3.0	3.5
L. pallida K376 x *L. leucocephala* K8, Special Composite	1	3.0	1.0	2.5
L. leucocephala K 565	2	4.0 b	5.5 a	3.5 d
L. leucocephala K 584	3	5.2 a	5.3 a	4.9 c
L. leucocephala K 584 x *L. leucocephala* K636	3	5.3 a	5.6 a	5.2 bc
L. leucocephala K 636 x *L. diversifolia* ssp *diversifolia* K156 (F3)< KX 3	3	5.3 a	6.0 a	5.0 bc
L. leucocephala K 997	1	6.0	5.0	6.0
L. leucocephala K 636	1	6.0	6.0	7.0

1 = undamaged; 9 = highest degree of damage

Accessions followed by the same letter are not significantly different.

0.5 m height. Subsequent prunings were also done at 0.5 m height whenever the coppice growth of unaffected accessions reached 1 to 1.5 m in height. The psyllid damage was scored periodically on 6 trees marked in each plot using the 1–9 scale, where 1 = undamaged and 9 = the highest degree of damage. An integrated damage rating for each year was computed by calculating median scores from the assessments that showed consistently high ratings in that year. The median scores were subjected to analysis of variance after square root transformation to ensure the small values of scores were normally distributed. However, non-transformed scores are reported showing significant differences based on transformed values. The biomass yields were analysed without any transformation. As the design was unbalanced, the means were adjusted for replicate differences before statistical comparisons were made.

The accessions of *L. pallida* (K806, K824, K748, K376 and K953), *L. esculenta* (K948) and *L. diversifolia* (K784) showed virtually no psyllid damage throughout the study period (table 52). The *L. diversifolia* accession K156 showed only slight infestation. These accessions were also found to be resistant to the psyllid in Hawaii and Florida, USA. Accessions K156 and K376 were also resistant to the psyllid in Queensland, Australia. The *L. leucocephala* accessions (K636, K565, K584 and K997) and the hybrid of *L. leucocephala* (K584 x K636) showed very high damage ratings, similar to those at many other sites. Among the interspecies hybrids, KX1 was as good as its *L. diversifolia* parent K156; KX2 showed better tolerance than its susceptible *L. leucocephala* parent K8 but was inferior to its *L. pallida* parent; and KX3 showed damage ratings as high as those of its *L. leucocephala* parent K636. Thus, the *Leucaena* hybrids were influenced more by the susceptible parent than by the resistant parents.

Based on 6 harvests made from December 1994 to May 1996, *L. pallida* K806 produced the highest edible biomass of 23.7 t ha^{-1} (table 53), which was closely followed by *L. pallida* K376 with 18.4 t ha^{-1}. Among the *L. leucocephala* accessions, K636 and K565 produced respectable yields in the range of 16 to 17 t ha^{-1}; KX1 also produced a similar yield. The hybrids KX3, KX2 and K584 x K636, *L. leucocephala* K584 and *L. pallida* accessions K748 and K824 were in the next category, with yields ranging from 11 to 13 t ha^{-1}. All other accessions yielded less than 10 t ha^{-1}. While accessions K784 and KX2 special composite gave 8 to 10 t ha^{-1}, the others, including *L. diversifolia* K156, *L. esculenta* K948, *L. leucocephala* K997 and *L. pallida* K953, yielded the least (6 t or less). A high proportion of biomass (up to 70%) was harvested as edible foliage in *L. leucocephala* accessions and in crosses involving them (K584, K584 x K636, KX3, KX2) and *L. esculenta* (K948). The proportion of edible biomass was low at 50 to 65% for the *L. pallida* and *L. diversifolia* accessions, which suggests that they are better suited for wood production than for fodder technologies. These biomass yields should be taken as indicators of relative productivity, not as absolute amount, as the plot sizes were small.

Before the psyllid arrived in Machakos, *L. leucocephala* (ex 19/81 Honduras) was harvested 4 times a year, yielding a total of 17 t ha^{-1} of edible biomass, dry weight. None of the entries tested in the trial produced as much biomass, which indicates that the potential of psyllid-resistant *Leucaena* species or selections cannot match that of the adapted *L. leucocephala* selections if there is no psyllid attack. Biomass production was not correlated with psyllid resistance. This was evident from the poor yields of many of the highly psyllid-resistant accessions (for example, K156, K784, K948, K953) and the fairly good yields of some accessions in spite of their receiving high levels of psyllid damage (for example, K636 and K565). The tolerance of *L. leucocephala* accessions K636 and K565 and their high productivity have been observed in many other places. The advantage with these accessions lies in their quick recovery from damage whenever the

Table 53. Dry-matter yields of 17 leucaena accessions belonging to 4 leucaena species and some of their hybrids from planting in November 1993 to May 1996 at Machakos, Kenya

Accession	Replications	Total biomass yield (t ha^{-1}) 1994 (2)[a]	1995 (3)	1996 (2)	Edible biomass[b]	Non-edible[a]	Edible amt of total (%)
K806	1	14.16	20.80	7.86	23.73	15.04	62
K376	3	13.19	18.30	5.89	18.35	13.54	58
K824	3	8.76	8.90	3.79	11.80	6.71	64
K953	2	5.83	5.90	1.01	4.24	4.84	47
K748	2	11.84	11.50	5.03	13.05	11.56	53
K948	3	3.90	5.20	2.73	6.58	3.09	68
K784	3	7.72	8.50	3.91	9.75	6.46	59
K156	3	5.68	5.20	2.13	6.08	3.92	61
KX1	2	12.68	13.40	5.76	16.30	10.50	61
KX2	1	6.13	8.80	5.06	11.58	6.12	66
KX2 spec. comp.	1	5.35	5.40	2.80	8.09	3.65	69
K565	2	12.03	11.90	5.54	16.44	8.14	67
K584	3	8.40	9.30	4.13	13.23	5.19	72
K584 x K636	3	7.45	6.80	3.52	10.49	4.38	71
KX3	2	6.49	7.10	3.48	10.88	4.34	72
K997	1	4.34	3.40	1.50	5.42	2.33	70
K636	1	12.06	11.20	7.46	17.45	9.88	64
SED	of 3 reps	1.86	2.70	1.14	2.44	2.31	2.4
SED	of 2 reps	2.28	3.30	1.39	2.99	2.83	3.0
SED	of 1 rep	3.23	4.67	1.97	4.22	4.00	4.2
SED	3 vs 2 reps	2.11	3.06	1.29	2.44	2.62	2.7
SED	3 vs 1 rep	2.73	3.95	1.66	3.57	3.38	3.5
SED	2 vs 1 rep	2.99	4.33	1.82	3.91	3.71	3.9

[a] Values in parentheses in the column heads are number of harvests made in the respective years. The 1st harvest was made in June 1994 and the last in May 1996.

[b] The biomass was separated into edible (leaves and twigs) and non-edible (stems > 5 mm) portions from the 2nd harvest in December 1994 to the 7th in May 1996.

psyllid populations subside, the high proportion of their edible biomass and their better nutritional value compared with that of other *Leucaena* species.

The leucaena psyllid is still very active throughout East Africa, more than 4 years after its arrival on the continent, and it is still causing extensive damage to susceptible leucaena selections. Based on the above results, *L. leucocephala* accessions K636 and K565 could be considered for fodder banks and hedgerow technologies until more resistant selections are identified. The *L. pallida* accessions K806 and K376 can be considered for fodder technologies under conditions of high psyllid infestation. The consistently high yields from these accessions over 7 harvests suggest their ability to withstand repeated pruning. There is a need to evaluate a much wider range of *Leucaena* species and provenances to identify material suitable for African conditions that is both psyllid resistant and productive.

Biological control

Biological control of the leucaena psyllid was initiated in Kenya and Tanzania under the leadership of the International Institute of Biological Control (IIBC), in collaboration with NARS of those countries and ICRAF, with financial assistance from the Food and Agriculture Organization (FAO). The control agents—2 hymenopterous parasitoids, *Tamarixia leucaenae* (Eulophidae) and *Psyllaephagus yaseeni* (Encyrtidae)—were first released in Tanga, Tanzania, in 1995, and further releases were made at Tumbi in 1996. In Kenya, first releases were made at Machakos, towards the end of 1995 and in the first few months of 1996. Both these parasitoids originate in meso-America, where the psyllid and its host plant, *L. leucocephala*, originate. While *T. leucaenae* is a solitary ectoparasitoid and prefers to attack later instars of the psyllid, *P. yaseeni* is a solitary endoparasite, which prefers to attack psyllid instars 1 and 2.

Both species have become established in Tanzania and Kenya. *P. yaseeni* has previously been established in several countries in Asia and the Pacific, but this is the 1st time that *T. leucaenae* has been successfully introduced anywhere in the world. The results with this later parasitoid appear to be promising, as evident from the reduced psyllid populations coinciding with the peak periods of the parasitiod populations (fig. 55). In addition to its greater abundance, it also appears to be dispersing more rapidly. Just over a year after its release in Tanga, Tanzania, it was found about 200 km northeast in Kilifi, Kenya. Further monitoring is in progress to assess the impact of the biological control agents on the psyllid.

Although biocontrol and host plant resistance are widely seen as the most appropriate control tactics for the psyllid, how these 2 strategies interact in combination has never been investigated. New leucaena germplasm from rangewide collections by OFI will be evaluated in Tanzania, Malawi and Kenya for their agronomic characters and to quantify the psyllid populations and the success of the biocontrol agents.

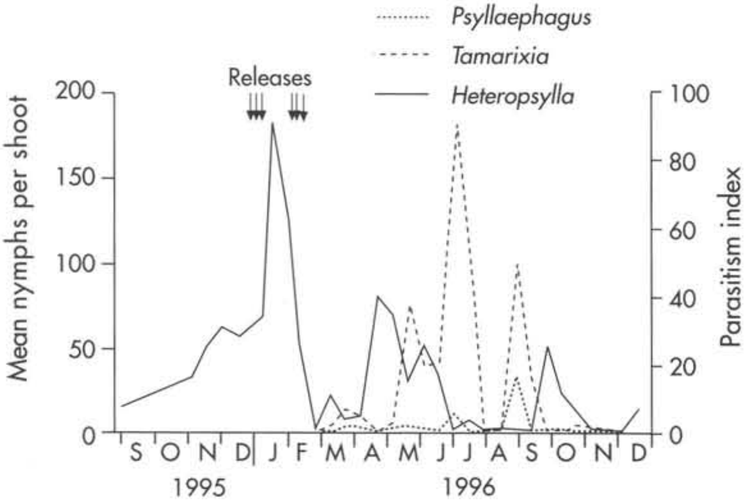


Figure 55. Population of the leucaena psyllid, Heteropsylla cubana, *and an index of parasitism by 2 introduced biocontrol agents, the hymenopterous parasitoids* Tamarixia leucaenae *and* Psyllaephagus yaseeni, *at Machakos, Kenya.*

TREE SEED DIRECTORY

In 1986, ICRAF published the first edition of the *Multipurpose tree and shrub directory,* as at that time the demand for seeds of agroforestry trees was increasing dramatically. Interestingly, this is still happening today, 10 years later. The directory was updated in 1991 when additional information on suppliers and species became available. The revised version with some 900 tree species also incorporated information on microsymbionts to take into account the recent advances in knowledge of biological nitrogen fixation. During the past 5 years more than 3000 copies of this publication have been distributed.

In 1996, a major revision of the directory was started after an analysis of the 1991 publication revealed much redundant and out-of-date information. To enhance the information content and utility of the directory, ICRAF teamed up with FAO, IUFRO and the Danish Forestry Seed Centre to carry out the revision. More than 2000 questionnaires were sent out to seed and microsymbiont suppliers. The questionnaires required not only an updating of existing details but also provision of new information on seed storage conditions, quantities supplied, seed pretreatments, origin of germplasm and documentation provided. This information can be employed by users of germplasm to choose the best quality and well-documented sources.

The revised *Tree seed suppliers directory* is being issued in 1997 in 3 forms. A book version is being published containing information on suppliers of 2400 species of trees. A computer database using Microsoft Access is being released on floppy disk and compact disk formats, and there will be an interactive version on the Internet.

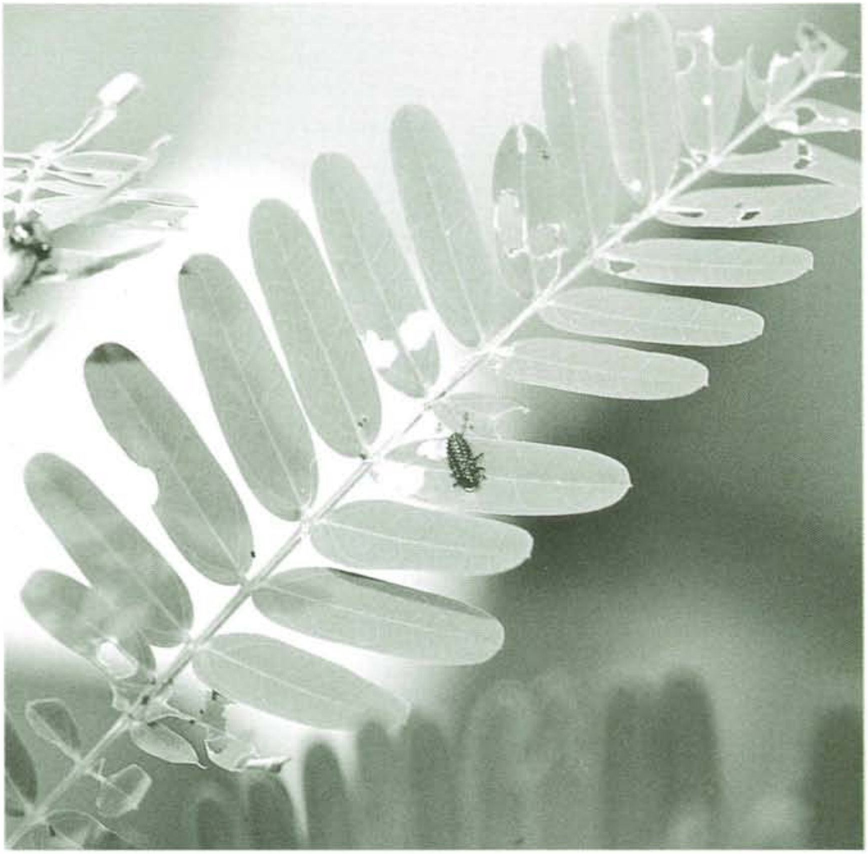
GERMPLASM RESOURCE UNIT

ADVISORY COMMITTEE

The Germplasm Resource Unit (GRU) of ICRAF has an International Advisory Committee, which

One of the trees from which germplasm was collected in 1996 is Guazuma crinita, *or bolaina blanca. In the Peruvian Amazon, it is valued for its poles, among other products.*

has met annually since 1994. The committee primarily reviews and advises on ICRAF's work in agroforestry tree germplasm, although its members also publicize the work of the GRU and assist in soliciting funding for its activities. The 8 members of the committee are assisted by representatives from FAO, ILRI, IPGRI and CIFOR. The 1996 meeting of the Advisory Committee was perhaps the best yet as members had greater opportunity to interact with ICRAF during the previous year because there were 2 full-time staff members in the GRU. Out of the 19 recommendations made at the 1995 meeting, 18 had been acted upon. The only omission was the development of a long-term plan for the GRU, which is scheduled for 1997.



The Mesoplatys *beetle has become a serious pest on* Sesbania sesban, *and populations are being screened for tolerance to it.*

GERMPLASM COLLECTIONS

Collections in 1996 focused on 6 priority species, 4 from Africa *(Prunus africana, Sclerocarya birrea, Uapaca kirkiana, Sesbania sesban)* and 2 from South America (*Calycophyllum spruceanum, Guazuma crinita)*. In Cameroon and Madagascar, collections were made of the high-value medicinal tree *Prunus africana* (see p 116–118). In southern Africa, 2 miombo fruit-tree species were collected: *S. birrea* and *U. kirkiana*. Both these species are top priorities for domestication work, and the collections are being used as the starting point for a new BMZ grant on their improvement. Following the collections of *S. sesban* in southern Africa in 1993, field trials with the 30 populations collected showed 2 riverine provenances from Malawi to be very productive and also tolerant to the *Mesoplatys* beetle. Despite the presence of crocodiles in nearby rivers, new collections were made so that seed orchards could be set up to meet the growing demand for *S. sesban* seed. *C. spruceanum* and *G. crinita* were collected in Peru by ICRAF scientists and national partners. Interestingly, these were the first-ever rangewide collections of any Peruvian tree (see p 43–44). The germplasm collected is to be used for community-based management projects as well as plantation trials.

SEED ORDERING AND PROCUREMENT

The procedures for ordering germplasm from the GRU were greatly streamlined in 1996 with the customization of a tree seed centre database. Modified specifically for ICRAF from the SISTEM programme developed at the Oxford Forestry Institute, the database deals with all aspects related to germplasm ordering, procurement, documentation, stock control and dispatch at ICRAF. It even writes out the seed labels, which, considering an individual order might have 200 seedlots, is a great time-saving feature. More than 350 requests for germplasm were dealt with during 1996 and this is expected to rise as our new seed stores in Nairobi become operational in 1997.

SEED ORCHARDS

In relation to agroforestry tree germplasm, it has been recognized that what is planted is what is readily available. For several species, sources of germplasm are already available on farm, but for many species there is a real deficiency in supply as cultivated trees or trees from wild populations cannot meet the increasing demand. In Malawi alone, the National Agroforestry Team estimates that annually up to 20 tonnes of *Sesbania sesban* seed, 140 tonnes of *Tephrosia vogelii* and 5 tonnes of *Gliricidia sepium* will be needed. For these species, and many more, there is a real need to establish seed orchards. In 1996, ICRAF launched a large initiative with an initial target of 100 hectares of seed orchards of priority species. Seed orchards were established in 1996 of the following species: *Calliandra calothyrsus, Gliricidia sepium, Leucaena diversifolia, L. esculenta, L. pallida* and *S. sesban.* Although only a small number relative to the number of species involved in agroforestry, this initiative marks the beginning of a more active seed multiplication programme, in which seed orchards will be set up during evaluation trials so that nucleus amounts of superior germplasm can be provided when trial results are known. Research is also progressing in Kenya and Malawi on how to give farmers incentives to become seed producers.

CAPACITY BUILDING

For details of capacity building activities carried out in each region, see the 'Capacity building' heading at the end of the regional reports.

TRAINING COURSES

A total of 8 training courses were held in 1996. Details of the courses follow (also see table 54).

Characterization and diagnosis

A training workshop, 'Characterization and diagnosis', held in Nairobi, is described on p 255. This workshop aimed not only to shape collaborative natural resource management research in the highlands of eastern Africa but also to shape the characterization and diagnosis module of the introductory training course 'Agroforestry research for integrated land use', as its content reflects ICRAF's recent thinking and advances in this cornerstone research area of agroforestry.

Table 54. ICRAF group training activities held in 1996

Topic	Date and venue	Participants	Geographic area	Audience
Characterization and diagnosis	15–26 April Nairobi, Kenya	17	African highlands	researchers
Design of agroforestry experiments	6–17 May Nairobi, Kenya	21	southern and eastern Africa	researchers
Integrated pest management	6–17 May Kakamega, Kenya	24	African highlands	researchers, senior technicians
Training materials for agroforestry	22–25 July Bamako, Mali	19	francophone Africa	training and education specialists
Agricultural information management	7–25 October Addis Ababa, Ethiopia	16	eastern Africa	documentation specialists
Agroforestry research for integrated land use	14 October–6 November Nairobi, Kenya	37	global	training and education specialists
Agroforestry tree improvement and management	2–6 December Nairobi, Kenya	12	Africa	researchers, senior technicians
Design of agroforestry experiments	December Niamey, Niger	20	francophone West Africa	researchers
Total		165		

Design of agroforestry experiments

As a result of its direct involvement in strategic and collaborative agroforestry research worldwide, ICRAF has acquired a wealth of relevant information and experience in experimental design and analysis. To further assist collaborating national institutions in improving the quality of their experimental work, this body of information has been epitomized in a 2-week training workshop, 'Design of agroforestry experiments'. In this highly participatory training activity, participants must be experienced and practising agroforestry researchers who bring their ongoing and planned experimental protocols to the workshop for discussion with members of ICRAF's Research Support Unit, who are the main resource persons for this activity.

Because of popular demand for this type of activity, 2 such training workshops were organized in 1996—1 for researchers from southern and eastern Africa, held in Nairobi, Kenya, and 1 in collaboration with the ICRISAT Sahelian Centre and WARDA for those from the semi-arid lowlands of francophone West Africa, held in Niamey, Niger.

Integrated pest management

The 'Integrated pest management' training course was held in Kakamega, Kenya (see p 255). ICRAF's research on agricultural pests and diseases is rather limited at this stage, and thus resource persons teaching this course came mainly from collaborating national and regional research institutions such as KARI, KEFRI, the University of Nairobi, the National Sugar Research Station, ICIPE, CIAT, IITA, CIMMYT and CIP.

A detailed course report is available for this training activity, and training materials have been developed.

Training materials workshops

These training workshops are an integral part of the ICRAF project on the development of agroforestry teaching materials sponsored by the Dutch DSO (Direct Support to Training Institutions in Developing Countries). Rather than produce training materials itself, ICRAF has opted to strengthen national and regional capabilities and efforts in developing these materials. During the initial session of these workshops, participants present their activities in agroforestry-related training and education as well as in the development of teaching materials. Other sessions deal with agroforestry curriculum development, the identification of existing and new materials needed to support the new curricula, the evaluation of training materials, and techniques related to the production of new written and audiovisual materials. At the end of each workshop, participants develop regional and national plans of action for the future collaborative development of such materials.

In 1996, ICRAF organized the 4th regional training materials workshop, held in Bamako, Mali, for the benefit of training and education specialists of selected countries in the francophone Africa region. An initial outcome of this workshop is the commitment of some key educational institutions in the semi-arid lowlands of West Africa to adapt and translate a series of ICRAF training materials for the benefit of several other training and education institutions in the Sahelian countries.

The 5th and last workshop of the ICRAF–DSO project on the development of agroforestry teaching materials was organized as a module in the context of the training of trainers course, 'Agroforestry research for development'. Its main purpose was to assist future trainers and educators to produce agroforestry training materials in direct support of future decentralized introductory training courses.

Agroforestry information management

For a number of years, CTA, ICRAF and ILRI have jointly organized training courses on agricultural information management, aimed at enhancing the capacity of NARS in this area. Such a training course was run 7–25 October in Addis Ababa, Ethiopia, in which 16 agricultural information professionals participated from Ethiopia, Ghana, Kenya , Lesotho, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda and Zambia. The principal objective of the course was to help improve the skills of the participants in the management of information services, with particular focus on selective dissemination of information (SDI), user needs assessment, quality control of information products, and promotion and marketing of information services.

Agroforestry research for integrated land use

This introductory training course has been the subject of a series of training courses sponsored by DSO and ICRAF between 1990 and 1995. As a result of the implementation of the centre's new strategies in training, it has been decided to scale down ICRAF's participation in introductory agroforestry training courses in favour of assisting regional and national training and education programmes to conduct them. Before transferring this responsibility, ICRAF decided to organize a 'training of trainers' course, for those who will be involved in organizing and implementing future courses, regionally and nationally.

The 4-week course was divided into 2 parts: 1 dealing with an update of agroforestry knowledge and skills based on advances in agroforestry research and development as a result of ICRAF's work, and a 2nd dealing with instructional methodologies such as needs assessment, curriculum development, course organization and implementation, training materials, and monitoring and evaluation, based on ICRAF's decade-long experience in organizing these introductory courses. The follow-up of this activity is covered under the subheading 'New directions in training' (p 283).

Agroforestry tree management and improvement

ICRAF's research on agroforestry tree management and improvement underwent some important changes over the last few years. As a result, the programme felt that there was a need to upgrade the knowledge and skills of its collaborating national scientists and technicians in some key areas, such as recent thinking in tree domestication, research priority setting and ethnobotanical surveys, germplasm collection and procurement, reproductive biology, field experimentation, seed and seedling production, and vegetative propagation. This is being done through a 1-week course that will become an annual feature of ICRAF's training programme.

INDIVIDUAL TRAINING

Individual training at ICRAF serves the twin functions of providing agroforestry research and developing research capacity for national institutions. By working with young researchers, ICRAF plays a significant role in stimulating interest in agroforestry science, thereby sustaining the future supply of agroforestry scientists for universities and NARS. Young scientists, who are attached at ICRAF research sites, can benefit from the supervision of our senior scientists.

Three categories of individual trainees are recognized:

- postgraduate trainees—students registered at universities for master's or PhD degrees or their equivalents
- research fellows—scientists with research experience in fields other than agroforestry, wishing to strengthen their agroforestry skills
- student attachments—undergraduates or technician-level trainees needing exposure to agroforestry

The combinations and permutations of these categories depend on the expertise available at the site and ICRAF's collaborative research agenda. Figure 56 presents the individual training statistics for 1996 by these 3 categories, showing a very strong emphasis on MSc-level attachments. Figure 57 shows the distribution of student attachments by continent. Africa enjoyed the highest numbers for 2 reasons:

- additional fellowships were available through the Sida-supported African Network for Agroforestry Education (ANAFE)
- a large number of undergraduate students were attached to ICRAF headquarters from the national universities and colleges in Kenya.

Figure 58 shows how the individual training of postgraduates is distributed among the various disciplines in our research agenda.

Individual training is an area of growth at ICRAF, and in 1996 we established strong

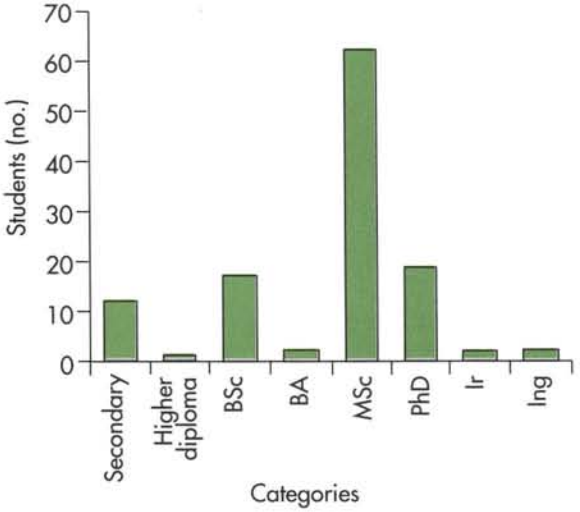


Figure 56. Distribution by educational category of students receiving individual training at ICRAF, 1996.

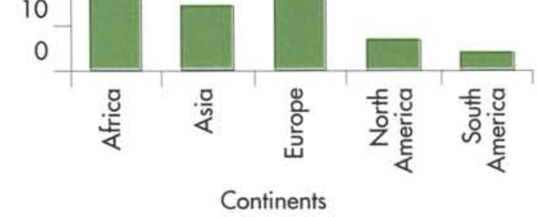


Figure 57. Distribution by continent of students receiving individual training at ICRAF, 1996.

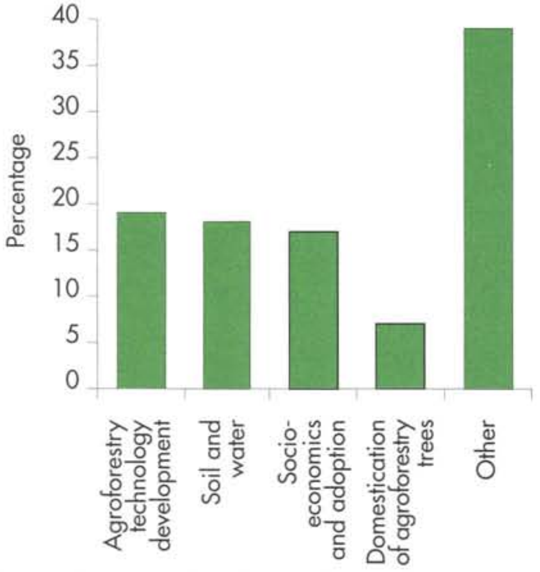


Figure 58. Distribution of individual training of post-graduates among the various disciplines in the ICRAF research agenda, 1996.

contacts with universities and signed memoranda of understanding in which much more research can be undertaken as student theses. With the move by several developed countries to link their universities with CGIAR centres, we look forward to expanding our collaboration. Senior research fellowships and sabbatical programmes are likely to feature in our future activities. However, emphasis will continue to be placed on young scientists from developing countries. This approach has been incorporated into ICRAF's medium-term plan, 1998–2000.

TRAINING MATERIALS

ICRAF continued to develop training materials in support of its short training courses (see box 7) and to assist national training and education institutions in their efforts to produce their own.

Training materials for the course 'Design in agroforestry experiments' are developed as guidelines and references for training workshop resource persons. They consist of a series of 12 session summaries and lecture notes, together with a portfolio of experimental protocols and assignments that allow a specific target audience to practise basic concepts and principles of experimental design and to apply this knowledge to their own agroforestry experiments.

Following the same approach, these materials have been adapted and translated into French in support of the Sahelian training on 'Conception expérimentale pour la recherche agroforestière'. A Spanish version will be developed for similar courses to be held in Latin America in 1997 (Peru) and beyond.

The characterization and diagnosis training workshop led to the production of a workshop outline and 9 lecture notes and session summaries. This workshop was important in that it provided new knowledge based on ICRAF's research on land-use characterization and diagnosis. The diagnosis and design module, previously at the centre of the introductory training courses on agroforestry research for integrated land use, is now being replaced by a characterization and diagnosis module, which builds on the previous module but provides more information on tools, methods and approaches to

Box 7. Written training materials produced during 1996

Characterization and diagnosis

Session 1 – Team building
Session 2 – Natural resources
Session 3 – Stakeholder interests
Session 4 – Systems thinking
Session 5 – Sampling and statistical rigor
Session 6 – Benchmark level characterization and diagnosis
Session 7 – Remote sensing
Session 8 – Geographic information systems
Session 9 – Household level characterization and diagnosis

Design of agroforestry experiments

Part 1 – Summaries and lecture notes

Experimental concepts and principles
Setting objectives
Choosing treatments
Site selection and characterization
Replication
Plot structure
Randomization
Sampling
Assessments
Plot layout
Incomplete block designs
The experimental planning process
An experimental design project

Part 2 – Experimental portfolio and assignments

land use and to agroecological characterization and analysis. Major improvements over the previous approach are refined sampling methods and a more quantified and qualified analysis of the data and information obtained.

Materials developed in support of training on 'Integrated pest management' consist of a series of 17 lecture notes and 5 practical exercises on integrated pest management concepts and principles. They cover some major pests and diseases of potatoes, beans and bananas, and the parasitic weed striga. These materials are being compiled in a more formal document on training materials in 1997.

In support of the training of trainers course, 'Agroforestry research for integrated land use', participants received the complete set of lecture notes, case studies, course manual, training exercise book and slide series that ICRAF has developed over the last 5 years. Participants also received a series of publications related to advances in agroforestry research and to instructional methodologies that will allow them to start organizing their own national and regional courses. Included was a 1996 version of an agroforestry training materials catalogue that allows trainers and educators to identify existing teaching aids in support of their curricula.

ICRAF's slide series collection has been expanded to include topics such as characterization and diagnosis for the coffee-based land-use system in Embu, in Kenya, design of agroforestry experiments, vegetative propagation of agroforestry trees, and trees on farms. Several slide series have been digitized, allowing them to be reproduced in composite slides, combining graphics, text and photographic images, which greatly enhances their use for teaching purposes.

Training materials developed for the 'Integrated pest management' course cover major pests and diseases and the parasitic weed striga, shown here, which attaches itself to maize roots.

NEW DIRECTIONS IN TRAINING

Capacity 'enabling' or 'building'?

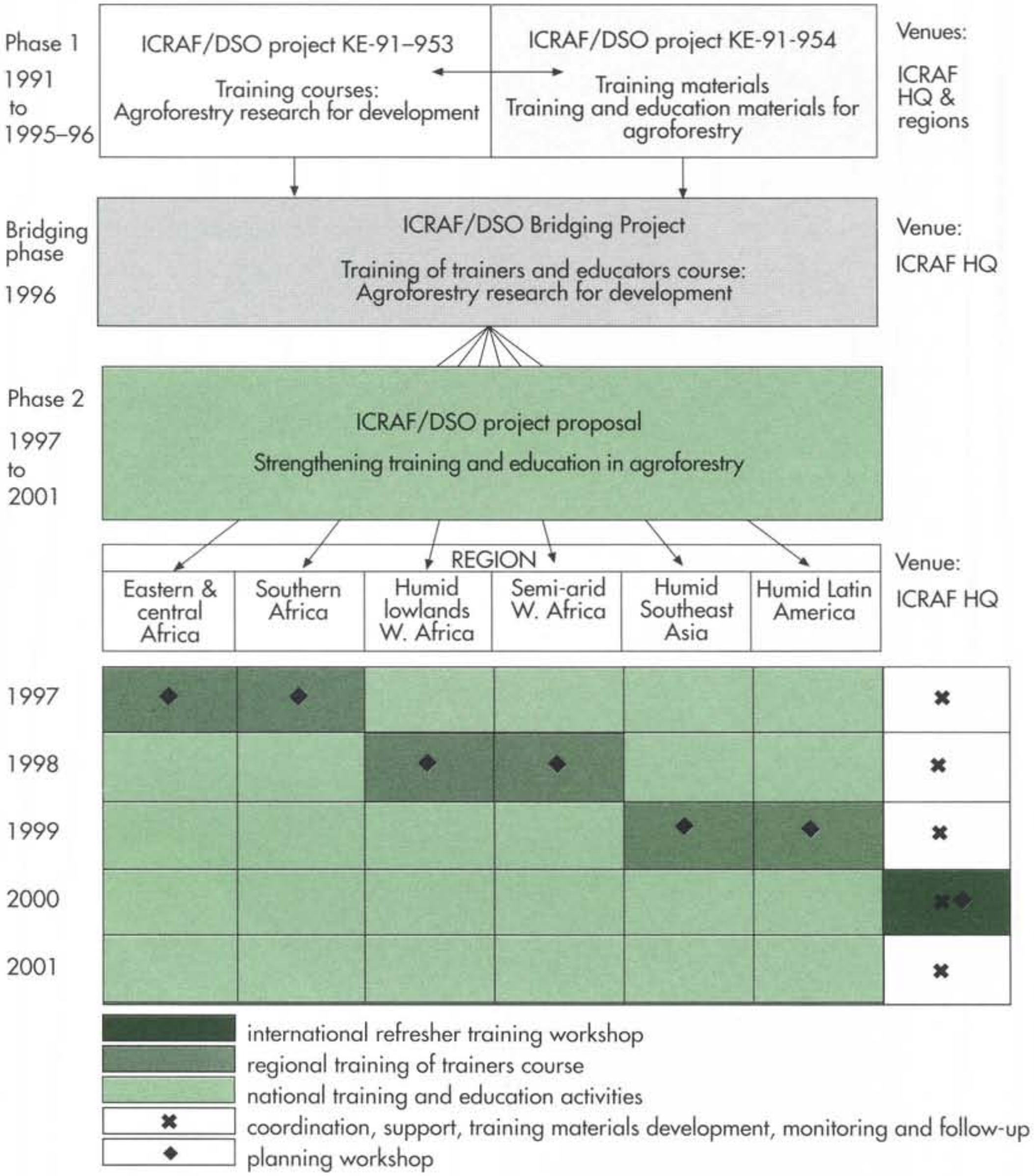
ICRAF's monitoring and evaluation of the impact of its previous group training courses shows that its alumni often have problems applying newly acquired knowledge and skills because of a lack of resources and teaching infrastructure. As ICRAF is on the verge of transferring the responsibility of introductory agroforestry training to national institutions in developing countries (fig. 59), it becomes more important than ever to make sure that these future training and education activities get implemented under optimal conditions.

Experimental Design
for
Research

Experimental design for agroforestry

Layout is likely to be more complex than in typical agronomy trials

Several of ICRAF's slide series have been digitized. This means they can be reproduced as composites, with photographic images, graphics and text combined on one slide. The range of possibilities greatly increases their classroom versatility.



	Eastern & central Africa	Southern Africa	Humid lowlands W. Africa	Semi-arid W. Africa	Humid Southeast Asia	Humid Latin America	ICRAF HQ
1997	▨ ◆	▨ ◆	🟩	🟩	🟩	🟩	✖
1998	🟩	🟩	▨ ◆	▨ ◆	🟩	🟩	✖
1999	🟩	🟩	🟩	🟩	▨ ◆	▨ ◆	✖
2000	🟩	🟩	🟩	🟩	🟩	🟩	■ ✖◆
2001	🟩	🟩	🟩	🟩	🟩	🟩	✖

■ international refresher training workshop
▨ regional training of trainers course
🟩 national training and education activities
✖ coordination, support, training materials development, monitoring and follow-up
◆ planning workshop

Figure 59. How ICRAF is implementing the decentralization process of its introductory agroforestry training courses.

Participants in the training of trainers course, held at ICRAF headquarters, Nairobi.

With this in mind, ICRAF has formulated a project proposal, 'Strengthening agroforestry training and education', that will enable regional teams and national institutions to conduct various training and education activities in agroforestry. Whereas the main responsibility for these activities will rest with the NARS, ICRAF will continue to support these efforts through its collaborative agroforestry research activities, the organization of refresher and specialist courses, the codevelopment of appropriate training materials, the coordination of the project and the implementation of a small grants scheme for training, and education in agroforestry.

Distance and computer-assisted learning

An increasing number of training and education institutions in developing countries now have access to computing facilities and electronic communication using the Internet and the World Wide Web. This is opening new opportunities for distance and computer-assisted learning methodologies and ICRAF's training programme will start exploring these possibilities in 1997. The programme presently collaborates with the Research Division in the production of 2 multimedia CD-ROMs and has started to make a selection of its training materials available on ICRAF's intranet.

Extension training

Several of ICRAF's earlier collaborative agroforestry research programmes and activities have produced conclusive agroforestry technology results, and we are now ready to disseminate information on these outside the scientific communities. Because of our role in developing these technologies, and since not all national extension services are capable of dealing with agroforestry extension, ICRAF will initially facilitate this technology transfer through selective extension training activities and the development of appropriate models of training materials.

EDUCATION

Understanding the education–extension link

No matter the quality of agricultural education, unless it can benefit the farming community, it will have been expensive and in vain. This is the philosophy that underpins ANAFE's efforts to bring about perceptual and attitudinal changes in agricultural education in Africa. The green revolution has bypassed the small-scale farmer in Africa. Policy and institutional obstacles were largely to blame. Emerging liberalization and privatization have removed or at least reduced these obstacles. But farmers are still not benefiting from recent advances in farming technologies and improved crops. This state of affairs has led ANAFE to hypothesize that existing knowledge systems are not poised to assist farmers.

Farmers have 3 major sources of new knowledge and information—research, training and extension systems (including NGOs). How well are institutions responsible for these systems communicating with each other, and how are they organized to share information and skills with farmers? This is a major area of concern, deserving in-depth research and analysis. In 1996, ANAFE undertook a pilot study in Malawi and Uganda to establish the volume and quality of agroforestry information reaching farmers, how the information was delivered, and the role of training institutions. The study was conducted through a questionnaire administered to 33 and 50 randomly selected frontline extension agents in Malawi and Uganda, respectively. In Malawi the study was focused in areas near Lilongwe and Salima, while in Uganda only Masindi District was involved. The findings will be published in the ICRAF Training and Education Report series. Following are some excerpts.

It is important to note here that if we really want to deliver an agroforestry message to farmers we must target our educational programmes at the certificate and diploma levels.

Obviously, depending on the country and district one is working in, it could be either the agricultural or the forestry services that are most in contact with farmers (fig. 60). In Malawi, other disciplines involved in extension are land husbandry and general education (science, the arts). In Uganda, the other disciplines are livestock management, fisheries, environmental education and again, some in science and the arts.

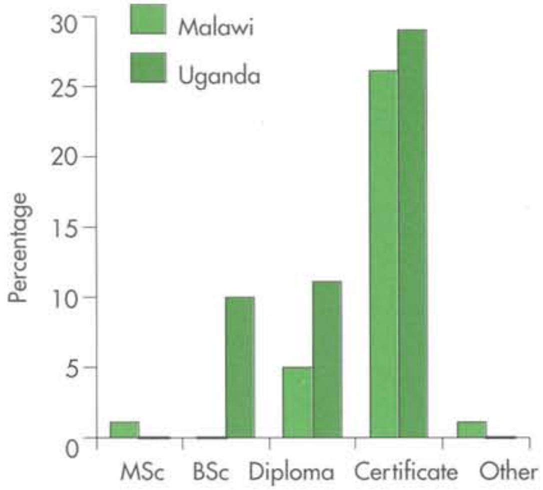


Figure 60. Disciplines of extension agents in Malawi and Uganda.

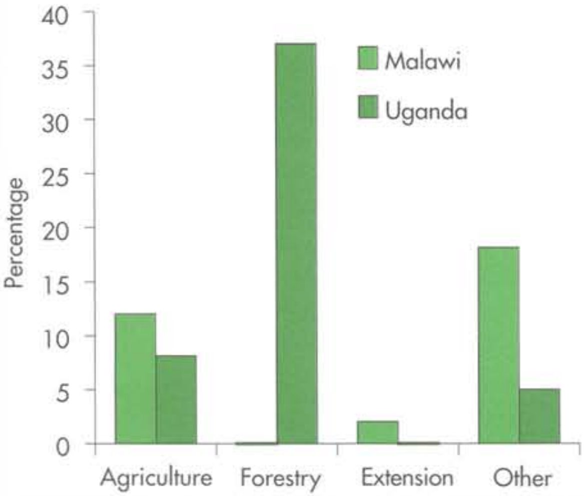


Figure 61. Qualifications of extension agents in Malawi and Uganda.

We were interested to know where and when the extensionists learned agroforestry (fig. 61). In Malawi, 15% had had formal training in agroforestry. They had all graduated from the Malawi Natural Resources College in 1989 or later. All others acquired agroforestry knowledge and skills through short courses; 45% had attended short courses organized by ICRAF, USAID and the Malawi government.

In Uganda, 22% of the respondents had received formal training in agroforestry at Makerere University, Bukalasa Agricultural College or Nyabyeya Forestry College. All of them had graduated in 1989 or later. The others had acquired agroforestry knowledge through short courses, 45% having attended short courses run by ICRAF, CARE, FAO, NGOs and FORI.

Extension agents in both countries described the courses they attended (both formal and short courses) as theoretical. They felt the courses did not help them to develop practical skills, were too focused on specific technologies and did not include enough field analysis with farmers.

We wanted to know how and where the extensionists obtained new information on agroforestry. The charts in figure 62 illustrate the importance of radio, extension bulletins, study tours, NGO reports, and ICRAF publications in putting agroforestry information in the hands of extension workers. These results are only indicative, as they are based on but a single district in each country. The methodology will be improved by restructuring the questionnaire and including farmers among the respondents. Then the research can be expanded to cover a wider area and broader socioeconomic conditions. Such expansion

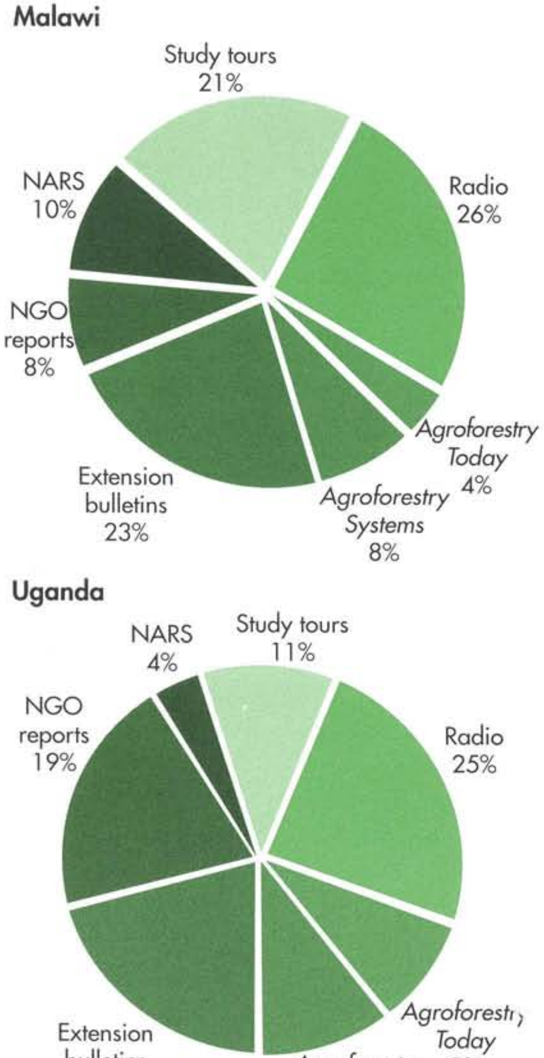


Figure 62. Additional sources of agroforestry information for extension agents.

should produce results that can be used to guide the design of training and information systems with potential for impact on farmers.

Global growth in agroforestry education

In 1992, USDA published a document listing the institutions offering agroforestry education and training. Since 1993, ICRAF has been collecting more data and updating available records to establish trends in agroforestry education and training. To make the data useful, especially in terms of possibilities to be queried, we developed the Agroforestry Education Database (AFED). Through AFED, it is possible to provide information to clients on many aspects of available programmes, worldwide.

In 1996, the data were analysed further and extracted to produce a 'Directory of Educational and Training Opportunities in Agroforestry', which has now been published and circulated worldwide. Figure 63 shows the 1996 status of agroforestry education worldwide. The figures for Asia and Australia should be read cautiously because we believe there are many institutions that we did not reach and that the actual figures are much higher.

ICRAF has made the results available through the publication and distribution of the directory. However, for the global community to reap the full benefits of the database, ICRAF plans to keep updating the information and by the end of 1997 to be sharing it on the World Wide Web.

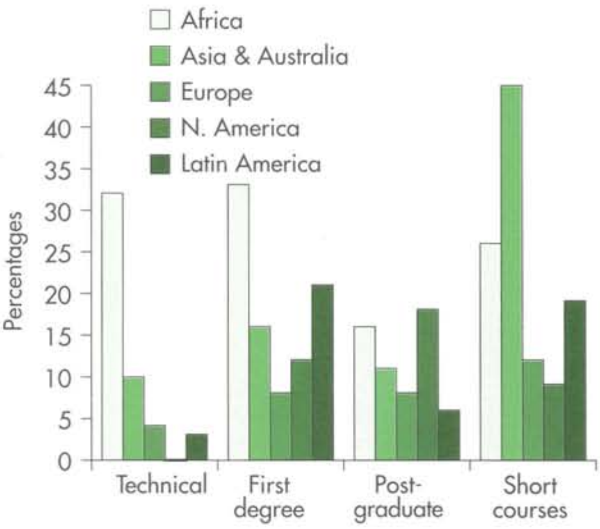


Figure 63. Global education and training opportunities in agroforestry.

Focal colleges and universities take the reins

ICRAF's capacity-building efforts are closely linked to our disengagement strategy. When an institution can take over partially or completely the activities ICRAF is now carrying out, we know that we have realized our aim of building the capacity of that institution. For about 20 years, ICRAF has been training young scientists in developing countries in agroforestry. During the last 3 years, ICRAF has worked closely with ANAFE to focus its training efforts on tertiary education institutions to build up their capacity to take over organizing and running short courses in agroforestry. In the Sahel, 2 institutions, the Institut polytechnique rural de Katibougou (IPR) in Mali and the Institut du développement rural (IDR) in Burkina Faso, signed memoranda of understanding accepting this responsibility (see box 8). Policymakers, education administrators, faculty and students received the celebrated event through formal signing ceremonies. Data were collected for the selection of focal institutions in southern Africa. The selection process will be completed in 1997 for all AFRENAs. As ICRAF sets into motion the disengagement mechanism from basic courses in agroforestry, continuity and adoption are assured. This, we think, is a very important milestone.

ICRAF works closely with ANAFE in building the capacity of colleges and universities to train students in agroforestry. Here ICRAF researchers and ANAFE representatives greet the Malian Minister of Higher Education.

Box 8. Focal institutions

Duties and responsibilities of the focal institutions

- To organize regional fora such as colloquia, geared at strengthening agroforestry education and training
- To provide leadership in organizing and running training courses in agroforestry
- To promote and coordinate links among educators, researchers, extension networks and farmers
- To catalyse the evolution of pools of expertise to address various aspects of agroforestry education and training
- To lead initiatives to develop, review and test teaching materials in agroforestry, including selection and improvement of practical training facilities
- To serve as a depository of ICRAF publications. In this context, the focal institution will collect, organize and make accessible training and educational materials in agroforestry and related areas
- To coordinate with ANAFE all education and training matters in the AFRENA
- To provide a regional, ecozonal focus to agroforestry education and training

Duties and responsibilities of ICRAF

- To make available to the focal institutions the training and educational materials produced by ICRAF. In this context, IPR will serve as a depository of ICRAF publications
- To provide technical and logistical support for organizing training and educational programmes
- To support the focal institutions' initiatives to secure donor support to implement its responsibilities as a focal institution
- To promote links between IPR and agroforestry research organizations

The duties of ICRAF will be executed through ANAFE.

Growing support for thesis research

As more universities become interested in conducting agroforestry research, there is evidence of a growing number of faculty and postgraduate students undertaking this research. ICRAF has moved fast to capture this interest and work out collaborative arrangements for it. The following approaches, which have also been used in the past, have now been institutionalized and streamlined for greater effectiveness:

- developing memoranda of understanding between ICRAF and universities to jointly support training and research activities
- including thesis research opportunities in research projects submitted to donors
- supporting research proposals by universities to donors
- providing opportunities for university faculty to carry out joint research with ICRAF scientists during their sabbaticals or study leaves
- allowing ICRAF scientists to participate in educational activities such as curricula reviews, giving lectures in agroforestry and cosupervising postgraduate research

The ICRAF regional coordinator for the Sahel and the vice chancellor of the Institut polytechnique rural de Katibougou in Mali discuss the memorandum of understanding that will enable the institute to build its capacity to train students in agroforestry.

All these activities are now built into ICRAF's programme of work and budget and are evaluated. By the year 2000 this strategic link with universities is expected to make a significant contribution to agroforestry output and capacity building. The process can also be seen as contributing towards capacity mobilization for the developing countries.

University training in Peru

ICRAF did a survey of universities in Peru to determine how best to assist the universities in giving students agroforestry training. Findings will help in drafting a proposal for donor funding. For more details of the survey, see p 68–69.

INFORMATION

The aims of ICRAF's Information Programme are—

- to facilitate the global exchange of agroforestry information through the use of print and electronic media, largely in partnership with other institutions
- to provide well-targeted agroforestry information to our key partners in national systems
- to raise awareness among different user groups about the importance of agroforestry as a sustainable approach to land use
- to build NARS capacity for accessing, managing and disseminating agroforestry information

To undertake these tasks effectively, the programme works in 2 broad areas: information and documentation support for agroforestry, and publications and public awareness.

Agroforestry information and documentation services

Over the years, ICRAF has developed a number of information services and products to respond effectively to information requests emanating from ICRAF staff, our NARS collaborators and others working in agroforestry research and development.

Our specialized agroforestry bibliographic database, AFBIB, continues to grow, now containing 35 000 entries of carefully selected, catalogued and abstracted literature. During the year, we compiled an annotated bibliography on indigenous fruit trees in the tropics, which consists of 240 records. The bibliography is available for distribution on diskette and will be published soon on the World Wide Web. To supplement our inhouse database, we continued our subscription to major agricultural and forestry databases on CD-ROM, including Agricola (US National Agricultural Library), Agris (FAO), TREECD and CAB Abstracts (CAB International), *Current Contents: Agriculture, Biology and Environmental Sciences* (Institute of Scientific Information) and Tropag & Rural (Tropical Royal Institute).

In 1996, we received and responded to over 10 000 requests for information, ranging from simple queries about ICRAF to complex ones for advice on how to overcome specific agroforestry-related problems. Some 700 literature searches were also conducted on various databases in response to user requests. This does not include searches conducted by ICRAF staff themselves from their computers or by outside users through computers provided to them at the library.

A user survey of our *Agroforestry Updates* service, which provides monthly tailor-made literature updates to over 450 of our NARS partners, was completed in 1996. The major findings indicate that users have found the *Agroforestry Updates* service beneficial in—

- keeping them abreast of new developments in their areas of interest
- improving their quality of work
- obtaining important sources of current information
- helping increase their ability to publish

Moreover, a significant proportion of users felt that for them the service was invaluable, as their own information centres were not able to meet their needs. Some 95% of the respondents complained about the difficulty of getting reprints once they identified articles of interest from their update printouts. About 55% of them also indicated that they would prefer to receive their monthly updates in electronic format—by email or on diskette.

The ICRAF library continued to serve as a major resource for delivering agroforestry documents to our partners. During the year, the library, on request, provided over 150 000 photocopies and 5100 loans to users.

AfricaLink—bringing African agricultural research into cyberspace

One of the most important constraints facing NARS researchers is the almost total absence of electronic mail and Internet facilities, seriously affecting their ability to communicate with their peers and access current information. In 1996,

Miti Ni Maendeleo

KEFRI/KARI/ICRAF and GTZ/MoALD&M

Number 3

November 1996

Tree seed — meeting the need

George Nii Gitonga, in Meru, plants trees to control erosion—and now raises his own seedlings

news & notes

questions & answers

other submissions

In this issue . . .

2 Message from the editor
3 Readers' letters

Tree seed
1 Tree seed—meeting the need
6 Translating science into seedlings—*Melia volkensii* seed

Indigenous trees
8 Propagating fodder species for farms
10 A handy tip for tree planting

Soils
10 Wood ash as fertilizer
11 Questions and answers

The regional newsletter Miti Ni Maendeleo (Trees are progress), *carrying stories, news and information for extension workers, NGOs and farmers, and published in conjunction with GTZ, is gaining a following that may make the newsletter outgrow its regional borders.*

ICRAF was requested by ASARECA (Association for Strengthening Agricultural Research in East and Central Africa) to be the lead centre for implementing the AfricaLink project, which aims to facilitate and improve electronic mail connectivity to NARS and their staff who participate in research networks for agricultural and natural resources management. We prepared a project proposal for funding by the Africa Bureau of USAID, which was approved during the year.

The key guiding principle in implementing AfricaLink is to rely and build upon local and national capacity, where it exists, to provide electronic connectivity. This will ensure sustainability and promote local entreprenuership.

The first task in implementing AfricaLink was to identify research networks that would benefit from email connectivity. We sent a request to all international agricultural research centres (IARCs) that coordinate regional research networks in eastern and central Africa to provide a list of their members. The 14 networks that responded provided a list of 250 members eligible for email connectivity through AfricaLink support. The international centres that participated by providing names of network members are CIAT, CIMMYT, CIP, ICLARM, IITA, ILRI and IPGRI. From among the

14 networks, the following were targeted as a priority for connectivity:

- Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)
- Eastern African Bean Research Network (EABRN)
- Programme régional d'amélioration de la pomme du terre et de la patate douce en Afrique centrale et de l'est (PRAPACE)
- East and Central Africa Agroforestry Research Network (ECA-AFRENA)
- East Africa Root Crops Research Network (EARNET)
- African Highlands Initiative (AHI)
- African Network for Agroforestry Education (ANAFE)
- Cattle Research Network (CARNET)
- African Feed Resources Network (AFRENET)
- Major stations collaborating with CIMMYT
- National Plant Genetic Resources Programmes—East Africa Network

During the year, email connectivity was provided to 65 NARS institutions and researchers in Tanzania and Uganda. Arrangements have been made with local Internet service providers in Ethiopia, Kenya, Madagascar, Eritrea and Rwanda to provide connectivity to AfricaLink/ICRAF partners in these countries.

Publications and public awareness

This was a watershed year for ICRAF's public awareness activities. We went all out to bring the public on board—letting people around the world in on the advances in agroforestry research and providing useful and useable information to those who practise or want to practise agroforestry.

Our public is enormous and diverse, and obviously we cannot reach everyone. For this reason, we have been tailoring and packaging our information—both old and new—for individual groups, particularly those for whom our work is geared and for those who support agroforestry research. These include our colleagues and partners in national research systems, policymakers, development and extension agents, farmers, donors and their tax-paying public. We also work closely with the mass media—newspapers, radio and television—as they are best placed to get messages out to burgeoning audiences around the world. And in 1996 we also leapt on the information superhighway and launched an ICRAF home page on the World Wide Web.

To monitor the effectiveness of our public awareness activities and our publications, we keep track of feedback from viewers, listeners, readers and those in the field who are trying the agroforestry approaches they learn about from our information packages. In the past year this feedback has been remarkable, with literally thousands of people writing to ICRAF about subscribing to our magazine, *Agroforestry Today*, and the new extension newsletter for eastern Africa, *Miti Ni Maendeleo.*

Another way of measuring the impact and relevance of our information is through reprints of our material. In 1996, for example, the prestigious *Scientific American* picked up on a story from *Agroforestry Today* and used it as a basis for one of their own features. Others, such as CIDA and the Université Laval in Canada, have begun to carry our monthly feature stories from *ICRAF Updates* on their Internet sites.

We also worked closely with the CGIAR to help prepare press material for worldwide distribution, and we offered well-received comments on ongoing efforts to raise systemwide public awareness within the CGIAR.

***Agroforestry Today*—and tomorrow.** In 1996, we began a trial subscription policy for ICRAF's flagship publication, the popular quarterly magazine *Agroforestry Today.* The intention was to get readers who could afford to, to help defray some of the costs of publication and distribution. This brings an element of sustainability to this magazine and is also a good test of its usefulness and relevance to a worldwide audience. The thousands of responses, both from paying subscribers, mostly in the developed world, and from those requesting exemptions, mostly practitioners of agroforestry in the developing world, proved beyond any doubt that the magazine has become essential reading for those with an interest in improved land use through agroforestry. The magazine continues to be a forum for researchers and practitioners to get their information out—quickly and succinctly—to a broad audience.

The income from paid subscriptions is already enough to cover the publication of 1 issue of the magazine, and the number of paying subscribers continues to rise. In a time of shrinking resources, this bodes well for the future of this magazine, which like agroforestry itself fits a crucial niche in the world of natural resource management and rural development.

Copublication. In 1996, ICRAF continued its copublication programme with both commercial and non-commercial organizations. With Kluwer Academic publishers, we continued copublishing *Agroforestry Systems*, ICRAF's flagship journal, which will increasingly be producing special issues on topics of major significance to agroforestry research. With CATIE, we also copublished 3 issues of *Agroforestería en las Américas,* which now reaches over 4000 subscribers, largely in Latin America. With CABI International, we continued our arrangement to copublish *Agroforestry Abstracts* and produced a new book, *Tree–crop interactions: a physiological approach,* which provides a scientific framework for the quantitative analysis of tree–crop interactions.

Elsevier publishers devoted a special issue of their journal *Agriculture, Ecosystems and Environment* to copublish with ICRAF papers on alternatives to slash-and-burn agriculture presented at the 25th World Congress of Soil Science in Mexico in 1994.

***ICRAF Updates*.** The newsy and very human stories we carry in our monthly *ICRAF Updates* bring information rapidly to donors and the media. These stories have been finding their way into newspapers in Africa and onto Web sites on the Internet. The updates are also to be found on ICRAF's own home page (see immediately following).

ICRAF on the Internet. Although not fully developed yet, ICRAF's home page on the Internet (http:www.cgiar.org/icraf) has placed us firmly on the cyberspace map of the world. We continue to receive daily requests from site visitors in far-flung corners of the world, and this has turned our public awareness offices into small but effective networks for linking agroforesters and providing information to the people who wish to apply the results of our research in their own agroforestry endeavours.

Newsletters and brochures. Our public awareness unit provides valuable support for global initiatives such as ASB and regional ones such as AHI, by boiling down the wealth of information generated by these research programmes and publishing it in newsletters. We produce and distribute 2 such newsletters: *AHI Updates* and *ASB News.*

But our public awareness push is by no means limited to what is visible from our Nairobi headquarters. In 1996, we also provided important support for regional programmes, putting together informative and handy brochures on activities at specific sites and in regions as a whole. These boost public awareness in the regions themselves, while helping to disseminate information about the regions globally.

Agroforestry in the news. In 1996, agroforestry and ICRAF received a great deal of attention in both the regional—particularly Kenyan—and the international media. In eastern Africa, the media have become one of ICRAF's strongest allies in dispensing public awareness information to the public, putting agroforestry firmly on the national agenda and bringing the science of agroforestry to the attention of farmers and policymakers. Indications of this heightened awareness include the amount of feedback from farmers and requests for planting material of agroforestry species, particularly those that have recently been featured in the media.

Kenya Broadcasting Corporation radio and television have been particularly supportive. Apart from covering various functions—seminars, workshops and international conferences—they carried original material produced by their reporters and virtually all the radio productions that emerge from ICRAF's partnership with the World Radio for the Environment and Natural Resources (WREN) through its Agfax radio documentaries and press releases.

The *Daily Nation*, the *East African Standard* and the *Kenya Times* all carried numerous items on agroforestry and ICRAF. Occasional items on agroforestry and ICRAF also appeared in *The East African*, the *Weekly Review*, the *Economic Review* and the *Agricultural Review* in Kenya, the *Farmers Review* in Zimbabwe, the *Daily Times* in Malawi, the *Swazi News* in Swaziland, and the *World Paper*, which is published in Boston, USA, and appeared as excerpts in more than 20 newspapers across the 5 continents. More technical articles—prepared by ICRAF's own public awareness staff—have appeared in *Scientific American*, the *South African Food Journal* and *Tropicultura*, among others.

Reaching rural people through radio. The partnership between ICRAF and WREN for the production of the Agfax radio interviews and press releases—based on interviews with ICRAF scientists and their collaborators—continued to yield good results. Every month, Agfax released at least

1 interview and 1 press release based on the interview. These were subsequently carried by the British Broadcasting Corporation (BBC) radio and national radio stations throughout Africa and in the Caribbean. Feedback from the stations indicate that the interviews are extremely popular with listeners throughout the continent.

***Fields of trees*—a global audience.** ICRAF's half-hour agroforestry video, *Fields of trees*—and an 18-minute version, *Farming with trees*—produced jointly with the Television Trust for the Environment (TVE), was very well received and widely distributed. Excerpts were aired on BBC World Service, CNN, WTN and a host of other global broadcasters. In 1996, ICRAF distributed over 400 tapes—in English, French and Spanish—to audiences as varied as donors, national and international research institutions, broadcasting stations, universities and training institutions, ambassadors and individual agroforestry practitioners. And this is on top of the many copies that TVE distributed to television stations in dozens of countries. The video, or excerpts of it, continues to be broadcast and cited worldwide.

Visitors—journalists, diplomats and dignitaries

Visitors to ICRAF continue to play a major role in the overall dissemination process of our research results. Many of ICRAF's visitors are the farmers who come to our research station in Machakos and to collaborative research sites within the ecoregions. They are attracted by the promise of agroforestry as a provider of products and services and as a sustainable land-use system. Development and extension workers come also, looking for new and promising agroforestry messages. Researchers, policymakers and students visit, seeking out the new frontiers in agroforestry science.

During the year, the public awareness team escorted more than 15 journalists into the field on visits to agroforestry research sites where ICRAF works with KEFRI and KARI in Kenya. These visits draw the media closer to the scientists, extension staff and farmers and help them to better understand the concept of agroforestry and how research can contribute to environmentally sustainable and economic development.

ICRAF also hosted numerous dignitaries at headquarters and at research sites in Kenya and in the regions. These visits brought together ambassadors, donors, directors of NARS, and ICRAF researchers and management, for high-level consultations and for grassroots visits to farms for frank and lively discussions with farmers using agroforestry.

In 1996, the total number of visitors to ICRAF headquarters increased by 22% while visitors to Machakos research station decreased by about 3%. Visitors in the largest number were students, 46%; next were extension agents, 23%; farmers, 20%; and policymakers and donors, 1% (table 55).

ICRAF seminars

The popular Friday seminar series at ICRAF House in Nairobi continued throughout the year. The topics, though related to agroforestry and

Table 55. Visitors at ICRAF research sites

Ecoregion	Research site	Visitors (no.)
Latin America	ICRAF-Mexico, Chetumal, Quintana Roo	41
Humid tropics of West Africa	ICRAF-IRAD Project, Yaoundé, Cameroon	52
Southeast Asia	ICRAF Southeast Asia Regional Office, Bogor, Indonesia	338
Eastern & central Africa	KARI/KEFRI/ICRAF National Agroforestry Project, Embu, Kenya	503
	KEFRI/KARI/ICRAF/Agroforestry Centre, Maseno, Kenya	410
Sahel	ICRAF Sahelian Programme, Bamako, Mali	53
Southern Africa	Malawi-ICRAF Agroforestry Research Project, Lilongwe	305
	SADC/ICRAF Agroforestry Project—Harare, Zimbabwe	232
	SADC/ICRAF Agroforestry Project—Zomba, Malawi	984
	Zambia-ICRAF Agroforestry project—Chipata	1200
	ICRAF-Shinyanga, Tanzania	44
Global	Machakos Research Station	1357
	Headquarters	512
Total		6031

ICRAF's work, were as diverse as ever, the aim being to broaden the general knowledge base not only in ICRAF's key areas of research. The presenters, ranging from eminent scientists and researchers to students attached to ICRAF, came from all over the world. With diverse topics ranging from specific agroforestry subjects to environmental ones, a total of 71 seminars were presented in 1996. What was new about these seminars in 1996 was the frequent presence of journalists, whose subsequent reports helped disseminate research findings on a range of agroforestry issues to the public at large.

1996 ICRAF staff publications

BOOKS AND BOOK-LENGTH PUBLICATIONS

Bondole LBM. 1996. *Agroforesterie au sahel: bibliographie annotée.* vol. 2. Nairobi: ICRAF. 180 p.

Mackill DJ, Coffman WR, Garrity DP. 1996. *Rainfed lowland rice improvement.* Los Baños, Philippines: IRRI. 242 p.*

Ong CK, Huxley P, eds. 1996. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI. 402 p.

Rudebjer P. 1996. *Directory of international training and educational opportunities in agroforestry.* Nairobi: ICRAF. 164 p.

Sanchez PA, Hailu M, eds. 1996. Alternatives to slash-and-burn agriculture. *Agriculture, Ecosystems and Environment* (special issue) 58(1). Amsterdam, Netherlands: Elsevier. 86 p.

Stewart JL, Allison GE, Simons AJ, eds. 1996. Gliricidia sepium: *genetic resources for farmers.* Oxon, UK: Oxford Forestry Institute. 125 p.*

JOURNAL ARTICLES

Akyeampong E. 1996. The influence of time of planting and spacing on production of fodder and fuelwood in associations of *Calliandra calothyrsus* and *Pennisetum purpureum* on contour bunds in the highlands of Burundi. *Experimental Agriculture* 32:79–85.

Akyeampong E, Dzowela BH. 1996. Fodder production from associations of leguminous shrubs and grasses on contour bunds in the highlands of Burundi. *Tropical Grasslands* 30:330–334.

Akyeampong E, Hitimana L. 1996. Agronomic and economic appraisal of alley cropping with *Leucaena diversifolia* on an acid soil in the highlands of Burundi. *Agroforestry Systems* 33:1–11.

Alegre JC, Cassel DK. 1996. Dynamics of soil physical properties under alternative systems to slash and burn. *Agriculture, Ecosystems and Environment* 58:39–48.

Alegre JC, Pachanasi B, Lavelle P. 1996. Dynamics of soil physical properties in Amazonian agroecosystems inoculated with earthworms. *Soil Science Society of America Journal* 60:1522–1529.

Alegre JC, Rao MR. 1996. Soil and water conservation by contour hedging in the humid tropics of Peru. *Agriculture, Ecosystems and Environment* 57:17–25.

Barrios E, Buresh RJ, Sprent JI. 1996. Nitrogen mineralization in density fractions of soil organic matter from maize and legume cropping systems. *Soil Biology and Biochemistry* 28:1459–1465.

Barrios E, Buresh RJ, Sprent JI. 1996. Organic matter in soil particle size and density fractions from maize and legume cropping systems. *Soil Biology and Biochemistry* 28:185–193.

---

*publications written on work done before staff joined ICRAF.

Beck MA, Sanchez PA. 1996. Soil phosphorus movement and budget after 13 years of fertilized cultivation in the Amazon Basin. *Plant and Soil* 184:23–31.

Cannell MER, van Noordwijk M, Ong CK. 1996. The central hypothesis: trees must acquire resources that the crop would not otherwise acquire. *Agroforestry Systems* 33:27–32.

Chamberlain JR, Galwey NW, Simons AJ. 1996. Population structure in *Gliricidia sepium* (Leguminosae) as revealed by isozyme variation. *Silvae Genetica* 45:112–118.*

Cooper PJM, Leakey RRB, Rao MR, Reynolds L. 1996. Agroforestry and the mitigation of land degradation in the humid and sub-humid tropics of Africa. *Experimental Agriculture* 32:235–290.

Dawson IK, Simons AJ, Waugh R, Powell W. 1996. Detection and pattern of interspecific hybridisation between *Gliricidia sepium* and *G. maculata* in Meso-America revealed by PCR-based assays. *Molecular Ecology* 5:89–98.*

Everaaits AP, de Moel CP, van Noordwijk M. 1996. The effect of nitrogen and the method of application on the nitrogen uptake of cauliflower and on nitrogen in crop residues and soil at harvest. *Netherlands Journal of Agricultural Science* 44:43–55.*

Garrity DP, Pernito R. 1996. Mungbean response to surface drainage when grown as a pre-rice crop on waterlog-prone ricelands. *Agricultural Water Management* 296:299–314.*

Govindarajan M, Rao MR, Mathuva MN, Nair PKR. 1996. Soil-water and root dynamics under hedgerow intercropping in semi-arid Kenya. *Agronomy Journal* 88:513–520.

Hairiah K, Kasniari DN, van Noordwijk M, de Foresta H, Syekhfani MS. 1996. Soil properties, litterfall, above- and below-ground biomass during a *Chromolaena odorata* fallow. *Agrivita* 19:184–192.

Hairiah K, van Noordwijk M, Latief AR. 1996. Soil organic matter fractionation under different land use types in N. Lampung. *Agrivita* 19:146–149.

Hartemink AE, Buresh RJ, Bashir Jama, Janssen BH. 1996. Soil nitrate and water dynamics in sesbania fallows, weed fallows and maize. *Soil Science Society of America Journal* 60:568–574.

Jama BA, Nair PKR. 1996. Decomposition and nitrogen-mineralization patterns of *Leucaena leucocephala* and *Cassia siamea* mulch under tropical semi-arid conditions in Kenya. *Plant and Soil* 179:275–285.

Kiepe P. 1996. Cover and barrier effect of *Cassia siamea* hedgerows on soil conservation in semi-arid Kenya. *Soil Technology* 9:161–171.

Lott JE, Khan AAH, Ong CK, Black CR. 1996. The uptake of lateral tree roots in grevillea/maize agroforestry systems. *Tree Physiology* 16:995–1001.

Maghembe JA, Chirwa PW. 1996. Growth and biomass production of some *Leucaena leucocephala* accessions grown at Makoka, Malawi. *Journal of Tropical Forest Science* 8(4):481–490.

McIntyre BD, Riha SJ, Ong CK. 1996. Light interception and evaporation in hedgerow agroforestry systems. *Agricultural and Forest Meteorology* 81:31–40.

Newton AC, Dick J McP, McBeath C, Leakey RRB. 1996. The influence of R:FR ratio on the growth, photosynthesis and rooting ability of *Terminalia spinosa* Engl. and *Triplochiton scleroxylon* K. Schum. *Annals of Applied Biology* 128:541–556.

Ngulube K, Hall JB, Maghembe JA. 1996. Silviculture of *Uapaca kirkiana* (Euphorbiaceae): an indigenous fruit tree of the miombo woodlands of southern Africa. *Tropical Forest Science* 8(3):393–411.

Niang A, Ugeziwe J, Styger E, Gahamanyi A. 1996. Forage potential of eight woody species: intake and growth rates of local young goats in the highland region of Rwanda. *Agroforestry Systems* 34(2):171–178.

Ofori DA, Newton AC, Leakey RRB, Grace J. 1996. Vegetative propagation of *Milicia excelsa* by leafy stem cuttings: effects of auxin concentration, leaf area and rooting medium. *Forest Ecology and Management* 84:39–48.

Ofori DA, Newton AC, Leakey RRB, Cobbinah JR. 1996. Vegetative propagation of *Milicia excelsa* by root cuttings. *Journal of Tropical Forest Science* 9(1):124–127.*

Pachanasi B, Lavelle P, Alegre J, Carpentier F. 1996. Effect of the endogeic earthworm *Pontoscolex corethrurus* on soil, chemical characteristics and plant growth in a low-input tropical agroecosystem. *Soil Biology and Biochemistry* 28(6): 801–810.

Peden DG, Okorio J, Wajja-Musukwe N. 1996. Commercial pole production in linear agroforestry systems. *Agroforestry Systems* 33:177–186.

Sanchez PA. 1996. Introduction to the special issue on alternatives to slash and burn agriculture. *Agriculture, Ecosystems and Environment* 58(1):1–2.

Sanchez PA, Palm CA. 1996. Nutrient cycling and agroforestry in Africa. *Unasylva* 185(47):24–28.

Schwartz D, de Foresta H, Mariotti A, Balesdent J, Massimba JP, Girardin C. 1996. Present dynamics of the savanna–forest boundary in the Congolese Mayombe: a pedological, botanical and isotopic (^{13}C and ^{14}C) study. *Oecologia* 106:516–524.*

Shepherd KD, Jefwa J, Wilson J, Ndufa JK, Ingleby K, Mbuthia KW. 1996. Infection potential of farm soils as mycorrhizal inocula for *Leucaena leucocephala*. *Biology and Fertility of Soils* 22: 16–21.

Shepherd KD, Ohlsson E, Okalebo JR, Ndufa JK. 1996. Potential impact of agroforestry on soil nutrient budgets at the farm scale in the East African highlands. *Fertilizer Research* 44:87–99.

Shiembo PN, Newton AC, Leakey RRB. 1996. Vegetative propagation of *Gnetum africanum*, a leafy vegetable from West Africa. *Journal of Horticultural Science* 71(1):149–155.*

Shiembo PN, Newton AC, Leakey RRB. 1996. Vegetative propagation of *Irvingia gabonensis:* a West African fruit tree. *Forest Ecology and Management* 87:185–192.*

Sitompul SM, Hairiah K, van Noordwijk M. 1996. Organic matter dynamics after conversion of forests to food crops or sugarcane: prediction of the Century model. *Agrivita* 19:198–206.

Tchoundjeu Z, Leakey RRB. 1996. Vegetative propagation of African mahogany: effects of auxin, node position, leaf area and cutting length. *New Forests* 11:125–136.

Torquebiau EF, Kwesiga F. 1996. Root development in *Sesbania sesban* fallow-maize system in eastern Zambia. *Agroforestry Systems* 34:193–211.

van Noordwijk M. 1996. Decomposition: driven by nature or nurture? *Applied Soil Ecology* 4:1–3.

van Noordwijk M. 1996. Models as part of agroforestry research design. *Agrivita* 19:192–197.

van Noordwijk M, Hairiah K, Guritno B, Sugito Y, Ismunandar S. 1996. Biological management of soil fertility for sustainable agriculture on acid upland soils in Lampung (Sumatra). *Agrivita* 19:131–136.

van Noordwijk M, Lusiana B, Suyanto, Tomich TP. 1996. Soil and other constraints to agricultural production with or without trees in the North Lampung benchmark area of the Alternatives to Slash-and-Burn project. *Agrivita* 19:136–145.

van Noordwijk M, van de Geijn SC. 1996. Root, shoot and soil parameters required for process-oriented models of crop growth limited by water or nutrients. *Plant and Soil* 83:1–25.

BOOK CHAPTERS

Allison GE, Simons AJ. 1996. Propagation and husbandry. *In:* Stewart JL, Allison GE, Simons AJ, eds. Gliricidia sepium: *genetic resources for farmers.* Oxon, UK: Oxford Forestry Institute. p 49–72.*

Dawson IK, Chamberlain J. 1996. Molecular analysis of genetic variation. *In:* Stewart JL, Allison GE, Simons AJ, eds. Gliricidia sepium: *genetic resources for farmers.* Oxon, UK: Oxford Forestry Institute. p 77–91.*

de Foresta H. 1996. Systèmes de culture, adventices envahissantes et fertilité du milieu: le cas de *Chromolaena odorata. In:* Pichot J, Sibelet N, Lacoeuilhe JJ, eds. *Fertilité du milieu et stratégies paysannes sous les tropiques humides.* Montpellier, France: CIRAD-Ministère de la Coopération. p 236–244.

de Foresta H, Michon G. 1996. Etablissement et gestion des agroforêts paysannes en Indonésie: quelques enseignements pour l'Afrique forestière. *In:* Hladik CM, Hladik A, Pagezy H, Linares OF, Koppert GJA, Froment A, eds. *L'alimentation en forêt tropicale—interactions bioculturelles et perspectives de développement.* Vol 2. *Bases culturelles des choix alimentaires et stratégies de développement.* Paris: UNESCO-MAB. p 1081–1101.

Dunsdon AJ, Simons AJ. 1996. Provenance and progeny trials. *In:* Stewart JL, Allison GE, Simons AJ, eds. Gliricidia sepium: *genetic resources for farmers.* Oxon, UK: Oxford Forestry Institute, p 93–118.*

Garrity DP. 1996. Tree-soil-crop interactions on slopes. *In:* Ong CK, Huxley P, eds. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI, p 299–318.

Garrity DP, Singh VP, Hossain M. 1996. Rice ecosystems analysis for research prioritization. Chapter 3. *In:* Evenson RE, Herdt RW, Hossain M, eds. *Rice research in Asia: progress and priorities.* Wallingford, UK: CABI in association with IRRI. p 35–58.*

Gunasena HPM, Simons AJ, Wickremasinghe IP. 1996. Evaluation of *Gliricidia* provenances. *In:* HPM Gunasena, ed. *UP-OFI Forestry Review.* Peradeniya, Sri Lanka: University of Peradeniya. p 97–106.*

Kooistra MJ, van Noordwijk M. 1996. Soil architecture and distribution of organic carbon. *In:* Carter MR, Stewart BA, eds. *Structure and organic carbon storage in agricultural soils.* Advances in Soil Science: vol 24. CRC Lewis Publication. p 15–57.

Levang P, Michon G, de Foresta H. 1996. De la jachère arborée aux agroforêts, des stratégies paysannes adaptées à des milieux de fertilité médiocre. *In:* Pichot J, Sibelet N, Lacoeuilhe JJ, eds. *Fertilité du milieu et stratégies paysannes sous les tropiques humides.* Montpellier, France: CIRAD-Ministère de la Coopération. p 228–235.

Mafongoya PL, Dzowela BH, Nair PK. 1996. Effect of multipurpose trees, age of cutting and drying method on pruning quality. *In:* Cadisch G, Giller KE, eds. *Driven by nature: plant litter quality and decomposition.* Wallingford, UK: CABI. p 167–174.

Michon G, de Foresta H. 1996. Agroforests: an original agroforestry model from smallholder farmers for environmental conservation and sustainable development. *In:* Ishizuka J, Hisajima S, Macer DRJ, eds. *Traditional technology for environmental conservation and sustainable development in the Asian Pacific Region.* UNESCO and Tsukuba University. p 52–58.

Michon G, de Foresta H, Aliadi A. 1996. Damar resins, from extraction to cultivation: an agroforest strategy for forest resource appropriation in Indonesia. *In:* Jain SK, ed. *Ethnobiology in human welfare.* New Delhi: Deep Publications. p 454–459.*

Ong CK. 1996. A framework for quantifying the various effects of tree–crop interactions. *In:* Ong CK, Huxley P, eds. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI. p 1–24.

Ong CK, Black CR, Marshall FM, Corlett JE. 1996. Principles of resource capture and utilization of light and water. *In:* Ong CK, Huxley P, eds. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI. p 73–158.

Pushpakumara DKNG, Simons AJ, Gunasena HPM. 1996. Pollination biology of *Artocarpus heterophyllus. In:* HPM Gunasena, ed. *UP-OFI Forestry Review.* Peradeniya, Sri Lanka: University of Peradeniya. p 49–64.*

Rajaselvam RJ, Simons AJ, Gunasena HPM, Wickremasinghe IP. 1996. Reproductive biology of *Calliandra calothyrsus* in relation to its seed production in Sri Lanka. *In:* HPM Gunasena, ed. *UP-OFI Forestry Review.* Peradeniya, Sri Lanka: University of Peradeniya. p 65–76.*

Sanchez PA. 1996. Foreword. *In:* Ong CK, Huxley P, eds. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI. p ix.

Simons AJ. 1996. Ecology and reproductive biology. *In:* Stewart JL, Allison GE, Simons AJ, eds. Gliricidia sepium: *genetic resources for farmers.* Oxon, UK: Oxford Forestry Institute. p 19–32.*

Simons AJ. 1996. Seed orchards and breeding. *In:* Stewart JL, Allison GE, Simons AJ, eds. Gliricidia sepium: *genetic resources for farmers.* Oxon, UK: Oxford Forestry Institute. p 119–123.*

Simons AJ, Wickremasinghe IP. 1996. Evaluation of *Leucaena* species for biomass production and psyllid resistance. *In:* HPM Gunasena, ed. *UP-OFI Forestry Review.* Peradeniya, Sri Lanka: University of Peradeniya. p 107–118.*

Swift MJ, Vandermeer J, Ramakrishna PS, Anderson JM, Ong CK, Hawkins BA. 1996. Biodiversity and agroecosystem function. *In:* Mooney H, Cushman JH, Medina E, Sala O, Schulze E-D, eds. *Functional roles of biodiversity.* London: Wiley. p 261–280.

van Noordwijk M. 1996. Mulch and shade model for optimum alley-cropping design depending on soil fertility. *In:* Ong CK, Huxley P, eds. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI. p 51–72.

van Noordwijk M, Lawson C, Soumaré A, Groot JJR, Hairiah K. 1996. Root distribution of trees and crops: competition and/or complementarity. *In:* Ong CK, Huxley P, eds. *Tree–crop interactions: a physiological approach.* Wallingford, UK: CABI. p 319–364.

Wickremasinghe IP, Simons AJ. 1996. Differentiation of types of jak (*Artocarpus heterophyllus* Lam.) and neem (*Azadirachta indica* A. Juss) by polyacrylamide gel electrophoresis. *In:* Gunasena HPM, ed. *UP-OFI Forestry Review.* Peradeniya, Sri Lanka: University of Peradeniya. p 77–96.*

PROCEEDINGS

Bahiru Duguma. 1996. Potential for agroforestry in the humid zone of Cameroon. *In:* Lawson GJ, Essame F, eds. *Proceedings of the Regional Seminar on the Regeneration and Protection of Forest,* 16–18 November 1993, Yaoundé, Cameroon. Yaoundé: Ministry of Environment and Forests. p 86–91.

de Foresta H. 1996. *Chromolaena odorata*: calamité ou chance pour l'Afrique tropicale. *In:* Prasad UK, Muniappan R, Ferrar P, Aeschliman JP, de Foresta H, eds. *Distribution, ecology and management of* Chromolaena odorata. Proceedings of the Third International Chromolaena Workshop, November 1993, Abidjan, Côte d'Ivoire. University of Guam Publication No. 202. Mangilao, Guam: University of Guam. p 45–53.

Duguma B, Mollet M. 1996. Provenance evaluation of *Calliandra calothyrsus* in the humid lowlands of Cameroon. *In:* Evans DO, ed. *International Workshop on the genus* Calliandra. Proceedings of workshop, 23–27 January 1996, Bogor, Indonesia. Morrilton, Arkansas: Winrock International. p 147–163.

Garrity DP. 1996. Improved agroforestry technologies for conservation farming: pathways toward sustainability. *In:* Maglinao A, Sajjapongse, eds. *Conservation farming for sloping uplands in Southeast Asia.* Proceedings of a workshop. IBSRAM Proceedings No.14. Bangkok: IBSRAM. p 145–168.

Garrity DP, Bandy D. 1996. A global focus on alternatives to slash-and-burn. *In*: Xu LiYu, Yang YuanZhang and Qin JingHui, eds. *Alternatives to slash-and-burn agriculture.* Proceedings of an international symposium, 6–16 March 1995, KunMing, China. Beijing: China Agricultural Scientech Press. p 52–59.

Kalinganire A, Harwood CE, Simons AJ, Moncur MW, Slee MU. 1996. Reproductive ecology of *Grevillea robusta* in western Kenya. *In:* Dieters MJ, Matheson AC, Harwood CE, Walker SM, eds. *The tree improvement for sustainable tropical forestry.* Proceedings of the QFRI-IUFRO conference, 27 October–1 November 1996, Caloundra, Queensland, Australia. Gympie, Queensland: Queensland Forestry Research Institute. p 238–243.

Leakey RRB. 1996. Capacity building in forestry as a basis for agroforestry research. *In:* International Foundation for Science (IFS). *Supporting capacity building in forestry research in Africa.* Proceedings of the First International Symposium, 28 June–1 July 1994, Nairobi, Kenya. Stockholm: IFS. p 59–68.

Leakey RRB, Izac A-MN. 1996. Linkages between domestication and commercialization of non-timber forest products: implications for agroforestry. *In:* Leakey RRB, Temu AB, Melnyk M, Vantomme P, eds: *Domestication and commercialization of non-timber forest products in agroforestry systems.* Proceedings of an international conference, 19–23 February 1996, Nairobi, Kenya. Non-Wood Forest Products No. 9. Rome: FAO. p 1–7.

Leakey RRB, Temu AB, Melnyk M, Vantomme P, eds. 1996. *Domestication and commercialization of non-timber forest products in agroforestry systems.* Proceedings of an international conference, 19–23 February 1996, Nairobi, Kenya. FAO Non-Wood Forest Products No. 9. Rome: FAO. 298 p.

Mesén F, Leakey RRB, Newton AC. 1996. Propagadores de subirrigación: un sistema simple y económico para la propagación vegetativa de especies forestales. *In:* Salazar R, ed. *Avances en la producción de semillas forestales en América Latina.* Proceedings of a symposium, 16–20 October 1995, Managua, Nicaragua. Turrialba, Costa Rica: CATIE. p 101–110.

Michon G, de Foresta H. 1996. Agroforests as an alternative to pure plantations for domestication and commercialization of NTFPs. *In:* Leakey RRB, Temu AB, Melnyk M, Vantomme P, eds. *Domestication and commercialization of non-timber forest products in agroforestry systems.* Proceedings of an international conference, 19–23 February 1996, Nairobi, Kenya. Non-Wood Forest Products No. 9. Rome: FAO. p 160–175.

Nielsen F. 1996. Methods for integrating indigenous knowledge and formal research in agroforestry. *In:* Kristensen NH, Høgh-Jensen H, eds. *New research in organic agriculture: down to earth—and further afield.* Proceedings of the 11th International Scientific IFOAM Conference, 11–15 August 1996, Copenhagen. vol 2. Tholey-Theley, Germany: IFOAM. p 117–122.

O'Neill MK, Okoba BO. 1996. Agroforestry and soil conservation in the central Kenyan highlands. *Agronomy Abstracts.* 88th American Society of Agronomy Meeting, 3–8 November 1996, Indianapolis, Indiana, USA. Madison, Wisconsin: American Society of Agronomy. p 44.

Oswald A, Frost H, Ransom JK, Kroschel J, Shepherd K, Sauerborn J. 1996. Studies on the potential for improved fallow using trees and shrubs to reduce striga infestations in Kenya. *In:* MT Moreno, Cobero JI, Berner D, Joel D, Musselman LJ, Parker C, eds. *Advances in parasitic plant research.* Congresos y Jornada 36/96. Proceedings of the Sixth International Parasitic Weed Symposium, 16–18 April 1996, Cordoba, Spain. Cordoba, Spain: Junta de Andalucía, Consejería de Agricultura y Pesca. p 796–800.

Paterson RT, Roothaert RL, Nyaata OZ, Akyeampong E, Hove L. 1996. Experience with *Calliandra calothyrsus* as a feed for livestock in Africa. *In:* Evans DO, ed. *International workshop on the genus* Calliandra. Proceedings of a workshop, 23–27 January 1996, Bogor, Indonesia. Morrilton, Arkansas: Winrock International. p 195–209.

Place F, ed. 1996. *Améliorer l'élaboration de politiques relatives à la gestion de ressources naturelles et des écosystèmes en Afrique subsaharienne.* Résultats d'une réunion d'experts tenue au Centre international pour la recherche en agroforesterie, 2–6 octobre 1995, Nairobi, Kenya. Nairobi: ICRAF and UNEP, 56 p.

Place F, ed. 1996. *Toward improved policy making for natural resources and ecosystem management in sub-Saharan Arica.* Results of a consultation meeting, 2–6 October 1995, Nairobi, Kenya. Nairobi: ICRAF and UNEP, 48 p.

Prasad UK, Muniappan R, Ferrar P, Aeschliman JP, de Foresta H, eds. 1996. *Distribution, ecology and management of* Chromolaena odorata. Proceedings of the Third International Chromolaena Workshop, November 1993, Abidjan, Côte d'Ivoire. University of Guam Publication No. 202. Mangilao, Guam: University of Guam.

Sanchez PA, Izac A-MN, Valencia I, Pieri C. 1996. Soil fertility replenishment in Africa. *In:* Breth SA, ed. *Achieving greater impact from research investments in Africa.* Proceedings of a workshop, 26–30 September 1996, Addis Ababa, Ethiopia. Mexico City: Sasakawa Africa Association. p 200–209.

Sanchez PA, Leakey RRB. 1996. Land use transformation in Africa: three imperatives for balancing food security with natural resource conservation. *In:* van Ittersum MK, Venner GEGT, van de Geijn SC, Jetteron TH, eds. *Book of abstracts.* 4th Congress of the European Society of Agronomy, 7–11 July 1996, Veldhoven, Netherlands, p 2–3.

Scott RB. 1996. ICRAF's role in capacity building in forestry research. *In:* International Foundation for Science (IFS). *Supporting capacity building in forestry research in Africa.* Proceedings of the 1st International Symposium, 23 June–1 July 1994, Nairobi, Kenya. Stockholm: IFS. p 87–104.

Simons AJ. 1996. Delivery of improvement for agroforestry trees. *In:* Dieters MJ, Matheson AC, Nikles DG, Hardwood CE, Walker SM, eds. *Tree improvement for sustainable tropical forestry.* Proceedings of the QFRI-IUFRO Conference, 27 October–1 November 1996, Caloundra, Queensland, Australia, Gympie, Queensland: Queensland Forestry Research Institute. p 391–400.

Simons AJ. 1996. ICRAF's strategy for domestication of non-wood forest products. *In:* Leakey RRB, Temu AB, Melnyk M, Vantomme P, eds. *Domestication and commercialization of non-timber forest products in agroforestry systems.* Proceedings of an international conference, 19–23 February 1996, Nairobi, Kenya. Non-Wood Forest Products No. 9. Rome: FAO. p 8–22.

Tchoundjeu Z. 1996. Vegetative propagation of Sahelian agroforestry tree species: *Prosopis africana* and *Bauhinia rufescens. In:* Dieters MJ, Matheson AC, Nikles DG, Hardwood CE, Walker SM, eds. *Tree improvement for sustainable tropical forestry.* Proceedings of the QFRI-IUFRO Conference, 27 October–1 November 1996, Caloundra, Queensland, Australia. Gympie, Queensland: Queensland Forestry Research Institute. p 416–420.

Tchoundjeu Z, Gerry LG. 1996. Prime au reboisement privé: mythe ou realité? *In:* Essame F, Lawson GJH, eds. *Proceedings of a regional seminar on the regeneration and protection of forests,* 16–18 November 1993, Yaoundé, Cameroon. Yaoundé: Ministry of Environment and Forests. p 21–24.

Temu AB. 1996. African forestry: leading research issues and constraints. *In:* International Foundation for Science. *Supporting capacity building in forestry research in Africa.* Proceedings of the First International Symposium, 28 June–1 July 1994, Nairobi, Kenya. Stockholm: IFS. p 29–36.

Temu AB. 1996. Global forest resources assessments beyond 2001: integrated resource databases—an emerging approach. *In:* Päivínen R, Vanclay J, Saija Miina, eds. *New thrusts in forest inventory.* Proceedings of the Subject Group S4.02-00, Forest Resource Inventory and Monitoring, and Subject Group S4.12-00, Remote Sensing Technology. Vol. 1. IUFRO 20th World Congress, 6–18 August 1995, Tampere, Finland. Tampere: IUFRO, CIFOR, EFI. p 251–259.

Thomas DE. 1996. Opportunities and limitations for agroforestry systems in the highlands of north Thailand. *In:* Turkelboom F, van Look-Rothschild K, van Keer K, eds. *Highland farming: soil and the future.* Proceedings of a conference, 21–22 December 1995, Chiang Mai, Thailand. Chiang Mai: Soil Fertility Conservation Project, Maejo University and Catholic University of Leuven. p 126–160.

Tomich TP. 1996. Market, policies and institutions in NTFP trade: nothing is perfect. *In:* Leakey RRB, Temu AB, Melnyk M, Vantomme P, eds. *Domestication and commercialization of non-timber forest products in agroforestry systems.* Proceedings of an international conference, 19–23 February 1996, Nairobi, Kenya. Non-Wood Forest Products No. 9. Rome: FAO. p 235–255.

Tomich TP, van Noordwijk M. 1996. What drives deforestation in Sumatra? *In:* Rerkasem B, ed. *Montane mainland Southeast Asia in transition.* Proceedings of an international symposium, 12–16 November 1995, Chiang Mai University, Thailand.

REPORTS

Atta-Krah K, Wakhu P. 1996. Agroforestry Research Networks for Africa—Eastern and Central Africa: annual report 1995 and research plans 1996. Based on the proceedings of the AFRENA-ECA annual review and planning workshop, 5–8 February 1996, Ukweli Pastoral Centre, Kiboswa, Kenya. 103 p.

Atta-Krah K, Wakhu P, comps. 1996. Proceedings of AHI-Kenya Research Planning Workshop, 18–20 March 1996, Embu, Kenya. 65 p.

Atta-Krah K, Wakhu P, comps. 1996. Proceedings of AHI-Uganda Research Planning Workshop, 4–7 September 1995, Kabale, Uganda. 71 p.

Atta-Krah K, Wakhu P. 1996. comps. Proceedings of AHI-Ethiopia Research Planning Workshop, 23–26 January 1996, Nazareth, Ethiopia. 50 p.

den Biggelaar C. 1996. Linking actors in the agricultural knowledge system in Embu District. AFRENA Report 103. 64 p.

Djimdé M. 1996. Systems improvement research in the semi-arid lowlands of West Africa: 1996 report. AFRENA Report 107. 40 p.

Duguma B, Degrande A, Kanmegne J, Bayomock LA, Assah E. 1996. IRA/ICRAF Agroforestry Project. Annual Report 1996.

Dzowela BH, Mafongoya PL, Hove L, Burgers PM. 1996. SADC-ICRAF Agroforestry Project, Zimbabwe. Annual Report 1996.

Franzel S, Jaenicke H, Janssen W. 1996. Choosing the right trees: setting priorities for multipurpose tree improvement. ISNAR Research Report No. 8. The Hague: ISNAR.

Garrity DP, Glynn C, Banaynal R. Buffer zone management and agroforestry. Summary report of a National Workshop. ICRAF-Philippines.

Guinand Y. 1996. A method to help select farmers for on-farm agroforestry trials, based on wealth ranking: examples from Uganda. AFRENA Report 102. 33 p.

Guinand Y. 1996. Impact assessment study of Two-Wing Agroforestry Groups, Kabale District, Uganda. Part 2. Agroforestry activities. AFRENA Report 101. 42 p.

Kasolo W, Niemelä R, Monare L, Rudebjer P. 1996. Integrating agroforestry into agriculture curriculum: the case of Lesotho Agricultural College. Proceedings of a curriculum review workshop, 3–7 April 1995, Lesotho Agricultural College, Leribe, Lesotho. Training and Education Report 37. 40 p.

Kwesiga F, Phiri D, Simwanza PC. 1996. Zambia–ICRAF Agroforestry Research Project: 1996 annual report. AFRENA Report 104. 90 p.

Minae S. 1996. Participatory farmer evaluation of organic matter technologies to enhance productivity and sustainability based on a micro-watersheds systems approach in selected countries of southern Africa. *In:* Research results and network outputs in 1994 and 1995, Harare, Zimbabwe.

Ngugi D. 1996. Agroforestry for sustainable rural development in the Zambezi Basin: project management plan. 60 p.

Niang AI, Amadalo BA, Gathumbi SM, Otieno JHO, Obonyo CO, Obonyo E. 1996. KEFRI/KARI/ICRAF AFRENA Maseno Project: progress report September 1995–September 1996. AFRENA Report 109. 110 p.

Okech SHO, Gold CS. 1996. Relationships of the banana weevil with its host plant and soil fertility: literature review with emphasis on studies in eastern and central Africa. AHI Technical Report Series No. 2. 22 p.

O'Neill M, Gachanja S, Karanja G, Kariuki I, Kanampiu F, Kiruiro E, Muriithi F, Okoba B, Nyaata Z, Mwangi J, Tuwei P, Roothaert R, Paterson R. 1996. National Agroforestry Research Project. KARI Regional Research Centre—Embu: annual report March 1995–March 1996. AFRENA Report 108. 92 p.

Otsyina R, Asenga D, Ngazi H, Mumba M. 1996. Tanzania–ICRAF Agroforestry Project, Shinyanga: 1996 annual report. AFRENA Report 106. 66 p.

Otsyina R, Msangi R, Gama B, Ramadhani T, Madulu J, Shirima D, Mapunda H. 1996. SADC-ICRAF Agroforestry Research Project, Tumbi, Tabora, Tanzania: 1996 annual report. AFRENA Report 105. 126 p.

Rudebjer P, Madoffe SS, Temu AB. 1996. Agroforestry education in Tanzania. Proceedings of a subregional workshop, 4–6 December 1995, Sokoine University of Agriculture, Morogoro, Tanzania. Training and Education Report 39. 78 p.

Rudebjer P, Quashie-Sam SJ. 1996. Postgraduate agroforestry education in Ghana. Proceedings of a curriculum development review workshop, 20–23 June 1995, University of Science and Technology, Kumasi, Ghana. Training and Education Report 36. 48 p.

Sall PN. 1996. Les parcs agroforestiers au Senegal: état des connaissances et perspectives. AFRENA Report 100. 148 p.

Simons AJ, Dunsdon AJ, Dawson IK, Stewart JL. 1996. Genetic improvement of non-industrial trees—final report. ODA FRP Project R4856, Oxford Forestry Institute, UK, 49 p.*

Temu AB, Rudebjer P, Zulberti E, eds. 1996. *Integrated land-use education in Africa: towards the 21st century.* Proceedings of the 2nd general meeting of the African Network for Agroforestry Education, 24–25 July 1995, Nairobi, Kenya. Training Report 38. 26 p.

Tomich TP, van Noordwijk M. 1996. A journey of discovery: guide for ASB field trip, 25–27 May 1996, Jambi, Sumatra, Indonesia. ASB Indonesia Report 5. 68 p.

Tyndall B. 1996. The socioeconomics of *Grevillea robusta* within the coffee land-use system of Kenya. AFRENA Report 109. 87 p.

Zoungrana I, Temu AB. 1996. L'agroforesterie et l'enseignement des systemes d'utilisations et de gestion des terres en Afrique de l'Ouest. Compte rendu du ler atelier regional sur l'education en agroforesterie, 15–19 August 1994, ENSA-Thiés, Senegal. Training and Education Report 34. 98 p.

Zoungrana I, Temu AB. 1996. Land-use education in Africa: a comparative study on educational systems. Training and Education Report No. 35. 60 p.

POPULAR PRESS

Cairns M. 1996. Study of farmer management of wild sunflower, *Tithonia diversifolia. ILEIA Newsletter* 12(2):31.

de Foresta H, Michon G. 1996. Tree improvement research for agroforestry: a note of caution. *Agroforestry Forum* 7(4):8–10.

Hove L, Chakoma C, Dzowela BH. 1996. Comparative evaluation of *Leucaena diversifolia* L. *pallida* syn. *L. esculenta* spp. *paniculata* and *L. leucocephala* cv Cunningham as supplements to veld hay. *Leucaena News* 5:24–28.

Khan AAH, Ong CK. 1996. A low cost heat pulse method for measuring tree root water uptake. *Agroforestry Forum* 7(2):19–22.

Leakey RRB. 1996. Definition of agroforestry revisited. *Agroforestry Today* 8(1):5–7.

Leakey RRB. 1996. Domestication and commercialization of non-timber forest products in agroforestry systems. Conference report. *Agroforestry Forum* 7(4):23–25.

Leakey RRB, Ladipo DO. 1996. Trading on genetic variation—fruits of *Dacryodes edulis. Agroforestry Today* 8(2):16–17.

Niang A, Amadalo B, Gathumbi S. 1996. Green manure from the roadside. *Miti Ni Maendeleo* 2(1):10.

Rao M R, Govindarajan M. 1996. Agroforestry field experiments: controlling interference among plots. *Agroforestry Today* 8(1):15–18.

Sanchez PA, Palm CA. 1996. Nitrogen and phosphorus in African soils—what role for agroforestry? *Agroforestry Today* 8(4):14–17.

Simons T, Kindt R. 1996. Agroforestry trees: to domesticate or not to domesticate? *Agroforestry Forum* 7(4):5–7.

van Noordwijk M, Ong CK, Buresh RJ. 1996. Current root research at ICRAF. *Agroforestry Forum* 7(2):10–18.

PERIODICALS

CATIE, ICRAF. 1996. *Agroforestería en las Américas,* vol 3.

ICRAF. 1996. *African Highlands Initiative Update*, vol 2, no 1–3.

ICRAF. 1996. *Agroforestry Education News* 3:1.

ICRAF. 1996. *Agroforestry Today,* vol 8, no 1–4.

ICRAF. 1996. GTZ-KEFRI-KARI-ICRAF. *Miti Ni Maendeleo*, vol 2, no 1–3.

ICRAF. 1996. *ICRAF Updates,* no 6–11.

BROCHURES

ICRAF. 1996. *Agroforestry—at the service of farmers and the environment.* 24 p (English, French and Spanish).

ICRAF. 1996. *Agroforestry in the Sahel of West Africa.* 12 p (English and French).

OTHERS

Calvo J, Haggar JP, Aroyo PJ, eds. 1996. *Memoria del primer taller nacional sobre especies forestales nativas.* Cartago, Costa Rica: ITCR. 71 p.

ICRAF. 1996. *ICRAF staff list April 1996.* 120 p.

Rarieya M, Muraya P, Wanjohi P, Coe R. 1996. Experiments Database, version 2.1. Software manual. ICRAF. 48 p.

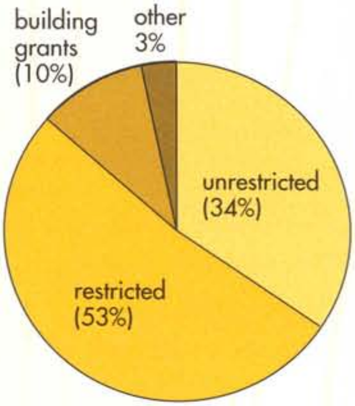
Financial statements for 1996

REVENUE AND EXPENDITURE ACCOUNT

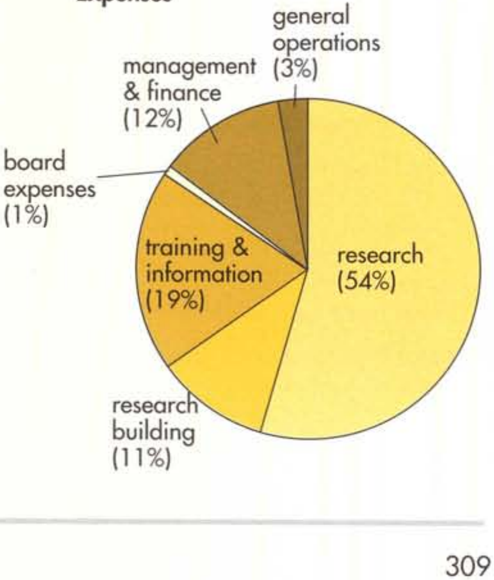
for the year ended 31 December 1996

	1996 USD '000	1995 USD '000
Revenue		
Unrestricted core grants	6 919	7 632
Restricted projects grants	10 460	8 475
Building grants	2 081	2 261
Other	684	515
Total revenue	**20 144**	**18 883**
Expenses		
Research	10 574	10 167
Research building	2 081	2 261
Training and information	3 751	3 514
Board expenses	175	163
Management and finance	2 310	2 021
General operations	523	903
Total operating expenses	**19 414**	**19 029**
Surplus/(deficit)	**730**	**(146)**
Allocated as follows:		
Operating fund	730	(146)
Balance at 31 December	**730**	**(146)**
Memo item **Operating expenses by object of expenditure**		
Personnel costs	10 535	10 911
Courses and workshops	1 340	1 378
Operational travel	1 008	786
Supplies and services	3 616	2 700
Capital development	2 081	2 261
Depreciation of fixed assets	834	993
Total operating expenses	**19 414**	**19 029**

Revenue



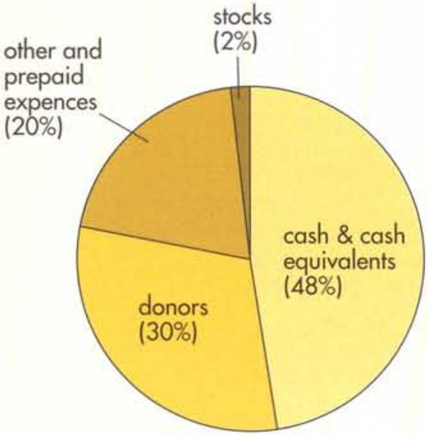
Expenses



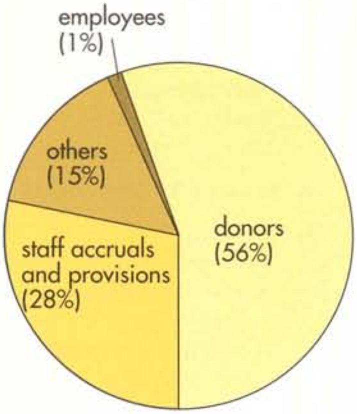
BALANCE SHEET
as at 31 December 1996

	1996 (USD '000)	1995 (USD '000)
Assets		
Current assets		
Cash and cash equivalents	4 985	3 495
Accounts receivable:		
Donors	3 202	2 279
Others and prepaid expenses	2 126	851
Stocks	174	194
Total current assets	**10 487**	**6 819**
Fixed assets		
Property, plant and equipment	9 659	9 188
Less: Accumulated depreciation	7 687	6 922
Total fixed assets—net	**1 972**	**2 266**
Capital work-in-progress	4 342	2 261
Total assets	**16 801**	**11 346**
Liabilities and fund balances		
Current liabilities		
Accounts payable		
Donors	4 548	2 803
Employees	24	81
Others	1 204	792
Staff accruals and provisions	2 290	1 643
Total current liabilities	**8 066**	**5 319**
Fund balances		
Capital invested in fixed assets	6 314	4 527
Capital fund	654	327
Building fund	493	629
Operating fund	1 274	544
Total fund balances	**8 735**	**6 027**
Total liabilities and fund balances	**16 801**	**11 346**

Assets



Liabilities & fund balances



SCHEDULE OF GRANT REVENUE

Unrestricted core grants

	1996 (USD '000)	**1995** (USD '000)
World Bank	1 500	1 340
Netherlands	893	949
Denmark	558	531
Switzerland	509	445
Japan	456	589
Canada	437	446
Sweden	430	232
Norway	387	748
United States	350	350
Germany	331	352
Ford Foundation	300	300
Finland	274	168
Austria	180	180
Ireland	172	166
Australia	112	112
Spain	30	0
India	0	500
France	0	94
Indonesia	0	50
Brazil	0	35
Mexico	0	25
Food and Agricultural Organization of the United Nations (FAO)	0	20
Total unrestricted core grants	**6 919**	**7 632**

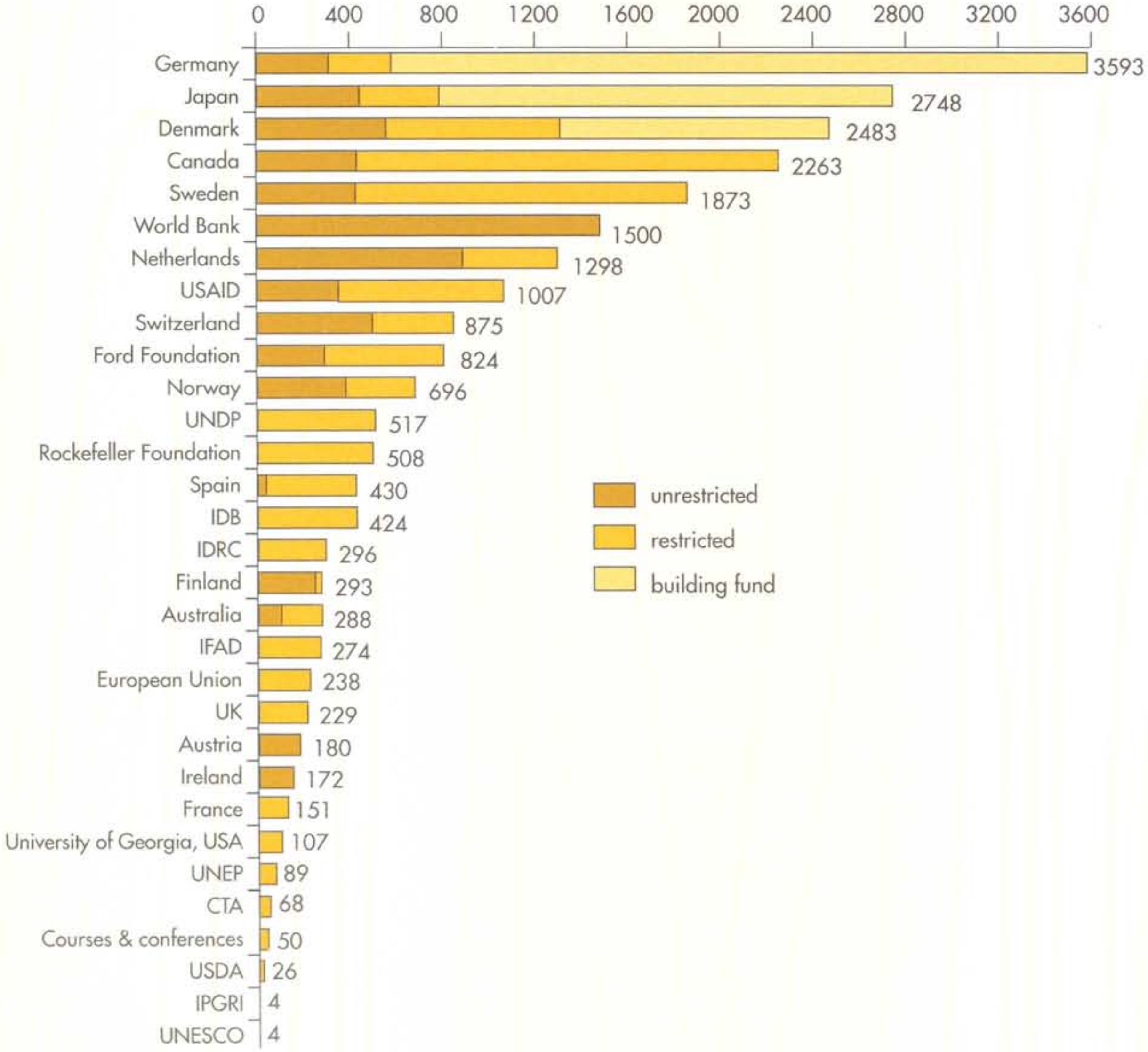
SCHEDULE OF GRANT REVENUE

Restricted core grants

	1996 (USD '000)	1995 (USD '000)
Canada	1 826	1 738
Sweden	1 443	1 538
Denmark	752	211
United States Agency for International Development (USAID)	657	721
Ford Foundation	524	221
United Nations Development Programme (UNDP)	517	198
Rockefeller Foundation	508	682
Interamerican Development Bank (IDB)	424	375
Netherlands	405	307
Spain	400	0
Switzerland	366	262
Japan	342	254
Norwegian Agency for Development Cooperation (NORAD)	309	242
International Development Research Centre (IDRC)	296	185
International Fund For Agricultural Development (IFAD)	274	368
Germany	256	690
European Union	238	0
United Kingdom	229	158
Australia	176	26
France	151	0
University of Georgia, USA	107	45
United Nations Environment Programme (UNEP)	89	115
Centre Technique de Cooperation Agricole et Rurale (CTA)	68	43
Course and conference participants	50	8
United States Department of Agriculture (USDA)	26	0
Finland	19	0
United Nations Educational, Scientific and Cultural Organization (UNESCO)	4	0
International Plant Genetic Resources Institute (IPGRI)	4	0
World Bank	0	58
Commonwealth Scientific and Industrial Research Organization (CSIRO)	0	28
Land Tenure Center, University of Wisconsin, USA	0	2
Total core restricted	**10 460**	**8 475**
Total core unrestricted and restricted	**17 379**	**16 107**

DONOR CONTRIBUTION

Unrestricted, restricted and building fund (USD '000)



IN-KIND CONTRIBUTION

Several countries second their nationals to work in various ICRAF programmes, covering the full costs of their salaries and benefits. In 1996, the countries and the values of their in-kind contribution, calculated on the basis of the standard costs of staff salaries and benefits, were France (USD 800 000), the Netherlands (USD 499 968), Belgium (USD 428 544), Denmark (USD 71 424), Sweden (USD 71 424), and the United States of America (USD 71 424).

BUILDING FUND

The governments of Germany, Japan and Denmark have contributed to a building fund that has been set up to expand the physical facilities at ICRAF. The expansion comprises rehabilitation of the ICRAF road, an extension of ICRAF House, new research laboratories and a germplasm resource unit.

	1993 USD '000	1994 USD '000	1995 USD '000	1996 USD '000	Pledged USD '000	Total USD '000
Germany	–	–	945	1003	1058	3006
Japan	–	647	720	583	–	1950
Denmark	374	440	–	359	–	1173
Total	**374**	**1087**	**1665**	**1945**	**1058**	**6129**

1996 agreements

ACIAR—for ICRAF to review ACIAR research project Improvement in Tree Establishment for Tropical Dryland Conditions in East Africa, Australia, Zimbabwe and Kenya (23 January)

ACIAR—in which ACIAR supports research on competitive interactions of trees, crops and pastures for water by agroforestry systems in Kenya and Australia (6 February)

Boehringen Ingelheim KG, Germany—for an assessment of the natural distribution and sustainability of harvesting practices of *Pausinystalia johimbe* (26 November)

Bogor University of Agriculture, Indonesia—for cooperation in the pursuit of educational and research objectives (7 February)

Caisse française de développement, France—to support research on sustainable alternatives to slash-and-burn agriculture (3 June)

Canadian government—to support the Agroforestry for Sustainable Rural Development Project in the Zambezi River Basin (22 March)

CIRAD-CA—for a collaborative worldwide research project to reduce the rate of tropical deforestation driven by slash-and-burn agriculture and to advance the reclamation of degraded lands

CTA—for collaboration in organizing and running a training course on the management of an agricultural selective dissemination of information service (15 May)

FIMP-INTAG of the EU-IFSSP (Forest Inventory and Monitoring Project—Inventarisasi dan Tata Guna Hutan), Jakarta, Indonesia—for collaborative research in land use and forest mapping in Indonesia (19 August)

Flemish Office for Development Cooperation and Technical Assistance (VVOB), Belgium—stipulating the terms and conditions under which VVOB associates will work at ICRAF (4 July)

Forestry institutions in the central, eastern and southern Africa region—to establish the Tree Pest Management Network for Central, Eastern and Southern Africa, with the objective of containing the damage caused by pests to trees and forest products in the region (November 1996)

Forestry Research Institute of Uganda—covering field surveys of about 240 households in 4 selected parishes in Uganda (26 March)

IFPRI—for cooperation in identifying topics of mutual interest for collaborative research and for strengthening capability in each centre through exchange of ideas and technologies (3 January)

IFPRI—covering intensive surveys of farm households in the savanna areas of Uganda (31 January)

IFPRI—covering household surveys in Rantau Pandan and Kerinci Districts of Indonesia (21 June)

IFPRI—covering an extensive survey of 60 parishes in Malawi (27 June)

ILRI—for collaborative research activities (31 January)

Indonesian Rubber Research Institute—for collaborative research programmes (18 June)

Indonesian Rubber Research Institute, ProRLK Project (West Sumatra), Dinas Perkebunan of West Sumatra Province, Dinas Pertanina of West Sumatra Province and the Rubber Association of Indonesia (GAPKINDO)—for a joint project to identify appropriate smallholder rubber agroforestry systems in selected locations of the Pasaman District, Indonesia (19 August)

Interamerican Development Bank—in which the bank agrees to support research in agriculture and natural resources management and sustainable agroforestry systems for the humid tropics (10 May)

IPGRI—for collaborative activities in relation to the project Handling and Storage of Recalcitrant and Intermediate Forest Tree Seeds (19 July)

Kenya government—ICRAF Country Agreement (13 May)

Kingdom of Thailand government—for collaboration to generate agroforestry technologies for Thailand and to strengthen the capacity of Thailand scientists to undertake agroforestry research and training (21 October)

Netherlands Ministry for Development Cooperation—in which the minister commits to support associate experts to work with ICRAF programmes (23 August)

ORSTOM—assigning a scientist to conduct research on plant ecology for modelling damar resin producing agroforests in Southeast Asia (5 July)

ORSTOM—extending the period of assignment of 2 scientists based in Indonesia working with the project Alternative Strategies for Forest Resource Development: Extractivism, Agroforestry or Plantations (5 July)

Rubber Association of Indonesia (GAPKINDO) **and Indonesian Rubber Research Institute**—to conduct a joint smallholder rubber agroforestry programme on sustainable rubber cropping systems (18 June)

State Secondary of Technical Agriculture School (SMTP), **Muara Bungo, Jambi, Indonesia**—for cooperation in agricultural research (26 May)

TSBF—in which TSBF undertakes to implement the components of the ASB Programme that focus on the climate change and soil biodiversity implications of alternative land-use practices and on the linking of environmental benefits to sustainable alternatives to slash-and-burn agriculture (1 January)

Board of Trustees

MEMBERS

Chair	David B Thorud (USA) (elected March 1992, as Chair in March 1994)
Vice Chair	Yemi Katerere (Zimbabwe) (elected March 1994, as Vice Chair in 1996)
	G Sten Ebbersten (Sweden) (elected March 1991; retired April 1996)
	Pedro A Sanchez (USA), ex-officio (appointed October 1991)
	Otto von Grotthuss (Germany) (elected October 1991)
	Edward W Tyrchniewicz (Canada) (elected March 1992)
	Uraivan Tan-Kim-Yong (Thailand) (elected April 1992)
	Bo M I Bengtsson (Sweden), ex-officio (appointed August 1992)
	Maria de Lourdes Davies de Freitas (Brazil) (elected April 1993)
	Minoru Kumazaki (Japan) (elected April 1993)
	Moise Mensah (Benin) (elected April 1993)
	J Matthijs Heering (Netherlands) (elected March 1994)
	Wellington K Ngulo (Kenya) (elected March 1994)
	Neil C Turner (Australia) (elected March 1994)
	Anette Reenberg (Denmark) (elected April 1996)

Secretary	R Bruce Scott

MEETINGS DURING 1996

Board of Trustees	28th meeting, 16–19 April 1996
	29th meeting, 10–13 December 1996
Executive/Finance Committee	9–11 September 1996
Audit Committee	7th meeting, 18 April 1996
Nominations Committee	10th meeting, 18 April 1996

ICRAF staff

OFFICE OF THE DIRECTOR GENERAL

Professional

Name (nationality) Position/discipline	Station (*left in 1996)
Pedro A Sanchez (USA) Director General	Nairobi
R Bruce Scott (Canada) Deputy Director General	Nairobi
Madeleine Shearer (UK) Projects Officer	Nairobi
Godfrey W Waweru (Kenya) Internal Auditor	Nairobi
George Mbiriri (Kenya) Protocol Officer	Nairobi
Christine Kalume (UK) Assistant to the Director General (Consultant)	Nairobi

Support

Name (nationality) Position/discipline	Station (*left in 1996)
Jane Waweru, Personal Assistant	Nairobi
Marion Kihori, Principal Secretary	Nairobi
Judith Mghalu, Secretary	Nairobi
Josephine Maina, Secretary	Nairobi

RESEARCH DIVISION

Office of the Director and Research Support

Professional

Name (nationality) Position/discipline	Station (*left in 1996)
Roger RB Leakey (UK) Director of Research	Nairobi
David N Ngugi (Kenya) Regional Coordinator, Southern Africa Regional Programme	Lilongwe
Bahiru Duguma (Ethiopia) Regional Coordinator, Humid West Africa Regional Programme	Yaoundé
Dale E Bandy (USA) Regional Coordinator, Latin America Regional Programme	Nairobi
Dennis P Garrity (USA) Regional Coordinator, Southeast Asia Regional Programme	Bogor
Kwesi Atta-Krah (Ghana) Regional Coordinator, Eastern and Central Africa Regional Programme, and Coordinator, African Highlands Initiative	Nairobi
Edouard Bonkoungou (Burkina Faso) Regional Coordinator, Sahelian Regional Programme	Samanko
Richard Coe (UK) Principal Statistician	Nairobi
Ahmed Khan (India) Electronics Engineer	Nairobi
Peter K Muraya (Kenya) Associate Scientist	Nairobi
Paul C Smithson (USA) Laboratory Manager	Machakos
Geeta Hasham (Kenya) Division Administrator	Nairobi*
Patrick Wanjohi (Kenya) Associate Research Officer	Nairobi
Marie Rarieya (Kenya) Associate Data Processing Officer	Nairobi
Jane Rubia (Kenya) Division Administrator	Nairobi
Patrick Wakhu (Kenya) Research Assistant	Nairobi
Philip Ndungu (Kenya) Accounts Officer	Maseno
Raymond (Chip) Rowe (UK) Coordinator, Systemwide Alternatives to Slash-and-Burn Programme (Consultant)	Nairobi
Catherine Kenyatta (UK) Assistant to the Coordinator, Systemwide Alternatives to Slash-and-Burn Programme (Consultant)	Nairobi

Name (nationality) Position/discipline	Station (*left in 1996)
Support	
Halima Abdalla, Personal Assistant	Nairobi
Claire Momoh, Senior Bilingual Secretary	Nairobi
Genevieve Pevoubou, Administrative Assistant	Yaoundé
Josephine Prasetyo, Administrative Assistant	Bogor
Joyce Somba, Administrative Assistant	Lilongwe
Glorilyn Acaylar, Administrative Assistant	Los Baños
Judith Njagi, Senior Secretary	Nairobi
Joyce Kasyoki, Senior Secretary	Nairobi
Susilowati Surachman, Senior Secretary	Bogor
Evalyn Amara, Administrative Secretary	Nairobi
Jennie Paz, Administrative Secretary	Lima
Malick Diabate, Secretary	Bamako
Charles Fonkem, Secretary	Yaoundé*
Rike Safitri, Accountant	Bogor
Felipe Castillo, Purchaser	Lima
Peter Mbiti, Laboratory Technician	Machakos
John Kimungunyi, Instruments Technician	Machakos
Mailu Muthoka, Instruments Technician	Machakos
Peter Mbugua, Laboratory Technician	Machakos
Samuel Bosire, Data Entry Specialist	Nairobi
Daniel Kubasu, Laboratory Technician	Machakos
Henry Musasia, Laboratory Assistant/Driver	Machakos
Marco Castillo, Driver	Lima
Paul Mutisya, Assistant Laboratory Attendant	Machakos
Martin Mkumbadzala, Driver	Lilongwe*
Andrew Nebaso, Driver	Yaoundé
John Fuh Angweneh, Driver	Yaoundé
Suparman Supardi, Driver	Bogor
Sutarja, Driver	Bogor
Muslihuddin Sharbinie, Office Assistant	Bogor
Armansyah, Office Aide	Bogor
Nestor Sanchez, Field Assistant	Los Baños
Catherine Kasinja, Tea Lady/Cleaner	Lilongwe
Namake Diallo, Driver	Samanko
Sekou Dembele, Watchman	Samanko

PROGRAMME 1: NATURAL RESOURCES STRATEGIES AND POLICY

Professional

Name (nationality) Position/discipline	Station (*left in 1996)
Anne-Marie Izac (France) Programme Coordinator	Nairobi
Susan Minae (Kenya) Senior Agricultural Extension Specialist	Chitedze
Keith Shepherd (UK) Senior Systems Agronomist	Nairobi
Thomas P Tomich (USA) Senior Natural Resource Economist	Bogor
David F Thomas (USA) Senior Policy Analyst	Chiang Mai
Jamie Wyant (USA) Senior Ecologist	Nairobi*
Frank Place (USA) Economist	Nairobi
Elias Ayuk (Cameroon) Agricultural Economist	Samanko
John Corbett (USA) Agroecologist	Nairobi*
Hubert de Foresta (France) Senior Ecologist	Bogor
Genevieve Michon (France) Senior Ethnobotanist	Bogor
Jacques Imbernon (France) Senior Remote Sensing Scientist	Nairobi
Meredith J Soule (USA) Economist	Nairobi
Katherine Snyder (USA) Postdoctoral Research Fellow	Nairobi*
Eve Crowley (USA) Postdoctoral Research Fellow	Nairobi*
Yves Guinand (Switzerland) Associate Geographer	Kabale*
Shigeru Iida (Japan) Associate Agricultural Economist	Nairobi*
Hans Sjögren (Sweden) Associate Forester	Maseno*
Erika C van Duijl (Netherlands) Associate Forester	Kabale
Pornwilai Saipothong (Thailand) Associate Research Officer	Chiang Mai
Eric Muchugu (Kenya) Assistant Research Officer	Nairobi
Ricardo A Labarta (Peru) Natural Resources Economist	Yurimaguas
Ann Snook (USA) Ecologist (Consultant)	Chetumal
Stewart Collis (Australia) GIS Analyst (Consultant)	Nairobi*
Richard O'Brien (Australia) GIS Analyst (Consultant)	Nairobi*

Name (nationality) Position/discipline	Station (*left in 1996)
Chip Fay (USA) Senior Land Tenure Specialist (Consultant)	Bogor
Ann Stroud (USA) Agronomist (Consultant)	Kampala
Joy Tukahirwa (Uganda) Postdoctoral Research Fellow	Kabale
Eva Ohlsson (Sweden) Postgraduate Fellow	Maseno
Maxwell Mudhara (Zimbabwe) Postgraduate Fellow	Harare*
Sara Mvududu (Zimbabwe) Postgraduate Fellow	Harare*
Wilson Bamwerinde (Uganda) Postgraduate Fellow	Kabale*
Taulana Sukandi (Indonesia) Posgraduate Fellow	Bogor
BCG Kamanga (Malawi) Postgraduate Fellow	Zomba
Bernard Pelletier (Canada) Postgraduate Fellow	Chitedze
Susan Kaaria (Kenya) Postgraduate Fellow	Lilongwe
Diaminatou Diaité Sanogo (Senegal) Postgraduate Fellow	Dakar
Suyanto (Indonesia) Postgraduate Fellow	Bogor

Support

Antonia Okono, Senior Bilingual Secretary	Nairobi
Elizabeth Wafula, Bilingual Secretary	Nairobi*
Cornelia Halim, Senior Secretary	Bogor
Pramualipis Kanthatham, Administrive Assistant	Chiang Mai
Atoumata Coulibaly, Bilingual Secretary	Samanko
Cheik Oumar Traore, Research Assistant	Samanko
Mary Chima, Secretary	Chitedze
Sarah Okoth, Secretary	Nairobi
Levison Khungwa, Technician	Chitedze
Luke Anjeho, Field Technician	Maseno
Stephen Kandeya, Senior Field Assistant	Chitedze
Florence Ochuka, Field Assistant	Maseno
Julius Otiende, Field Assistant	Maseno
Benedict Ounza, Field Assistant	Maseno
Mussa Itimu, Field Assistant	Chitedze
Richard Mtambo, Junior Field Assistant	Chitedze
Davison Phiri, Driver	Chitedze

Name (nationality) Position/discipline	Station (*left in 1996)
Mamoudou Dia, Driver	Samanko

PROGRAMME 2: DOMESTICATION OF AGROFORESTRY TREES

Professional

Anthony Simons (UK) Programme Coordinator	Nairobi
Jumanne Maghembe (Tanzania) Principal Forester	Zomba
John Weber (USA) Forest Geneticist	Yurimaguas
Hannah Jaenicke (Germany) Propagation Physiology Scientist	Nairobi
Ian Dawson (UK) Germplasm Specialist	Nairobi
Zacharie Tchoundjeu (Cameroon) Postdoctoral Research Fellow	Niamey
Roeland Kindt (Belgium) Associate Ethnobotanist	Nairobi
Stephen Ruigu (Kenya) Associate Research Officer	Maseno
Carmen Sotelo (Peru) Germplasm Specialist	Yurimaguas
James Were (Kenya) Associate Research Officer	Nairobi
Ahmed Salim (Kenya) Database Specialist	Nairobi
Samuel Koffa (Liberia) Forester (Consultant)	Claveria
Moses Maliro (Malawi) Postgraduate Fellow	Zomba*
Mzoma Ngulube (Malawi) Postgraduate Fellow	Zomba
Joyce M Jefwa (Kenya) Postgraduate Fellow	Zomba
Antoine Kalinganire (Rwanda) Postgraduate Fellow	Maseno
Grace Abigaba (Uganda) Postgraduate Fellow	Kabale
Bintony Kutsaira (Malawi) Postgraduate Fellow	Zomba

Support

Stella Muasya, Principal Secretary	Nairobi

Name (nationality) Position/discipline	Station (*left in 1996)
Josina Kimotho, Senior Secretary	Nairobi
Karina Davila, Computer Technician	Yurimaguas
Kettie Mkandawire, Secretary	Zomba
Pamela Olwal, Secretary	Maseno
Joseph Chacha, Field Supervisor	Muguga
Gawani Kaunda, Accounts/ Computer Clerk	Zomba
Aw Boubou, Senior Technician	Sadore
Rose Bell, Senior Field Assistant	Zomba
Baker Kamuyango, Senior Technical Assistant	Zomba
Holder Ocmin, Field Technician	Yurimaguas
José Sánchez, Field Technician	Yurimaguas
Ester Ruiz, Laboratory Technician	Yurimaguas
Walter Adongo, Field Technician	Maseno
Julius Aduwo, Field Technician	Maseno
Laban Nyambega, Field Technician	Maseno
Hama Moumouni, Technician	Sadore
Joseph Kapeya, Laboratory Assistant	Zomba
Fada Abas, Laboratory Assistant	Sador
Maurice Phangwa, Forestry Technician	Zomba
Charles Mumbo, Field Assistant	Maseno
Stonic Opiyo, Field Assistant	Maseno
Majida Mdala, Laboratory Assistant	Zomba
Francis Gone, Laboratory Assistant	Maseno
Janet Asewe, Laboratory Attendant	Maseno
Aubrey Semu, Data Collector II	Zomba
Jean Kamwendo, Data Collector	Zomba
Bentry Simwaka, Data Collector	Zomba
Ephraim Dumbo, On-farm Technician	Zomba
James Obande, Field Attendant	Maseno
Laws Thuchila, Driver/Messenger	Zomba
Andrés Jiménez, Driver	Yurimaguas
Jenifa Ntenda, Tea Lady/Cleaner	Zomba
Albade Hamo, Labourer	Sadore
Mounkaila Yaye, Labourer	Sadore

PROGRAMME 3: TREE-CROP-ENVIRONMENT INTERACTIONS

Professional

Name (nationality) Position/discipline	Station (*left in 1996)
Meka Rao (India) Programme Coordinator	Nairobi
Chin Ong (Malaysia) Principal Crop Physiologist	Nairobi
Roland Buresh (USA) Principal Soil Scientist	Nairobi
Julio Alegre (Peru) Senior Soil Scientist	Yurimaguas
Meine van Noordwijk (Netherlands) Senior Soil Scientist	Bogor
Carlos Castilla (Colombia) Soil Scientist	Porto Velho*
Bashir Jama (Kenya) Soil Scientist	Maseno
Mirjam Njoroge-van Roode (Netherlands) Associate Physical Geographer	Nairobi
Ramun Kho (Netherlands) Associate Forester	Niamey
Johan Desaeger (Belgium) Associate Nematologist	Maseno
Simone Radersma (Netherlands) Associate Soil Scientist	Maseno
Arnold Braun (Netherlands) Associate Soil Scientist	Pucallpa
Gregoire Vincent (France) Associate Scientist, Biological Systems Modelling	Bogor
Luis Arévalo (Peru) Research Officer	Yurimaguas
Peter Kurira (Kenya) Farm Manager	Machakos
Moses Mathuva (Kenya) Associate Research Officer	Machakos
Jeremiah Maroko (Kenya) Associate Research Officer	Machakos
Pratiknyo Purnomosidhi (Indonesia) Associate Research Officer	Bogor
Betha Lusiana (Indonesia) Associate Research Officer	Bogor
Eva Gacheru (Kenya) Associate Research Officer	Maseno
Josiah Kinama (Kenya) Postgraduate Fellow	Machakos*
Roy Chiti (Zambia) Postgraduate Fellow	Machakos*
James Lott (UK) Postgraduate Fellow	Machakos
Allan Kwabiah (Ghana) Postgraduate Fellow	Nairobi*
Gemma Shepherd (UK) Postgraduate Fellow	Machakos
Almaz Tekleberhan Tefera (Ethiopia) Postgraduate Fellow	Machakos

Name (nationality) Position/discipline	Station (*left in 1996)
Generose Nziguheba (Burundi) Postgraduate Fellow	Machakos
Susan Ikerra (Tanzania) Postgraduate Fellow	Zomba
Kindu Mekonnen (Ethiopia) Postgraduate Fellow	Maseno*
Jeremy Broadhead (UK) Postgraduate Fellow	Machakos
Stephen Livesley (UK) Postgraduate Fellow	Maseno
Herman Odhiambo (Kenya) Postgraduate Fellow	Machakos

Support

Zarina Dossa, Principal Secretary	Nairobi
Subekti Rahyu, Secretary/Data Technician	Bogor
Trinidad Trigoso, Bilingual Secretary	Yurimaguas
Jennifer Muriuki, Secretary	Nairobi*
Lilian Wangui, Secretary	Nairobi*
Carlos Alvarado, Laboratory Technician	Yurimaguas
Paul Ambani, Field Technician	Machakos
Gilbert Mwasambu, Field Assistant	Maseno
Obadiah Kyunguti, Field Technician	Machakos
Belardes Tambor, Field Technician	Yurimaguas
Raymond Mutura, Data Entry Specialist	Nairobi*
James Kinyangi, Field Technician	Maseno
Justus Muli, Laboratory Assistant	Maseno
George Kilonzo, Driver—Machinery	Machakos
Justus Obara, Driver/Field Attendant	Maseno
Japheth Kyengo, Field Attendant	Machakos
Kennedy Chondo, Field Attendant	Machakos
Sammy Kimau, Field Attendant	Machakos
Joshua Mulinge, Laboratory Attendant	Machakos
Maweu Ndambuki, Field Assistant	Machakos
Gideon Mbinda, Driver/Field Attendant	Machakos
Joseph Nyalianga, Driver/Field Attendant	Machakos
Dominic Tumbo, Field Attendant	Maseno
Robin Chacha, Assistant Field Attendant	Machakos
Benjamin Muoki, Assistant Field Attendant	Machakos
Elijah K Musau, Assistant Field Attendant	Machakos
Elijah Mutinda, Skilled Labourer	Machakos
Boniface Kamba, Skilled Labourer	Machakos
George Kiilu, Skilled Labourer	Machakos
William Kyule, Skilled Labourer	Machakos
Leonard Mutunga, Skilled Labourer	Machakos
Elijah Letaulo, Skilled Labourer	Machakos
Thomas Ondieki, Skilled Labourer	Machakos
John Mailu, Skilled Labourer	Machakos
John Malonzah, Skilled Labourer	Machakos
Daniel Mbithi, Skilled Labourer	Machakos
Boniface Muli, Skilled Labourer	Machakos
Benson Mwanthi, Skilled Labourer	Machakos
Muthoka Kioko, Unskilled Labourer	Machakos
Tiberius Eget, Unskilled Labourer	Machakos
John Nazareno, Unskilled Labourer	Machakos

PROGRAMME 4: SYSTEMS IMPROVEMENT

Professional

Name (nationality) Position/discipline	Station (*left in 1996)
Peter Cooper (UK) Programme Coordinator	Nairobi
Freddie Kwesiga (Uganda) Principal Forester	Chipata
Amadou Niang (Senegal) Principal Forester	Maseno
Mamadou Djimdé (Mali) Senior Animal Scientist	Samanko
Donald Peden (Canada) Senior Scientist, Range Management	Kampala*
Belson Dzowela (Malawi) Senior Forage Agronomist	Harare
Steven Franzel (USA) Senior Agricultural Economist	Nairobi
Robert Otsyina (Ghana) Senior Scientist, Range Management	Shinyanga
Mick O'Neill (USA) Senior Agronomist	Embu
Ekow Akyeampong (Ghana) Agronomist	Kabale
Jeremy Haggar (UK) Agroforester	Chetumal
Robert Paterson (UK) Senior Animal Scientist	Embu*
Eric Penot (France) Farming Systems Agronomist	Bogor
Flemming Nielsen (Denmark) Associate Agricultural Scientist	Kabale
Ann Degrande (Belgium) Associate Socioeconomist	Yaoundé
Joris De Wolf (Belgium) Associate Tropical Agronomist	Maseno

Name (nationality) Position/discipline	Station (*left in 1996)
Ralph Roothaert (Netherlands) Associate Animal Scientist	Embu
Malcolm Cairns (Canada) Associate Scientist	Bogor
Gerriete Kooi (Netherlands) Associate Crop Scientist	Zomba
Paulus Burgers (Netherlands) Associate Human Geographer	Harare
Retno Winahyu (Indonesia) Associate Research Officer	Bogor
Augustin Mercado (Philippines) Associate Research Officer	Claveria
Geoffrey Ebong (Uganda) Agricultural Economist	Kampala
Donald Phiri (Zambia) Associate Research Officer	Chipata
Stephen M Maduka (Tanzania) Research Assistant	Shinyanga
Atwitye Makwetta (Tanzania) Research Assistant	Shinyanga
Hilda Ngazi (Tanzania) Postgraduate Fellow	Shinyanga*
Daniel Mugendi (Kenya) Postgraduate Fellow	Embu
Harry Otieno (Kenya) Postgraduate Fellow	Maseno*
Francis Kihanda (Kenya) Postgraduate Fellow	Embu*
Lewis Hove (Zimbabwe) Postgraduate Fellow	Harare
Bir Thapa (Nepal) Postgraduate Fellow	Claveria
Jacques Kanmegne (Cameroon) Postgraduate Fellow	Yaoundé*
James Hafner (USA) Postgraduate Fellow	Bogor*
Samson Angima (Kenya) Postgraduate Fellow	Embu*
Christina Glynn (USA) Postgraduate Fellow	Claveria
Marco Stark (Germany) Postgraduate Fellow	Claveria
Jayne Mwangi (Kenya) Postgraduate Fellow	Embu*
Paul Tuwei (Kenya) Postgraduate Fellow	Embu*

Name (nationality) Position/discipline	Station (*left in 1996)
Peter Suson (Philippines) Postgraduate Fellow	Claveria
Patrick Purser (UK) Postgraduate Fellow	Embu*
David Siriri (Uganda) Postgraduate Fellow	Kabale*
Mark Tarleton (UK) Postgraduate Fellow	Embu*
Anette Meyr (Austria) Postgraduate Fellow	Embu*
Chris Nyakanda (Zimbabwe) Postgraduate Fellow	Harare
Godfrey Manyawu (Zimbabwe) Postgraduate Fellow	Harare
Victor Kakengi (Tanzania) Postgraduate Fellow	Shinyanga

Support

Mercy Mwangi, Senior Bilingual Secretary	Nairobi
Wambui Karimi, Administrative Assistant	Embu
Arnold Mbandu, Administrative Assistant	Chipata
Dolphina Truter, Senior Secretary	Harare
Paul Phiri, Data Analyst	Chipata
Hellen Makala, Administrative Secretary	Shinyanga
Erica Chimuka, Secretary	Harare*
Mary Mruma, Secretary	Tabora
Yannick Kafando, Secretary	Ouagadougou
Rebecca Lusumba, Secretary	Chipata
Kenneth Linyunga, Technical Officer	Chipata
Stanslous Phiri, Technical Officer	Chipata
Joseph Banda, Technical Officer	Chipata
Edward Tembo, Technical Officer	Chipata
Joseph Banda, Technical Officer	Chipata
Michael Odongo, Research Technician	Maseno
Angela Zulu, Typist	Chipata
Emmanuel Mkalipi, Assistant Technician	Chipata
Patricia Daka, Data Collector	Chipata
David Kumalinga, Data Collector	Chipata
Vincent Phiri, Data Collector	Chipata
Richard Phiri, Data Collector	Chipata
Ebenezer Asaah, Technician	Yaoundé
Scholar Marwa, Data Entry Specialist	Shinyanga
Harrison Ngethe, Field Technician	Maseno
Theophile Dibloni, Technician	Ouagadougou
Jonas Koala, Technician	Ouagadougou

Name (nationality) Position/discipline	Station (*left in 1996)
Andrew Chibwana, Technician	Shinyanga
Mwenje Chitalu, Field and Laboratory Assistant	Chalimbana
Philemon Weiner, Field Assistant Technician	Tabora
Gervas Magulukwenda, Technician	Shinyanga
Denis Tugume, Technician	Kampala
Abdul Ly Abbas Diarra, Technician	Dakar
Michael Bauteni, Data Recorder	Domboshawa
Maxwell Doba, Data Collector	Makoholi
Pauline Bhegedhe, Data Collector	Domboshawa
Liveson Maposa, Data Recorder	Domboshawa
Anthony Gwangwa, Enumerator	Yaoundé
Evencio Gwaravanda, Data Recorder	Makoholi
Onward Chirimuzhengeni, Nursery Attendant	Domboshawa
Gershom Kapambwe, Senior Driver	Chipata
Pius Abuoro, Driver	Shinyanga
Crispin Fatini, Driver	Harare*
Ridgeway Dube, Driver	Harare
Isaacky Sokotta, Driver	Tabora
Mbaye Diagne, Driver	Dakar
Yaya Gnanou, Driver	Ouagadougou
Lawrence Mwazamphando, Junior Driver/Mechanic	Chipata
Mary Yona, Office Attendant	Shinyanga
Francis Mazhangara, Nursery Attendant	Domboshawa
Bonaventure M'mamba, Casual Labourer	Yaoundé
Justin Omangle, Casual Labourer	Yaoundé
Paul Ngomo Besong, Casual Labourer	Yaoundé
Cyrian Mudadiso, Security Guard	Makoholi
Simon Murambiwa, Security Guard	Domboshawa
Tichaona Murerwe, Security Guard	Domboshawa
James Mutongo, Security Guard	Makoholi

TRAINING AND INFORMATION DIVISION

Office of the Director and Training and Information Support

Professional

Ester Zulberti (Argentina) Director of Training and Information	Nairobi
Milcah Mbindyo (Kenya) Division Administrator	Nairobi
Jimmy Kiio (Kenya) Training and Information Officer	Nairobi

Support

Eunice Gimode, Personal Assistant	Nairobi
Rita Mulinge, Administrative Secretary	Nairobi
Lucy Theuri, Secretary	Nairobi

PROGRAMME 5: TRAINING

Professional

Habib M Ibrahim (Sudan) Programme Coordinator	Nairobi*
Jan Beniest (Belgium) Senior Training Officer	Nairobi
Bruno Verbist (Belgium) Associate Training Officer	Nairobi
James Wahome (Kenya) Training Officer	Nairobi

Support

Alice Aduol, Senior Secretary	Nairobi
Mary Memia, Secretary	Nairobi

PROGRAMME 6: EDUCATION

Professional

August Temu (Tanzania) Programme Coordinator	Nairobi
Issiaka Zoungrana (Burkina Faso) Ecologist	Samanko
Per Rudebjer (Sweden) Associate Forester	Nairobi*
Jennie Andersson (Sweden) Associate Scientist	Nairobi

Support

Marie Kimenye, Senior Secretary	Nairobi

PROGRAMME 7: INFORMATION

Professional

Michael Hailu (Ethiopia) Programme Coordinator	Nairobi

Name (nationality) Position/discipline	Station (*left in 1996)
Eloy Molinero (France) Senior French Translator	Nairobi*
Helen van Houten (USA) Senior Science Editor	Nairobi
Joan Baxter (Canada) Senior Science Writer	Nairobi
Bruno Cammaert (Belgium) Associate Information Officer	Nairobi
Lucille Teemba (Kenya) Information Officer	Nairobi
Hildah Munyua (Kenya) Information Officer	Nairobi*
William Umbima (Kenya) Information Officer	Nairobi
Kellen Kebaara (Kenya) Associate Information Officer	Nairobi
Anthony Njenga (Kenya) Associate Audiovisual Officer	Nairobi
Bofete Bondole (Zaire) Associate Information Officer	Nairobi*
Damary Odanga (Kenya) Associate Graphic Arts Officer	Nairobi
Conrad Mudibo (Kenya) Associate Graphic Arts Officer	Nairobi
Gregory Agola (Kenya) Associate Information Systems Officer	Nairobi
McOwiti O Thomas (Kenya) Public Awareness Officer	Nairobi

Support

Dali Mwagore, Senior Editorial Assistant	Nairobi
Lucy Chege, Senior Secretary	Nairobi
Alfred Mureithi, Senior Library Assistant	Nairobi
Josephine Ngugi, Senior Library Assistant	Nairobi
Cathy Gecau, Senior Secretary	Nairobi
Elizabeth Mwamunga, Publications Assistant	Nairobi
Bainitus Alenga, Graphic Arts Technician	Nairobi

FINANCE AND ADMINISTRATION

Professional

Name (nationality) Position/discipline	Station (*left in 1996)
Michael Klass (Sweden) Director of Finance and Administration	Nairobi
Augustine Aghaulor (Nigeria) Head of Finance Unit	Nairobi
Ramneek Bhabra (Kenya) Head of Operations Unit	Nairobi
Roselyne C Lécuyer (France) Head of Human Resources Unit	Nairobi
Marco van den Berg (Netherlands) Information Systems Manager	Nairobi
George Maina (Kenya) Finance Officer	Nairobi
Samuel Omollo (Kenya) Travel and Conferences Officer	Nairobi*
Harkiran Lalani (Kenya) Budget Officer	Nairobi
Kennedy Auka (Kenya) Treasury Accountant	Nairobi
Salome Gitoho (Kenya) Human Resources Officer	Nairobi
Muoki Nzioka (Kenya) Accountant—Payables	Nairobi
Margaret DeSouza (Kenya) Human Resources Officer	Nairobi
Ernest Gatoru (Kenya) Project Accountant	Nairobi
Lawrence Nguri (Kenya) LAN Systems Administrator	Nairobi
Rukiya Mohamed (Kenya) Assistant Operations Officer	Nairobi
Mahmouda Hamoud (Kenya) Assistant Travel Officer	Nairobi
Barnabas Inyaa (Kenya) Maintenance Assistant	Nairobi
Justina Nthenge (Kenya) Project Accountant	Nairobi
Linus K Githuku (Kenya) Information Systems Specialist	Nairobi

Support

Peter Ochieng, Senior IT Technician—Hardware	Nairobi
Margaret Mutua, Senior Information Systems Assistant/Accounts	Nairobi*
Bithia Kedeng'e, Senior Recruitment Assistant	Nairobi
Gladwell Njenga, Principal Secretary	Nairobi
Kariuki King'aru, Administrative Assistant—Transport	Nairobi*
Rose Thuo, Senior Administrative Secretary	Nairobi

ICRAF staff

Name (nationality) Position/discipline	Station (*left in 1996)
Grace Wanyoike, Assistant Accountant—Accounts Payable	Nairobi*
Irene Njiraini, Assistant Accountant—Payroll	Nairobi
Jane Mabwa, Assistant Accountant—Treasury	Nairobi
Nelson Mukuriah, Administrative Assistant	Nairobi
William Mburu, Assistant Accountant	Nairobi
Anthony Githui, Assistant Accountant—Projects	Nairobi
Anthony Mathenge, Assistant Accountant—Payables	Nairobi
Frank Namunaba, IT Technician—Software	Nairobi
Lucy Mwangi, Senior Secretary	Nairobi
Morris Akiri, Accounts Assistant	Nairobi*
Thaddeus Kamundi, Computer Operator	Nairobi
Margaret Kiarie, IT Assistant	Nairobi
George Nginja, Senior Storekeeper	Nairobi
Ronald Irungu, Senior Accounts Clerk	Nairobi
Dorothy Kamaan, Senior Communications Clerk	Nairobi
Grace Ngugi, Senior Communications Clerk	Nairobi
Jane Moraa, Secretary	Nairobi
Stanley Gichui, Cashier	Nairobi
Peter Ndichu, Assistant Accountant—Projects	Nairobi*
Lucy Wanjau, Senior Communications Clerk	Nairobi
Patrick Nabiswa, Senior Communications Clerk	Nairobi
Brian Kidula, Computer Operator	Nairobi
Joseph Kanyonyo, Principal Driver	Nairobi
Theophilus Ivati, Mechanic	Nairobi
Bernard Hware, Senior Production Operator	Nairobi
Josphat Muli, Senior Carpenter	Nairobi
Abel Mageto, Assistant Storekeeper	Nairobi
Paul Waweru, Senior Driver	Nairobi
Barnabas Nyachieng'a, Senior Driver	Nairobi
James Kariuki, Senior Driver	Nairobi
John Gitau, Senior Registry Clerk	Nairobi
Francis N Wanyoike, Principal Office Attendant—Messenger	Nairobi
Hannah Gitere, Principal Office Attendant—Accounts	Nairobi
James Kagiri, Production Operator	Nairobi
Anthony Okello, Electrician	Nairobi*
Robert Kimani, Senior Driver	Nairobi
Philip Nzioka, Artisan	Nairobi
Isaac Inanga, Senior Driver	Nairobi
Onesmus Matute, Driver	Nairobi
George Obonyo, Senior Driver	Nairobi
Peter Ndungu, Senior Driver	Nairobi
Lucy Munge, Senior Office Attendant—Tea Lady	Nairobi
Faith Mbonjuki, Senior Office Attendant—Tea Lady	Nairobi
Samuel Maina, Senior Office Attendant—Messenger	Nairobi
David Musili, Senior Office Attendant—Cleaner	Nairobi
Humphrey Wanjohi, Senior Office Attendant—Messenger	Nairobi
Julius Akhatsika, Senior Office Attendant—Cleaner	Nairobi
Samuel Omondi, Senior Maintenance Attendant	Nairobi
Frashia Chege, Senior Office Attendant—Tea Lady	Nairobi
Albert Kirima, Senior Office Attendant—Messenger	Nairobi
Catherine Omega, Senior Office Attendant—Cleaner	Nairobi
Hudson Luvinzu, Senior Office Attendant—Cleaner	Nairobi Nairobi
Margaret Kabaya, Office Attendant—Tea Lady	Nairobi
David Nyaga, Office Attendant—Messenger	Nairobi
John Ayodi, Office Attendant—Cleaner	Nairobi
Gertrude Kagombe, Office Attendant—Tea Lady	Nairobi

Collaborating institutions

ICRAF works with a wide range of collaborators worldwide. The following list is of institutions with which we have active, substantive, ongoing collaboration.

INTERNATIONAL CENTRES AND ORGANIZATIONS

Centre for International Forestry Research, Indonesia (CIFOR)
Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica (CATIE)
Centro Internacional de Agricultura Tropical, Colombia (CIAT)
Centro Internacional de la Papa, Peru (CIP)
Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico (CIMMYT)
International Board for Soils Research and Management, Thailand (IBSRAM)
International Centre for Applied Biological Sciences, UK (CABI)
International Centre of Insect Physiology and Ecology, Kenya (ICIPE)
International Crops Research Institute for the Semi-arid Tropics (ICRISAT)
International Fertilizer Development Center, USA (IFDC)
International Food Policy Research Institute, USA (IFPRI)
International Institute of Tropical Agriculture, Nigeria (IITA)
International Irrigation Management Institute, Sri Lanka (IIMI)
International Livestock Research Institute, Kenya (ILRI)
International Plant Genetic Resources Institute, Italy (IPGRI)
International Rice Research Institute, Philippines (IRRI)
International Services for National Agricultural Research, Netherlands (ISNAR)
Technical Centre for Agriculture and Rural Cooperation, The Netherlands (CTA)
Tropical Soil Biology and Fertility Programme, Kenya (TSBF)
United Nations Educational, Scientific and Cultural Organization (UNESCO)
United Nations Environment Programme (UNEP)
West Africa Rice Development Association, Côte d'Ivoire (WARDA)

REGIONAL ORGANIZATIONS

Asia-Pacific Agroforestry Network (APAN), Indonesia
Association for Strengthening Agricultural Research in East and Central Africa, Uganda (ASARECA)
Centre régional de formation et d'application en agrométéorologie at hydrologie opérationelle (AGRHYMET), Niger
Comité permanent inter-états de lutte contre la sécheresse dans le Sahel, Burkina Faso (CILSS)
Consultative Advisory Committee on Semi-arid Food Grains Development of the Organization of African Unity (OAU-SAFGRAD)
Cooperative Program on Research and Technology Transfer for the South American Tropics, Brazil (PROCITROPICOS)
Institut du Sahel, Mali (INSAH)
Instituto Interamericano de Cooperación para la Agricultura, Costa Rica (IICA)
Regional Centre for Tropical Biology of the Southeast Asian Ministries of Education Organization, Indonesia (BIOTROP)

Regional Community Forest Training Centre, Thailand (RECOFTC)
Regional Network of Environmental Experts, Zimbabwe
Sida Regional Soil Conservation Unit, Kenya (RSCU)
Southern Africa Development Community, Tree Seed Centre, Zambia (SADC–TSC)
Southern African Centre for Cooperation in Agricultural Research, Botswana (SACCAR)

NATIONAL AGRICULTURAL RESEARCH SYSTEMS IN DEVELOPING COUNTRIES

(* indicates lead NARS)

BRAZIL

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)*
Empresa de Assistencia Tecnica Extenção Rural (EMATER)

BURKINA FASO

Institut de recherche en biologie et écologie tropicale (IRBET)*

BURUNDI

Institut des sciences agronomiques du Burundi (ISABU)*

CAMEROON

Institut de la recherche agricole pour le développement (IRAD)*

CHINA

International Farm Forestry Training Centre (INFORTRACE)

ETHIOPIA

Institute of Agricultural Research (IAR)*
Forestry Research Centre (FRC)
Ministry of Agriculture
Ministry of the Environment

GHANA

Centre for Scientific and Industrial Research (CSIR)*

INDONESIA

Agency for Agricultural Research and Development (AARD)*
Agency for Forestry Research and Development (AFRD)
Centre for Agricultural, Social and Agro Economic Research
Centre for Soil and Agroclimate Research
Central Research Institute for Food Crops (CRIFC)
Forest Nature Conservation Research Development Centre, Bogor (FRDC)
Sembawa Rubber Research Institute
Transmigration Research Institute

KENYA

Kenya Agricultural Research Institute (KARI)*
Kenya Forestry Research Institute (KEFRI)
National Dairy Development Project
National Museums of Kenya
National Poultry Development Project
Small Ruminants Project, Ministry of Agriculture
Soil and Water Conservation, Embu Agroforestry Branch

MADAGASCAR

Association nationale d'actions environnementales (ANAE)

Centre Malagasy-Norvégien pour l'élevage et l'agriculture (FIFAMANOR)
Centre national de la recherche appliquée au développement rural (FOFIFA)*
Centre pour le développement de la gestion des forêts (FAFIALA)
Department of Agricultural Research, National Agroforestry Commodity Team

MALAWI

Forestry Research Institute of Malawi (FRIM)*
Malawi Agroforestry Extension Project (MAEP)
Ministry of Agriculture and Livestock Development

MALI

Institut d'économie rurale (IER)*

MEXICO

Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP)*

NIGER

Institut national de recherches agronomiques du Niger (INRAN)*

NIGERIA

National Centre for Genetic Resources and Biotechnology (NACGRAB)
Nigerian Institute of Horticulture (NIHORT)

PERU

Instituto Nacional de Investigación Agraria, Peru (INIA)*
Instituto de Investigaciones de la Amazonía Peruana (IIAP)
Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA)
Ministerio de Agricultura—Dirección Regional, Pucallpa

PHILIPPINES

Philippine Council on Agriculture and Resources Research and Development (PCARRD)*
Department of Environment and Natural Resources (DENR)
International Institute of Rural Reconstruction (IIRR)

RWANDA

Institut de sciences agronomiques du Rwanda (ISAR)*

SENEGAL

Institut sénégalais de recherches agricoles (ISRA)*

TANZANIA

Tanzania Forestry Research Institute (TAFORI)*
Commission for Research and Training
Hifathi Ardhi Shinyanga (HASHI)

THAILAND

Royal Forestry Department (RFD)*
Ministry of Agriculture and Cooperatives (MAC)

UGANDA

National Agricultural Research Organization (NARO)*
Forestry Research Institute, Uganda (FORI)
Ministry of Agriculture (Extension)

ZAMBIA

Ministry of Agriculture, Food and Fisheries, Zambia*

ZIMBABWE

Department of Research and Specialist Services, Zimbabwe (DRSS)*

UNIVERSITIES AND COLLEGES IN DEVELOPING COUNTRIES

(* indicates ANAFE member)

BRAZIL

Escola Superior Luiz de Queiroz, Centro de Energia Nuclear para Agricultura (CENA), Brazil
Federal University of Acre
Federal University of Pernambuco
Federal University of Rondonia

BENIN

Université nationale du Bénin*

BOTSWANA

Botswana Agricultural College*

Burkina Faso

Ecole nationale des eaux et forêts*
Institut panafricain pour le développement*
Université de Ouagadougou, Institut du développement rural*

BURUNDI

Université catholique de Bukavu*
Université du Burundi*

CAMEROON

Faculté d'agronomie et des sciences agricoles, Université de Dschang*
Université de Yaoundé

CONGO

Institut chrétien polytechnique et professionnel des arts et métiers*

CÔTE D'IVOIRE

Ecole nationale supérieure d'agronomie*
Institut agricole de Bouaké, Yamoussoukro*

EGYPT

Institute of Efficient Production, Zagazig University*

ETHIOPIA

Addis Ababa University*
Alemaya University of Agriculture*
Awassa College of Agriculture*
Jimma College of Agriculture*
Mekelle University College*
Wondo Genet Forestry College*

GAMBIA

School of Agriculture, Gambia College*

GHANA

School of Agriculture, University of Cape Coast*
School of Forestry, Sunyani*
St Andrew's College, Mampong Campus*
United Nations University, Institute for Natural Resources in Africa*
University of Ghana, Legon*
University of Science and Technology*

INDONESIA

Bogor Agricultural University
Brawijaya University

Institut Pertanian Bogor
Jambi University
University of Andalas, Padang
University of Brawijaya, Malang
University of Gadjah, Mada, Yogyakarta
University of Lampung, Bandar Lampung
University of Lampung Mangkurat, Banjarmasin

KENYA

Bukura Agricultural College*
Egerton University*
Embu Agricultural Staff Training College*
Jomo Kenyatta University of Agriculture and Technology*
Kenya College of Forestry*
Maseno University College*
Moi University*
University of Nairobi*

LESOTHO

Lesotho Agricultural College*
National University of Lesotho*

LIBERIA

Liberia Forestry Training Institute*

MADAGASCAR

Centre d'expérimentation et de diffusion en gestion paysanne des Tanety/Centre FAFIALA*
Ecole supérieure des sciences agronomiques (ESSA), Campus Université Antananarivo*

MALAWI

Bunda College of Agriculture*
Chancellor College*
Malawi Forestry College*
Natural Resources College*

MALI

Centre de formation pratique forestier de Tabakoro*
Institut polytechnique rural de Katibougou*

MAURITIUS

University of Mauritius*

MEXICO

El Colegio de la Frontera Sur—Chetumal
El Colegio de la Frontera Sur—Chiapas
Universidad Autónoma de Chapingo
Universidad Autónoma de Yucatán

MOZAMBIQUE

Universidade Eduardo Mondlane*

NAMIBIA

Ogongo Agricultural College*

NIGER

Faculté d'agronomie, Université Abdou Moumouni de Niamey*
Institut pratique de développement rural*

NIGERIA

Ahmadu Bello University*
Anambra State College of Agriculture*
Borno College of Agriculture*
Federal University of Technology, Akure*
Ladoke Akintola University of Technology*
University of Agriculture*

University of Ibadan*
University of Nigeria, Nsukka*
University of Science and Technology, River State

PERU

Universidad Nacional de la Amazonía Peruana
Universidad Nacional Agraria La Molina
Universidad Nacional de Ucayali

PHILIPPINES

Central Mindanao University
University of the Philippines at Los Baños

RWANDA

Institut supérieur d'agriculture et d'élevage de Busogo*
Université nationale du Rwanda*

SENEGAL

Centre national de formation des techniciens des eaux, forêts, chasses et parcs nationeaux*
Ecole nationale des cadres ruraux*
Ecole nationale supérieure d'agriculture*

SIERRA LEONE

Njala University College, Faculty of Agriculture*

SOUTH AFRICA

Stellenbosch University*
Technikon South Africa*
University of Fort Hare*
University of Natal*
University of Zululand*

SUDAN

University of Gezira*
University of Juba*
University of Khartoum*
University of Sennar*

SWAZILAND

University of Swaziland*

TANZANIA

Forestry Training Institute, Olmotonyi*
MATI Ukiriguru*
Sokoine University of Agriculture*
Tengeru Horticultural Research and Training Institute*
Uyole Agriculture Centre*

THAILAND

Chiang Mai University
Kasetsart University

TOGO

Ecole supérieure des sciences agronomiques, Université du Bénin*

UGANDA

Arapai Agricultural College*
Bukalasa Agricultural College*
Makerere University*
Nyabyeya Forestry College*

ZAIRE

Institut facultaire des sciences agronomiques de Yangambi*

ZAMBIA

Copperbelt University*
Natural Resources Development College*
University of Zambia*
Zambia Forestry College*

ZIMBABWE

Africa University, Zimbabwe*
University of Zimbabwe*
Zimbabwe Forestry College*

NON-GOVERNMENTAL ORGANIZATIONS

BRAZIL

Fundacão para o Desenvolvemento Tecnológico de Acre (FUNTACRE)
Instituto de Prehistoria Homen e Agro Ecologia (IPHAE)
Pesquisadoras de Acre (PESACRE)
Rede Brasileira Agroflorestal (REBRAF)
Reflorestamento Economico Consorciado e Adensado

BURKINA FASO

Oxford Charity Organization (OXFAM)
Save the Children Fund (SCF)

CAMEROON

Africa 2000
Birdlife International
Cercle international pour la promotion de la création (CIPCRE)
Institut africain pour la développement économique et social (INADES)
Private Voluntary Organization and Non-Governmental Organizations in Natural Resource Management Support (PVO-NGO/NRMS)
Sucre Village
Worldwide Fund for Nature (WWF)

INDONESIA

Association of Junior Businessmen
Bina Kelola Padang
Bina Swadaya
Forestry Concession Holders' Organization
GAPKINDO (Rubber Processors Association of Indonesia)
Indonesian Forum for Environment
Indonesian Institute for Tropical Environment (LATIN)
Institute for Tropical Nature Conservation
Jaringan Kerjasama Pelestarian Hutan Indonesia
Kawal, Lampung
Keluarga Pencinta Alam Dan Lingkungan Hidup
Lembaga Bela Banua Talino
National Consortium for Nature and Forest Conservation in Indonesia
Network for Environmental Concerns (NECI)
Pelangi Indonesia
Pesticide Action Network
Rainforest Alliance
Volunteers for Overseas Cooperation Assistance, Sumatra

KENYA

Action Aid, Kenya
African Research Utilization Network (ARUNET)
African Women Leaders in Agriculture and Education (AWLAE/Winrock International)
Bellerive Foundation
CARE Kenya
Dairy Goat Development Programme
Education Training Consultants–Kenya (ETC–K)

Hope Community Development, Kenya
International Union for the Conservation of Nature and Natural Resources (IUCN)
Kakamega Biointensive Group, Kenya
Kamukunji Project, Embu
Kenya Energy Organization (KENGO)
Kenya Institute of Organic Farming (KIOF)
Kenya Woodfuel and Agroforestry Project (KWAP)
Laikipia Research Project
Lutheran World Relief (LWR)
Manor House, Kenya
Miti Mingi Mashambani
National Dairy Development Project
Organic Matter Management Network (OMMN)
Plan International (PI)
Project Modifications against Desertification (MAD)
Rural Service Project

MALAWI

Action Aid
ADDFOOD
Caritas Malawi
Catholic Agricultural Project (CAP)—Zomba
Catholic Agricultural Services
Chilembwe Women's Group
Christian Science Council
Christian Service Committee (CSC)
Coordination Unit for the Rehabilitation of the Environment (CURE)
Evangelical Lutheran Development Project (ELDP)
Malawi Council for the Handicapped (MCH)
Mchenga Self-Help Irrigation Project
Nathenje Women's Group
Poverty Alleviation Pilot Project in Agroforestry
Wildlife Society of Malawi (WSM)

MALI

CARE–Mali

MEXICO

Consejo Regional Agropecuario, Forestal y Servicios de Xpujil (CREX)
Organización de Ejidos Forestales Productores de la Zona Maya (OEFPZM)
Plan de Acción Forestal Tropical (PROAFT)

PERU

Consejo de Desarrollo Sostenible de Ucayali (CODESU)
Fundación para el Desarrollo del Agro (FUNDEAGRO)
Investigadores Civiles en Agroforestería Yurimaguas

PHILIPPINES

Apu Agbilin Community
Green Mindanao
Mag-uugmad Foundation
Mindanao Baptist Rural Life Centre
Network of Environmental Concerns

RWANDA

AFRICARE–Rwanda
CARE International–Rwanda

TANZANIA

Moravia Church, Tabora

THAILAND

CARE–Thailand
Cooperatives' National Agroforestry Working Group
Thailand Development Research Institute

UGANDA

CARE Uganda—Development through Conservation

International Union for the Conservation of Nature and Natural Resources (IUCN)
Ndere Troupe
Soroti Catholic Development Organization
Two-Wings Agroforestry Group
Uganda National Farmers Association
VI Tree Planting Project
World Vision (Uganda)

ZAMBIA

Heifer International, UK
Katete District Women's Association (IWF/ZCRS)
Lutheran World Federation (LWF)
Madzimoyo Reformed Church (RCZDP)
Minga Catholic Church
Msekochika Community Development Project (MSIPAZI)
Mthilakubili Agricultural Project
Pan African Institute for Development—East and Southern Africa (PAID–ESA)
Reformed Church of Zambia
Zemba Social Development

ZIMBABWE

Centre for Agricultural Social Sciences (CASS)
Cooperation Development in Rural Communities (COOPIBO)
Environment and Development Activities—Zimbabwe (ENDA)
Permaculture (FAMBIDZANAI)
Regional Network of Environmental Experts (ZERO)
Zimbabwe Council of Churches (ZCC)

ADVANCED RESEARCH INSTITUTES

Agricultural University of Austria
Agricultural University of Norway, Aas
Australian National University
Australian Tree Seed Centre
Bundesforschungsanstalt für wirtschaftliches Zusammenarbeit, Germany (BFH)
Catholic University of Leuven, Belgium
Centre de coopération international de recherche agronomique pour le développement, France (CIRAD)
Centre for Agrobiology and Soil Fertility, Ministry of Agriculture, The Netherlands (AB-DLO)
Centre for Development and Environment, Institute of Geography, University of Berne, Switzerland (CDE)
Commonwealth Scientific and Industrial Research Organisation, Australia (CSIRO)
Cornell University, USA
Council for Scientific and Industrial Research, South Africa (CSIR)
DANIDA Tree Seed Centre, Denmark
Deutsche Gesellschaft für Technische Zusammenarbeit, Germany (GTZ)
Ecole Politechnique Federal, Switzerland (ETH)
Flemish Association for Development Cooperation and Technical Assistance (VVOB)
Food and Agriculture Organization of the United Nations, Italy (FAO)
Forestry Research and Technology, South Africa (FORSTEK)
Global Change in Terrestrial Ecosystems, Australia (GCTE)
Göttingen University, Germany
Groningen University, Netherlands
Hamburg University, Germany
Indian Council for Agricultural Research, India (ICAR)
Institute of Geography, University of Copenhagen, Denmark
Institute of Hydrology, UK (IH)
Institute of Soil Science, China
Institute of Terrestial Ecology, UK (ITE)
Institut français de recherche scientifique pour le développement en cooperation (ORSTOM)

International Institute for Biological Control, UK (IIBC)
International Institute of Economic Development, UK (IIED)
International Institute of Parasitology, UK
International Soil Science Society, Austria (ISSS)
International Union of Forestry Research Institutes (IUFRO)
Iowa State University
Japan International Cooperation Agency (JICA)
Japan International Research Center for Agricultural Sciences (JIRCAS)
Japanese Agroforestry Project for Land Development, Japan (JALDA)
Kluwer Scientific, Netherlands
Laval University, Canada
McGill University, Canada
Michigan State University, USA
National Agroforestry Research Center, USDA Forest Service, USA
Natural Resources Institute, UK (NRI)
North Carolina State University, USA
Overseas Development Institute, UK (ODI)
Oxford Forestry Institute, UK (OFI)
Purdue University, USA
Royal Botanical Gardens, Kew, UK (RBG–K)
Royal Veterinary and Agricultural University, Denmark
Scottish Crops Research Institute, UK (SCRI)
Soil Science Society of America, USA (SSSA)
Sustainable Agriculture for Natural Resource and Environmental Management CRSP, University of Georgia, USA
Swedish Agricultural University, Umea
Swedish University of Agricultural Sciences, Sweden
Television Trust for the Environment, UK (TVE)
Terrestrial Initiative in Global Environmental Research (TIGER)
Texas A&M University, USA
United States Department of Agriculture, Forest Service, USA (USDA–FS)
Université de Paris 6, France
Université Pierre et Marie Curie, France
University College of North Wales, UK
University of Agricultural Sciences, Uppsala, Sweden
University of Alberta, Canada
University of Bayreuth, Germany
University of California at Davis, USA
University of Copenhagen, Denmark
University of Dublin, Ireland
University of Dundee, UK
University of Florida, USA
University of Guelph, Canada
University of Hawaii, USA
University of Kassel, Germany
University of Minnesota, USA
University of New York, USA
University of North Wales, UK
University of Nottingham, UK
University of Reading, UK
University of Saskatchewan, Canada
University of Wales, School of Agricultural and Forestry Sciences
University of Western Australia
University of Wisconsin, USA
Wageningen Agricultural University, The Netherlands
Winand Staring Centre for Integrated Soil and Water Research, The Netherlands (SC–DLO)
Winrock International (WI)
World Conservation and Monitoring Centre, Switzerland (WCMC)
Wye College, UK
York University, Canada

PRIVATE SECTOR

Boehringen Ingelheim, Germany
Daimler-Benz, Germany
Valmar SA, France
Warm Seas Shipping and Trading Co. Ltd., UK

Addresses

ICRAF HEADQUARTERS AND REGIONAL OFFICES

International Centre for Research in Agroforestry
PO Box 30677
Nairobi, Kenya
Telephone: 254 2 521450
1 415 833 6645
Fax: 254 2 521001
1 415 833 6646
Email: icraf@cgnet.com
Internet: www.cgiar.org/icraf

Southern Africa Regional Programme
SADC-ICRAF Agroforestry Project
Makoka Agricultural Research Station
PO Box 134
Zomba, Malawi
Telephone: 265 534277
Fax: 265 534283
Email: j.maghembe@unima.wn.apc.org

Sahelian Regional Programme
ICRAF Sahel Programme
c/o ICRISAT
BP 320
Bamako, Mali
Telephone: 223 223375/227707
Fax: 223 228683
Email: e.bonkoungou@cgnet.com

Humid West Africa Regional Programme
ICRAF-IRAD Agroforestry Research Project
BP 2123
Yaoundé, Cameroon
Telephone: 237 237560
Fax: 237 237440
Email: icraf-cameroun@cgnet.com

Latin America Regional Programme
c/o INIA-Centro Forestal
Carretera Federico Basadre Km 4.2
Apartado Postal 558
Pucallpa, Peru
Telephone: 51 64 578704
51 1 436 6920
Fax: 51 64 571784
51 1 435 1570
Email: d.bandy@cgnet.com

Southeast Asia Regional Programme
Jalan Gunung Batu No. 5
PO Box 161
Bogor 16001, Indonesia
Telephone: 62 251 315234
Fax: 62 251 315567
62 251 326433
Email: icraf-indonesia@cgnet.com

Acronyms and abbreviations

AARD	Agency for Agricultural Research and Development (Indonesia)
AAS	African Academy of Sciences (Nairobi, Kenya)
ACIAR	Australian Centre for International Agricultural Research (Canberra, Australia)
AFED	Agroforestry Education Database
AFRENA	Agroforestry Research Networks for Africa
AFRENA-SALWA	Agroforestry Research Networks for Africa—Semi-Arid Lowlands of West Africa (Bamako, Mali)
AGRHYMET	Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (Niamey, Niger)
ANAFE	African Network for Agroforestry Education (Nairobi, Kenya)
ASARECA	Association for Strengthening Agricultural Research in East and Central Africa (Kampala, Uganda)
AsDB	Asian Development Bank (Manilla, Philippines)
AVHRR NDVI	advanced very high resolution radiometer—normalized difference vegetation index
BARNESA	Banana Research Network for Eastern and Southern Africa (Kampala, Uganda)
CABI	Centre for Agriculture and Biosciences International (Wallingford, UK)
CGIAR	Consultative Group on International Agricultural Research (Washington, DC, USA)
CIAT	Centro Internacional de Agricultura Tropical (Cali, Colombia)
CIFOR	Centre for International Forestry Research (Bogor, Indonesia)
CILSS	Comité permanent inter-états de lutte contre la sécheresse dans la Sahel (Ouagadougou, Burkina Faso)
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo (Mexico City, Mexico)
CIP	Centro Internacional de la Papa (Lima, Peru)
CIPCRE	Cercle international pour la promotion de la création (Yaoundé, Cameroon)
CIRAD	Centre de coopération international en recherche agronomique pour le développement (Paris, France)
CIRAD CA	Département des cultures annuelles de Centre de coopération internationale en recherche agronomique pour le développement (Nogent-sur-Marne, France)
CORAF	Conférence des responsables de la recherche agronomique africains (Dakar, Senegal)
DANIDA	Danish International Development Agency (Copenhagen, Denmark)
DAP	diammonium phosphate
dbh	diameter at breast height
DFID	Department for International Development (London, UK) (formerly ODA, Overseas Development Agency)
DM	dry matter
DMI	Desert Margins Initiative (Hyderabad, India)
DSG	Donor Support Group (ASB)
DSO	Direct Support to Training Institutions in Developing Countries (The Hague, The Netherlands)
EARRNET	East Africa Root Crops Research Network (Kampala, Uganda)
ECABREN	East and Central Africa Bean Research Network (Kampala, Uganda)
ECEC	effective cation exchange capacity
EEC	European Economic Community (Brussels, Belgium)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brasilia, Brazil)
EPHTA	Ecoregional Programme for the Humid and Sub-Humid Tropics of Sub-Saharan Africa (IITA)
ERS	European radar satellite
FAFIALA	Centre pour le développement de la gestion des forêts (Madagascar)
FIFAMANOR	Centre Malagasy-Norvégien pour l'élevage et l'agriculture (Madagascar)
FINNIDA	Finnish International Development Agency (Helsinki, Finland)
FOFIFA	Centre national de la recherche appliquée au développement rural (Madagascar)
FORI	Forestry Research Institute (Kampala, Uganda)
FTP	Forests, Trees and People (Helsinki, Finland)
FUNDEAGRO	Fundación para el Desarrollo del Agro (Peru)
GEF	Global Environment Facility
GMI	Global Mountain Initiative (Lima, Peru)
GRU	Germplasm Resource Unit (of ICRAF)
HRVIR	high resolution visible and infrared radiometer (Spot imagery)
IADB	Interamerican Development Bank (Washington, DC, USA)
IAR	Institute of Agricultural Research (Addis Ababa, Ethiopia)
IARC	international agricultural research centre
ICIPE	International Centre of Insect Physiology and Ecology (Nairobi, Kenya)
ICRAF	International Centre for Research in Agroforestry (Nairobi, Kenya)
ICRISAT	International Centre for Research in the Semi-arid Tropics (Hyderabad, India)
IDR	Institut du développement rural (Burkina Faso)
IDRC	International Development Research Centre (Ottawa, Canada)
IER	Institut d'économie rurale (Bamako, Mali)
IFAD	International Fund for Agricultural Development (Rome, Italy)

Acronyms and Abbreviations

IFDC	International Fertilizer Development Center (Muscle Shoals, Alabama, USA)
IFPRI	International Food Policy Research Institute (Washington, DC, USA)
IFS	International Foundation for Science (Stockholm, Sweden)
IIAP	Instituto de Investigaciones de la Amazonía Peruana (Iquitos, Peru)
IIBC	International Institute of Biological Control (Ascott, UK)
IITA	International Institute of Tropical Agriculture (Ibadan, Nigeria)
ILRI	International Livestock Research Institute (Nairobi, Kenya)
INADES	Institut africain pour le développement économique et social (Cameroon)
INERA	Institut d'études de recherche agricoles (Farako Ba, Burkina Faso)
INIA	Instituto Nacional de Investigación Agraria (Lima, Peru)
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias (Yucatan, Mexico)
INRAN	Institut national de recherches agronomiques du Niger (Niamey, Niger)
IPCC	International Panel on Climate Change (Geneva, Switzerland)
IPGRI	International Plant Genetic Resources Institute (Rome, Italy)
IPM	integrated pest management
IPR	Institut polytechnique rural de Katibougou (Mali)
IRAD	Institut de recherche agricole pour le développement (formerly IRA, Institut de la recherche agronomique) (Yaoundé, Cameroon)
IRBET	Institut de recherche en biologie et écologie tropicale (Burkina Faso)
ISAR	Institut des sciences agronomiques du Rwanda (Butare, Rwanda)
ISNAR	International Service for National Agricultural Research (The Hague, The Netherlands)
ISRA	Institut sénégalais de recherches agricoles (Dakar, Senegal)
ITE	Institute of Terrestrial Ecology (Midlothian, UK)
IVITA	Instituto Veterinario de Investigaciones Tropicales y de Altura (Lima, Peru)
JICA	Japanese International Cooperation Agency (Ibaraki, Japan)
JRS	Japanese radar satellite
KARI	Kenya Agricultural Research Institute (Muguga, Kenya)
KEFRI	Kenya Forestry Research Institute (Nairobi, Kenya)
KWAP	Kenya Woodfuel and Agroforestry Project (Eldoret, Kenya)
MAC	Ministry of Agriculture and Cooperatives (Bangkok, Thailand)
MIR	mid-infrared
MOA	Ministry of Agriculture
NARO	National Agricultural Research Organization (Kampala, Uganda)
NARS	national agricultural research system(s)
NEX	national extension network
NGO	non-governmental organization
NPV	net present value
OFI	Oxford Forestry Institute (Oxford, UK)
OMMN	Organic Matter Management Network (Nairobi, Kenya)
ONADEF	Office national de développement des forêts (Cameroon)
PAR	photosynthetically active radiation
PR	phosphate rock
PRAPACE	Programme régional d'amélioration de la culture de la pomme de terre et de la patate douce en Afrique central et de l'est (Kampala, Uganda)
RAE	relative agronomic effectiveness
RRA	rapid rural appraisal
RSCU	Regional Soil Conservation Unit, Sida (Nairobi, Kenya)
SAFGRAD	Consultative Advisory Committee on Semi-Arid Food Grains Research and Development of the Organization of African Unity (Ouagadougou, Burkina Faso)
SANREM	Sustainable Agriculture and Natural Resources Management Project (Philippines)
SDI	selective dissemination of information
SECAP	Soil Erosion Control and Agroforestry Project (Arusha, Tanzania)
SLP	Systemwide Livestock Programme (Nairobi, Kenya)
SOM	soil organic matter
SPOT	Système probatoire d'observation de la terre
SWI	systemwide initiative
SWNM	Soil, Water and Nutrient Management Programme (Nairobi, Kenya)
TAC	Technical Advisory Committee of the CGIAR
TLU	tropical livestock unit
TM	thematic mapper
TREECD	CABI CD-ROM database on forestry and agroforestry
TSBF	Tropical Soil Biology and Fertility Programme (Nairobi, Kenya)
TSP	triple superphosphate
UCAD	Université Cheick Anta Diop (Dakar, Senegal)
UK	United Kingdom
UNU	Universidad Nacional de Ucayali (Peru)
US, USA	United States of America
USAID	United States Agency for International Development (Washington, DC)
USD	United States dollar
VA	vesicular-arbuscular (mycorrhizal infection)
WANULCAS	water, nutrient and light capture in agroforestry systems model
WARDA	West Africa Rice Development Association (Bouaké, Côte d'Ivoire)
WATALA	Society of Nature Lovers (Indonesia)
WWF	Worldwide Fund for Nature (Gland, Switzerland)

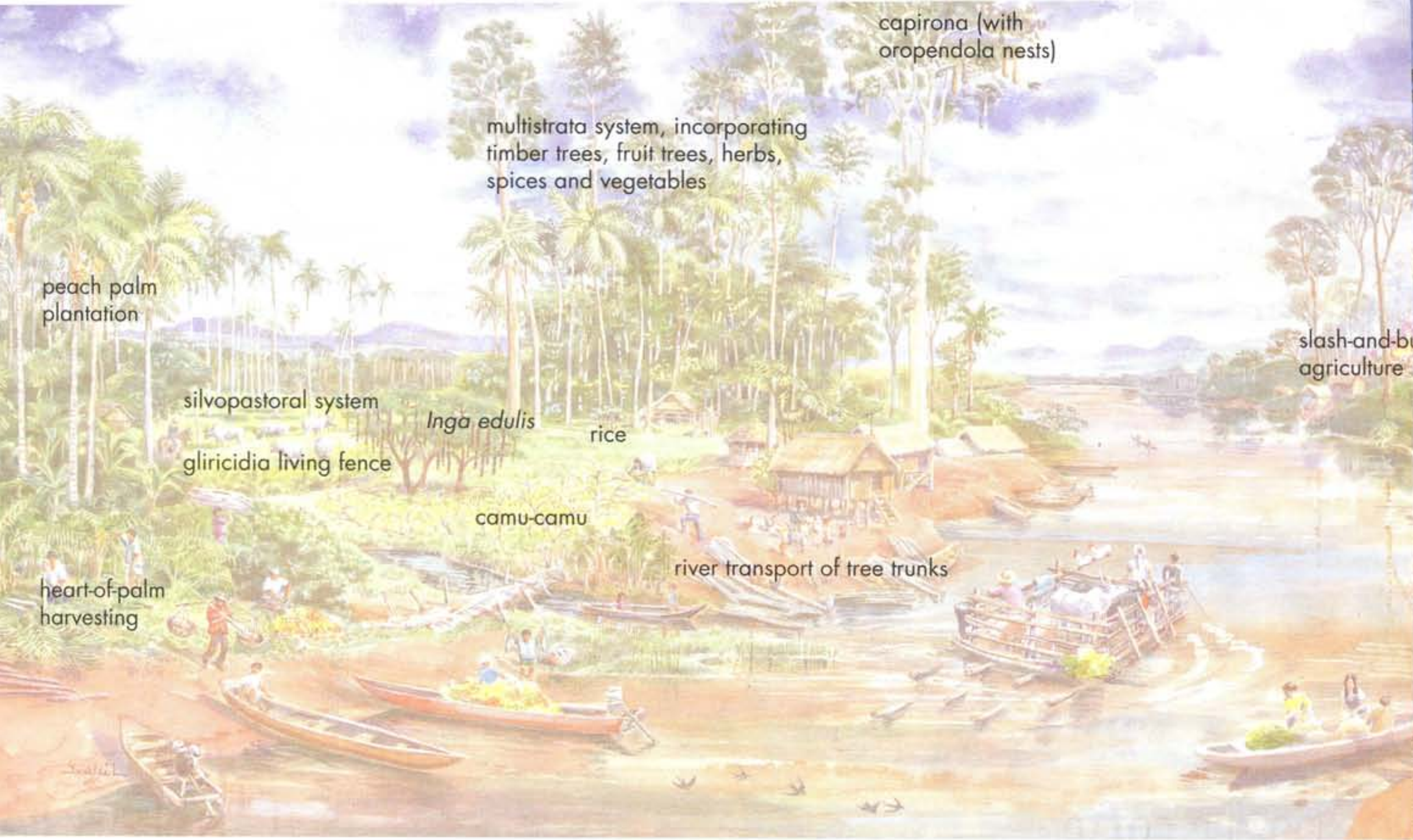
ICRAF

The International Centre for Research in Agroforestry (ICRAF), established in 1977, is an autonomous, non-profit research body supported by the Consultative Group on International Agricultural Research (CGIAR). ICRAF aims to improve human welfare by alleviating poverty, increasing cash income, improving food and nutritional security, and enhancing environmental resilience in the tropics.

ICRAF's objectives are to conduct strategic and applied research, in partnership with national agricultural research systems, for more sustainable and productive land use. Its research and development agenda addresses 5 themes: diversification and intensification of land use through domestication of agroforestry trees; soil fertility replenishment in nutrient-depleted lands with agroforestry and other nutrient inputs; socioeconomic and policy research leading to enabling policy environment for the benefit of smallholder farmers; acceleration of impact on farm by ensuring research results are utilized; and capacity and institutional strengthening through training and the dissemination of information.

ICRAF is governed by a Board of Trustees, with representation from developed and developing countries. Financial support for ICRAF's research and development activities is provided by 30 donors.

In 1996, they were (in alphabetical order): Australia, Austria, Belgium, Brazil, Canada, the Centre Technique de Coopération Agricole et Rurale (CTA), Denmark, the European Union, Finland, the Ford Foundation, France, Germany, the Interamerican Development Bank (IDB), the International Development Research Centre (IDRC), the International Fund for Agricultural Development (IFAD), Ireland, Japan, the Netherlands, Norway, the Rockefeller Foundation, Spain, Sweden, Switzerland, the United Kingdom, the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the United States of America, the University of Georgia, the World Bank. Generous assistance also comes from many other governments, national institutions, centres and agencies with which ICRAF collaborates around the world.



The magic of the Amazon arises from its extensive rivers. They are the region's pulse and lifelines, providing transport and communication among villages. Their rise and fall marks the rhythm of the seasons and continually brings change.

Edited by
Helen van Houten

Art direction
Damary Odanga

Cover
Jill Last

Graphics
figures and maps, Conrad Mudibo and Bainitus Alenga;
remote sensing images p 241, 244, 247 Jacques Imbernon

Editorial assistance
Kellen Kebaara, Dali Mwagore, Michael Hailu

Photos
photo coordination by Anthony Njenga
credits: inside front cover A Njenga; p 2 P Sanchez; 3 top A Njenga, bottom P Sanchez; 4 top P Sanchez, bottom T Tomich; 5 P Sanchez; 6 A Njenga; 7 top & bottom left, bottom right A Njenga, top & middle right P Sanchez; 8 A Njenga; 9 A Simons; 10 P Sanchez; 11 J Weber; 12 P Sanchez; 14 S Franzel; 15 J Baxter; 17 J Baxter; 18 Daimler Benz; 19 I Dawson; 20 C Mudibo; 25 J Baxter; 26 top A Njenga, bottom P Sanchez; 27 top N Smith, bottom IRRI; 28 A Njenga; 30 top P Sanchez, bottom A Njenga; 31 top A Njenga, bottom P Sanchez; 32 A Njenga; 33 C Fay; 34 I Dawson; 35, 36 A Njenga; 48 J Weber; 51, 60, 61 P Sanchez; 66 M Rao; 72 T Tomich; 74 J Baxter; 80 R Labelle; 93, 95 D Garrity; 125, 129 B Duguma; 130 M Mollet; 138, 145, 155 A Njenga; 172 J Baxter; 174 R Leakey; 179 J Baxter; 180, 181 M Hailu; 186 J Baxter; 201, 203, 206, 212 B Dzowela; 217 Otsyina; 228 E Fernandes; 232 P Sanchez; 233 J Baxter; 245, 250, 253, 260, 268 A Njenga; 274 A Simons; 275, 283 A Njenga; 285 A Njenga; 289, 291 Kone Brahima; 293 A Njenga

Prepress production
Kulgraphics, PO Box 18095, Nairobi, Kenya

Printing
Majestic Printing Works Ltd, PO Box 42466, Nairobi, Kenya

published in 1997
International Centre for Research in Agroforestry
PO Box 30677, Nairobi, Kenya
tel: 254 2 521450; 1 415 833 6645
fax: 254 2 521001; 1 415 833 6646
email: icraf@cgnet.com
internet: http://www.cgiar.org/icraf

ISBN 92 9059 126 9; UDC 634.0.26.001

printed on chlorine-free paper

ICRAF


]