3. An underutilized resource: indigenous ecofarming knowledge

Traditional farming systems are classical low-external-input systems, making use of locally available energy and materials plus the practical environmental knowledge accumulated by generations of farmers. Communities with long experience in a particular area have developed techniques and strategies of resource use to suit the prevailing conditions. The very fact that their production systems have survived is a testimony to their ecological appropriateness: mismanagement of the natural resources would have destroyed their basis of livelihood. The traditional techniques and strategies of subsistence farmers can be regarded as the result of "deliberate efforts to improve and/or protect the value of life-supporting resources and to insure some reasonably secure long term viability" (BEYER 1980).

Seen in this way, millions of small farmers throughout the tropics and subtropics are "ecofarming experts". It is important that their practices and knowledge be studied by agricultural scientists for three main reasons:

1. **Present forms of resource use which have long sustained the life of large numbers of people in resource-poor and/or fragile environments must be preserved until provably superior forms of resource use have been developed.**

2. **Indigenous farming practices and environmental knowledge offer starting points for developing ecofarming measures which will increase the productivity and sustainability of local resources in developing countries.**

3. **Indigenous ecofarming knowledge can reveal missing ecological keys which may help scientists to develop alternative farming techniques in industrialized countries which will be less dependent on nonrenewable resources than present systems and technologies of modern farming.**

Some agricultural researchers have already begun to recognize this, and various ecofarming measures presently being developed, e.g. multiple cropping, agroforestry, minimum tillage and new forms of cover cropping or "living mulches", were derived from traditional farming systems. Indigenous methods of plant protection have offered starting points for scientists trying to develop integrated plant protection measures as an alternative to chemical pesticides. Despite these welcome exceptions, HATCH'S (1976) statement still largely holds that:

The small farmer's expertise "represents the single largest knowledge resource not yet mobilized in the development enterprise."

In order to develop low-cost ecofarming measures, scientists must learn *to learn from the local farmers:* to recognize and understand indigenous ecofarming systems and technologies so that these can be promoted, developed and diffused to other farmers operating under similar conditions.

3.1 Indigenous ecofarming practices

Within an indigenous farming system, it is difficult to distinguish the individual ecofarming measures visualized by agricultural scientists, because man, animals, forests, grasslands and fields are inseparable components of a single agroecosystem. For example, agroforestry is a relatively new concept in agricultural science, but it is not at all new to smallholders in the tropics, most of whom regard trees as a integral part of their farming systems. Particularly in densely populated Southeast Asia, indigenous farmers have developed highly productive and sustainable land-use systems in which agroforestry, multiple cropping, use of biological symbionts, mulching, composting, integrated plant protection, integration of fish and other livestock, and other ecofarming measures are inextricably combined. In less densely populated parts of the tropics and subtropics, the indigenous farming systems represent a less intensive form of resource use, but the techniques and strategies applied by the farmers to gain a more or less secure livelihood are equally dependent on their detailed ecological knowledge.

Various elements of ecofarming in traditional systems, e.g. the burning of vegetative growth before planting to enhance soil fertility, are not immediately evident to an observer trained in formal agricultural science and may even be regarded as harmful until the underlying principles are understood. There has also been a tendency among western scientists to regard the farming practices of different ethnic groups as representative of stages in an evolutionary development of agriculture. Only now are scientists beginning to realize that techniques once regarded as "primitive" (e.g. minimum tillage) reflected local adaptations to rainfall intensity, soil texture and erosion risks (RICHARDS 1985). They are ecofarming techniques: ecologically appropriate for a specific site.

Here, only a few examples can be given of the innumerable different systems and techniques of ecofarming developed by smallholders in the tropics and subtropics. Although various physical measures are also employed to conserve water and soil or to make conscious use of erosion to create arable areas (methods of run-on water and soil)[1], the emphasis here will be on biological measures of indigenous ecofarming. These measures are often difficult to classify because they may serve a multitude of purposes simultaneously.

1) For example, indigenous farmers on the Mossi Plateau in Burkina Faso construct low permeable bunds of stones, bundled sticks, crop residues or living fences along contour lines to harvest runoff water and improve water infiltration; and dig water pockets, i.e. depressions for harvesting runoff water, which are then manured and cultivated. In Tunisia, farmers divert runoff water from catchment areas (sometimes cleared of stones to improve formation of surface crust to increase runoff) to lower-lying fields. They also construct small dams in seasonal streambeds to capture runoff water and silt from small watersheds; the terraces in front of the dams are then cropped (REIJNTJES 1986). With the system of tunnels and shafts known as the *qanat*, farmers in Iran developed an extremely sophisticated technique for tapping groundwater with the least possible evaporation loss (MANNERS 1980).

Vegetation design and manipulation

Indigenous agroforestry practices range from **forest manipulation** to highly intensive gardening. Investigation of these practices reveals complex knowledge systems with respect to plant interactions and the dynamics of plant communities. In the rainforests of Brazil, for example, scientists are only beginning to understand how the Indians simultaneously exploit and conserve the ecosystem through careful manipulation, e.g. gathering plants in primary and secondary forests and transplanting them into old fields. Applying their knowledge of subtle similarities between different ecological units within the forest, the Indians have been able to increase biological diversity to meet their subsistence needs. Their knowledge and practices could provide keys to successful management of what are considered by scientists to be infertile tropical forest soils (POSEY 1985).

Another ancient system of agroforestry is **shifting cultivation.** Soil fertility is restored by lengthy periods of tree or bush fallow after short periods of arable farming. This is still practised today in forest and derived savanna areas with low population density. When increasing population density necessitated a shortening of the fallow period, many farming groups found ways of speeding up soil fertility regeneration, e.g. by protecting certain tree or shrub species when clearing a plot for cultivation, by leaving the roots and stumps of cleared species which could regrow quickly after the cropping period, or by planting fast-growing shrubs at the beginning of the fallow period. British colonial officers noted in 1943 that the Igbo farmers of eastern Nigeria planted fallows with *Acioa barterii* (RICHARDS 1985). RUTHENBERG (1980) refers to indigenous practices of planting nitrogen-fixing fallow bushes: *Anthonota* in eastern Nigeria, *Leucaena* in the Philippines. Farmers in Papua New Guinea developed the technique of planting *Casuarina oligodon* to regenerate soil fertility (ILEIA 1985).

In some cases, reversion to fallow after a cropping period is assisted by planting a perennial catch crop together with the final annual crop in the rotation. In Nigeria, the catch crop is often cassava in the forest zone and pigeon pea (*Cajanus cajan*) in the savanna (RICHARDS 1985). Also farmers in Kenya were observed using *C. cajan* to replace natural fallow vegetation (RUTHENBERG 1980). This not only speeds up the process of fertility recovery but also provides ground cover after harvest of the main crop until the land reverts to bush. Farmers return periodically to the bush plot to harvest the crop in the "fallow" shrubland.

In Mambila, Nigeria, farmers plant fast-growing bush legumes (*Tephrosia spp*) with the final cereal crop (sorghum) in the rotation and leave it as a one-year improved fallow after grain harvest. The thicker stems are then harvested for fuel and the remaining vegetation is burnt to give wood ash as fertilizer for the subsequent crop (maize). This system was recorded already in 1926 by a colonial officer (IZARD 1926), who marvelled at the skill of the Mambila farmers and their understanding of soil fertilization. Similarly, on Ukara Island in East Africa, the indigenous farming system involves relay cropping of millet and shrubby legumes (*Tephrosia* and *Crotalaria spp*) which are used as green manure (ALLAN 1965).

Trees in cultivated fields are vital components of many permanent farming systems. The scattered large trees which are left in the fields reduce wind speed and moisture losses, i.e. they have a similar effect to shelter belts (CHAMBERS & LONGHURST 1986). The stumps and roots of the felled trees are not removed, and help to bind the soil. The farmers also value the trees as sources of food, fodder, timber, fibre and medicinal ingredients. Branches are cut for firewood. Certain trees are preferred for bee-keeping.

Besides protecting trees in cultivated fields, farmers often deliberately introduce plants to serve similar purposes, e.g. they plant *Euphorbia spp* or perennial grasses such as *Andropogon* around their plots to reduce water runoff and soil erosion; these sometimes also serve to keep out animals (BALASUBRAMANIAN & EGLI 1986, REIJNTJES 1986). The Quechua Indians in Peru maintain heavy growths of grasses and woody shrubs along field boundaries and terrace walls on slopes (FREEMAN & FRICKE 1980). Some farmers in South Asia plant hedgerows on slopes to reduce erosion

through water and wind, and to have better control over livestock; the hedges are often planted in association with low-piled rock walls (MURTON 1980). Some hill-farming groups in Nepal traditionally plant trees and shrubs in contour strips on cropped land, not only to protect the soils and crops but also to provide fodder, firewood and timber (FONZEN & OBERHOLZER 1984). Local farming practices in the Philippines include planting fast-growing legume trees and/or fruit trees on contours or around crop patches (OLOFSON 1985).

The motivation of smallholders to plant trees is especially high in areas where, as in many parts of Africa, they can traditionally secure land-use rights by planting trees and/or where they have usufructory rights to the trees they plant. Particularly where these conditions are combined with high population density and high market demand for fuel and timber, indigenous efforts to incorporate trees into their farms have astounded researchers. In smallholder areas of the Kenyan highlands, ICRAF found that the area covered by trees and shrubs on farms *increased* as population density increased and average farm size decreased. Most newly-planted trees came not from official nurseries but rather from farmers' nurseries (CHAVANGI & NGUGI 1987). Similarly in the densely settled zone around Kano in northern Nigeria, where fuelwood has long been a market commodity, AFOLABI-FALOLA et al (1984) found that tree densities on farmland have been increasing in recent years, and most of the woodsellers were deliberately planting trees. Thus, some smallholders now regard trees as cash crops.

However, the prevalance of trees in subsistence production systems suggests that the ecological and economic benefits within the farming system and household economy were the original motivations of smallholders to protect, plant and nurture trees. It is noteworthy that many of the trees and shrubs that form part of indigenous farming systems are leguminous and have the capacity to fix atmospheric nitrogen, e.g. *Acacia albida* and *A. senegal* in the semiarid zone of Africa (FREEMAN & FRICKE 1980), *Leucaena* spp in Central America and the Philippines (NAS 1984), *Erythrina poeppigiana* on smallholder coffee farms in Costa Rica (GLOVER & BEER 1986) and *Albizia adianthifolia* on the Bamenda Plateau in

Cameroon (PRINZ 1986). Fallen leaves and pruned branches serve as mulch and/or green manure. The farmers apply their knowledge of the fertility enrichment function of trees and of the fertility and shade requirements of crop plants in designing their pattern of mixed cropping under the trees.

In addition, some farmers deliberately pair fast-growing woody species and climbing crop plants to provide support for the latter, thus sparing themselves the building material and labour which would otherwise be required for this purpose. BALASUBRAMANIAN & EGLI (1986) describe how Rwandan farmers support growing banana stems in the forked branches of castor bean (*Ricinus communis*). In southeast Nigeria, the local leguminous shrub *Anthonota* is planted to support water yam plants (VAN NOORDWIJK 1985).

In these indigenous multistorey systems, farmers display a detailed knowledge of how to manage light and shade through plant spacing as well as coppicing, pollarding, bending and espaliering in order to increase dry matter production of trees and/or lower-level crops, stimulate flowering, improve ground cover, or redistribute dry matter to leafy shoots for fodder or to branches for fuelwood (MERGEN 1987). They also manipulate vegetative design to influence the time of labour demands – a particularly important aspect in farming systems with seasonal labour constraints. For example, smallholders in Costa Rica can deliberately delay the harvest time of coffee by delaying the pruning of the trees (BUDOWSKI 1983).

Other forms of **intercropping and crop rotations** have recently been so well documented (cf. NORMAN et al 1982, STEINER 1982) that examples need not be given here. Apart from irrigated rice, which has been grown as a sole crop for thousands of years, multiple cropping was in the past the most common form of arable cropping in the tropics and subtropics and is still practised today, particularly in fields close to farm dwellings.

In densely populated areas, farmers have developed highly complex forms of horticulture which involve a mixture not only of several different species but also of different varieties of species. Probably

the most intensive **home gardens** are to be found in Southeast Asia: these are agroforestry microsystems including animals and fishponds, all combined in an effective nutrient cycle which permits high productivity and stability with relatively low energy inputs (MERGEN 1987). The Kandy forest gardens in Sri Lanka, which contain a great variety of tubers, vines, mid-level perennials and canopy crops, have been in operation for several centuries. Over this time, an extremely refined management system has been evolved to make optimal use of nutrients, moisture and light. The gardens provide erosion protection on the steep slopes, as well as a stable livelihood, and are regarded as one of the most productive agricultural systems in the tropics (FREEMAN & FRICKE 1980).

Also in East Africa on the slopes of Mount Kilimanjaro, the Chagga gardens integrate numerous elements of ecofarming: intercropping of multipurpose trees and shrubs with perennial cash crops (coffee and cardamom) and various lower-level food crops; stall-feeding of animals with fodder from trees/shrubs, banana plants and grasses grown on the homestead; and use of household wastes and manure as fertilizer (FERNANDES et al 1984). In West Africa, the home gardens of smallholders in the humid lowland of eastern Nigeria are similarly characterized by multistorey intercropping, in this case, of oil and coconut palms, various other useful trees and shrubs, bananas, maize, vegetables and root crops. Goats are stabled during the main crop season and are fed palm leaves and crop residues. Household wastes, plant materials and goat manure are collected in pits and used as fertilizer. Organic matter for mulching the home plot is gathered from more distant fields (LAGEMANN 1977).

Although not as intensively managed as in humid or hill-farming areas, kitchen gardens are a widespread feature of indigenous farming systems also in other parts of the tropics and subtropics. In the West African savanna, for example, gardens directly around the home comprise a mixture of trees, shrubs, and perennial and annual crops, which receive higher concentrations of household waste, animal manure and night soil than outlying fields (BEYER 1980).

The combination and spatial arrangement of components within home gardens and their management reveal that the indigenous horticulturists possess considerable knowledge about plant/animal/soil requirements and interactions. A striking feature of these gardens is the great diversity of plant species and varieties, even within a single garden. Farmers select seed from their own stands and obtain seed from neighbours. Among some of these local seed supplies, agricultural taxonomists and geneticists could discover a treasure of plant species and genes which are, in part, virtually unknown to formal agricultural science. The guardians of specialist knowledge about the specific traits and requirements of these plants are the men and women who grow them.

Soil fertility enhancement

In addition to the techniques of soil fertility enhancement involved in the above-mentioned multiple cropping and agroforestry systems, smallholders in the tropics and subtropics apply techniques which could be classified as mulching, green manuring or composting, as well as techniques which have yet to be studied and classified by agricultural scientists. These techniques deserve recognition and investigation before attempts are made to introduce, for example, complicated composting techniques which are presently known to agricultural scientists but may be less effective and more labour-intensive.

The use of intercropped leguminous plants, e.g. *Leucaena*, *Tephrosia*, *Crotalaria*, as **green manure** has already been mentioned above. Some smallholders also collect leaves and branches from noncultivated land and dig them into the soil of their farms (RUTHENBERG 1980).

The widespread practices of **ridge or mound farming** in the tropics are also traditional forms of green manuring. Grass and residues from previous crops are buried under ridges or mounds of soil on which the next crops are planted. During weeding, the ridge sides are broken down to bury the weeds, which compost naturally and are then worked into the ridges. Farmers who practise relay intercropping incorporate the residues from the earlier crop into the ridges on which the later crop is still growing, so that this can benefit from an increased supply of nitrates (RICHARDS 1985). Farmers in Angola use termites to speed up the decomposition process: they pile maize straw, cassava stalks and other plant wastes around termite mounds, let the termites go to work, and then use the mounds for cropping. A variation of mound farming is to set the mounds alight after the fallow vegetation has been covered with earth, so as to increase phosphate availability to the subsequent crop (RUTHENBERG 1980).

Constructing ridges or mounds is a multipurpose technique which combines the maintenance of organic matter in the soil with numerous other advantages. Where a laterite crust lies close to the soil surface, farmers heap up the topsoil to ensure adequate depth of soil for root growth without having to break up the crust (RICHARDS 1985). In soils with a low pH, heaping the topsoil creates a larger area of less acid soil for plant establishment. Where rainfall is heavy, ridging improves drainage and keeps the plants above the water table, yet prevents the soil from washing away. In low rainfall areas, tied ridges help to capture rainwater and encourage infiltration. Mounds can provide soil microclimates suitable for specific plant species or combinations; farmers apply their knowledge of plant interactions, root systems and water needs in positioning the crops on the mounds.

The use of **cultivation pits,** as by the Matengo in southern Tanzania (ALLAN 1965), combines aspects of green manuring, composting and erosion control. A particularly complex system has been developed in the rainforest of Brazil, in areas which the unpractised eye might regard as untouched. Here, the Indians prepare heaps of sticks, branches and leaves, let them rot, then beat them with sticks to produce a mulch which is spread in slight depressions. The mulch is mixed with soil from termite mounds and smashed-up bits of ant nests, including living ants and termites, and are planted with several different species of useful plants found in other parts of the forest (POSEY 1985).

Composting has an extremely long tradition in the Middle and Far East. WEBSTER & WILSON (1966, p.207) detail the careful practices of preparing and applying compost in Chinese irrigated farms. Indigenous composting practices are also reported from Africa. Farmers on Ukura Island in Tanzania make compost out of stall litter which includes crop residues, leafy branches of trees and shrubs, and old roofing grass (LUDWIG 1967). Rwandan farmers pile household wastes, crop residues, weeds, and dried leaves and twigs of trees into heaps to be used as fertilizer (BALASUBRAMANIAN & EGLI 1986). The Shona in Zimbabwe apply a composted mixture of maize stalks and cattle dung to their vegetable gardens, and the Dogon in Mali combine crop residues, dung, household refuse and ash to produce fertilizer (HARRISON 1987). Using wood ash as fertilizer, either as a component of compost or directly, is a common way of importing nutrients from bushland into cropped areas (RUTHENBERG 1980).

Mulching is a regular practice in some smallholder cropping systems, e.g. ginger-growers in central Nigeria collect branches and leaves from bushland for this purpose. In other cropping systems, use of mulch depends on variations in rainfall: e.g. if rainfall is late, mulching is practised to conserve moisture (RICHARDS 1985). This was also observed in central Nigeria, where yam ridges were mulched with sorghum stalks or *Euphorbia* branches only in dry years. As already mentioned in the previous section, mulching is often practised in indigenous agroforestry and horticulture systems. Also "poor" weeding can be regarded as a form of mulching. Many farmers distinguish between "good" and "bad" weeds (cf. HATCH 1976). Good weeds which are left in the fields help to reduce erosion, prevent soil heating and preserve soil moisture. They may also fix some nitrogen.

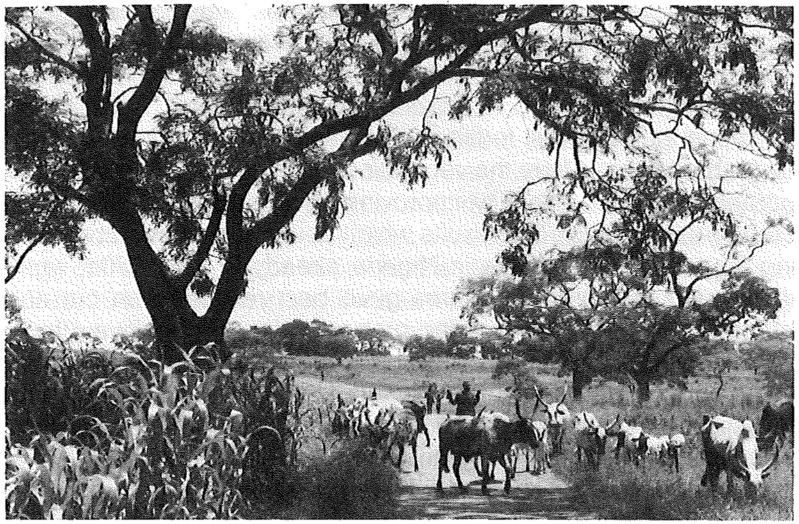
Farmers in South Asia have shown that heat and moisture fluxes can be controlled not only by mulching with organic material (or "poor" weeding) but also through tillage practices, which produce a fine surface tilth which could be referred to as "dry soil mulch" (MURTON 1980).

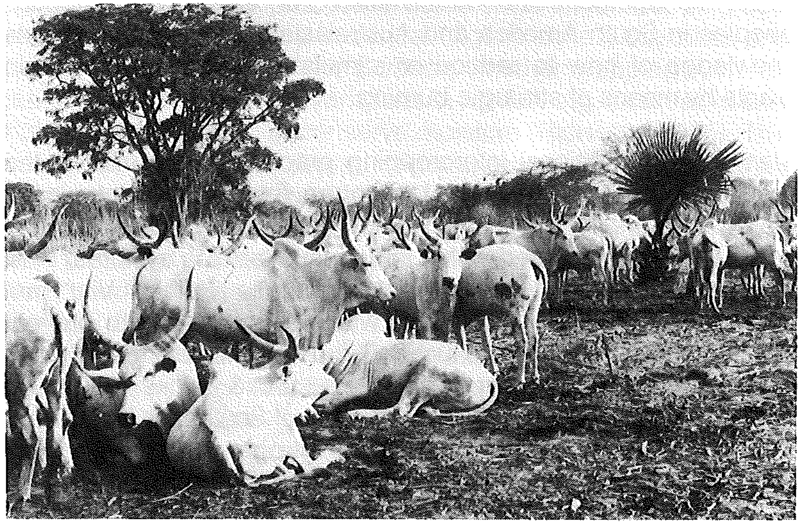
Burning plant matter is a widespread indigenous technique of manipulating soil fertility. Particularly shifting cultivators have, through long experience, acquired much knowledge about the timing and intensity of burns to achieve different aims. A well-timed burn can increase soil fertility. It releases phosphorus, potassium and other minerals from the vegetation to the soil. The ash also temporarily raises soil alkalinity, improving phosphate availability to the crops (ALLAN 1965). The results which could be achieved by burning surprised researchers in Nigeria already in the 1930s, when they found that green manures gave best results when cut and burnt (RICHARDS 1985). Burning probably also has positive effects in destroying weed seeds, insects and harmful bacteria. In any case, burning is undeniably a low-input technique of clearing land. Investigation of the indigenous use of fire could lead agricultural scientists to a better understanding of the effects of burning and how fire could be most advantageously used within ecofarming systems. It could also assist scientists in finding low-cost methods of forest management and reforestation. For example, indigenous peoples in South America and Australasia possess considerable knowledge of how to reduce or stimulate the growth of certain plants by means of strategic burning.

Many of the traditional intercropping practices mentioned in the previous section make **use of nitrogen fixation** by leguminous plants. Also the symbiotic association of blue-green algae and the water fern *Azolla* is used within indigenous farming systems. Until recently, only a select group of rice farmers in Northern Viet Nam knew how to regulate the acidity within a rice paddy to prevent senescence of the *Azolla* culture and, thus, to maintain "seed" colonies for inoculation of other paddies (FREEMAN & FRICKE 1980). Use of the fern has now spread to other parts of Southeast Asia. Other traditional techniques of managing nitrogen-fixing organisms doubtless exist but have yet to be discovered by formal science.

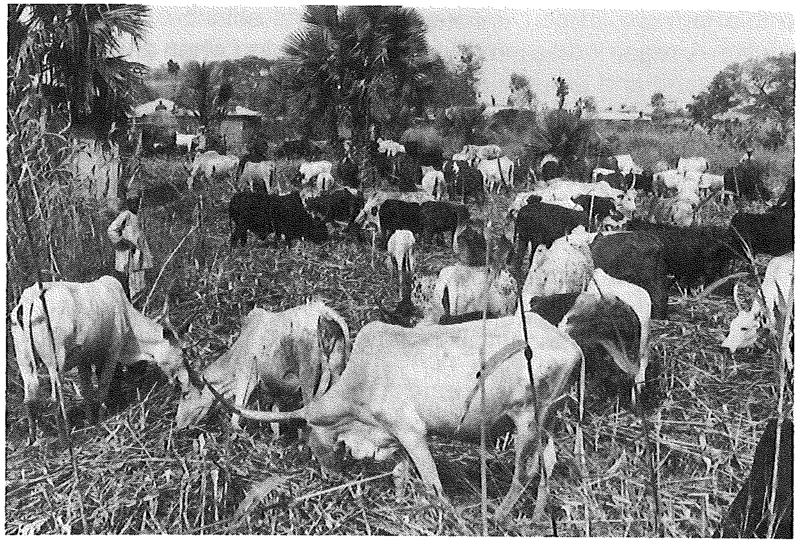
Crop-livestock integration

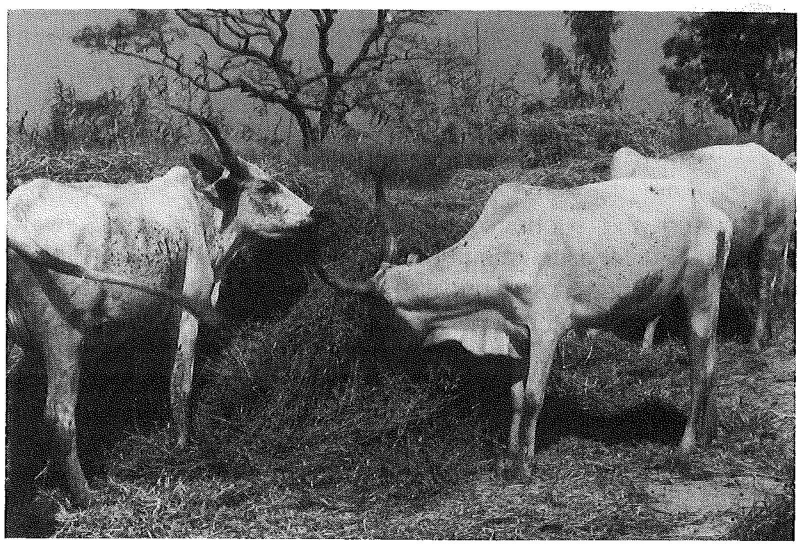
Just as trees are an integral part of many indigenous farming systems, so also are animals – even if the animals do not belong to the





Plates 14 and 15:
Land-use systems involving an association of cereal cultivation, a park-like tree cover and cattle raising can be found throughout the African savanna, as here in Nigeria. Fallow fields provide better grazing (top) than bushland. Overnight camping of cattle concentrates manure on areas to be cropped (bottom).





Plates 16 and 17:
Crop residues make an important contribution to cattle diet in the dry season: the harvested fields are grazed (top) and cattle are brought to threshing areas to eat the residues, here of soybean (bottom).

arable farmers. In conventional agricultural science, animal production is regarded as integrated with cropping when animals provide manure and draught power for cultivation, forages are part of the cropping cycle, and the animals and crops form part of the same production unit. Whereas these forms of integration do exist in smallholdings in the tropics, additional forms of crop-livestock integration have also evolved which occur not only within but also between production units. The close spatial integration of crops and livestock is demonstrated by the fact that, in the Nigerian savanna where different ethnic groups specialize in either cattle-keeping or cropping, cattle and cultivation densities are positively correlated over a wide range (BOURN & MILLIGAN 1983).

Some crop-livestock linkages which have evolved within indigenous land-use systems in the tropics and subtropics include (cf. MCCOWN et al 1979):

Investment linkage. Surplus cash earned by farmers is often invested in livestock; the offspring provide the interest. Animals, in turn, can be used to finance cropping inputs.

Manure linkage. Many farming systems depend on animal manure to maintain soil fertility. Examples of using manure in compost have already been discussed above. In less intensive land-use systems in semiarid and subhumid areas, pastoralists (i.e. people who derive their livelihood primarily from grazing livestock) are often welcomed by farmers during the dry season because overnight kraaling of herds in the fields is a labour-efficient way of obtaining and applying fertilizer. In some areas, farmers are even prepared to pay herd owners for overnight kraaling (WATERS-BAYER & BAYER 1984). Hausa farmers in northern Nigeria also consider the breaking down of cultivation ridges and the trampling in of crop residues by cattle to be beneficial (VAN RAAY 1975).

Animals are used to transfer nutrients to cropland, as in Sudan, where cattle are taken to graze the Nile floodplain but are brought back to concentrate manure on the small areas of higher, better-drained cropland around the homesteads (VAN NOORDWIJK 1985).

Indigenous methods of handling manure and strategies of applying it, e.g. using a mixture of trampled goat manure and wood ash for millet nurseries, may be just as or more efficient in biological and labour-economy terms than the conventional methods known to agricultural scientists, and deserve investigation before attempts are made to replace them by "modern" methods.

The efforts made by many smallholders to obtain animal dung reflect not only their awareness of the need for adding nutrients to the soil but also their concern for improving soil physical properties through addition of organic matter. Also their various techniques of green manuring and composting reflect this concern. This is an important point to ponder by agricultural scientists attempting to promote the use of chemical fertilizers, which address only the problem of nutrient supply.

Forage linkage. Although little is grown explicitly as forage, crop products are important for animal production in several indigenous livestock-keeping systems. Throughout West Africa, keepers of ruminant livestock make arrangements with arable farmers to graze crop residues (MCCOWN et al 1979). In a pastoral system in Nigeria, it was found that cattle ate crop residues for up to 80% of their grazing time in the first two months after harvest (VAN RAAY & DE LEEUW 1974). In Kenya, an estimated 40% of total energy intake of livestock in the highlands is derived from crop residues (STOTZ 1983). Crop thinnings, weeds, and lower leaves stripped from standing crops are also fed to livestock.

Farming systems involving an association of cereal cultivation, a park-like tree cover and cattle raising can be found throughout semiarid and subhumid Africa from the Senegal to the Sudan. Various species of trees, above all *Acacia albida* in the Sahel, not only enrich the soil with nutrients and organic matter; they also provide a valuable source of dry-season fodder. During grazing of millet and sorghum residues plus the leaves and pods from the tree layer, cattle enrich the soil with manure (FREEMAN & FRICKE 1980).

Draught linkage. Animals have been used for draught purposes for centuries over much of North Africa; in other parts of Africa, only

Ethiopia has a long tradition of animal traction, using a simple hook plough (MUNZINGER 1982). Animal traction is much more widespread in Asia, e.g. in smallholdings in India, a country in which the energy for ploughing two-thirds of the cultivated area comes from draught animals (RAMASWAMY 1985). In waterlogged fields in parts of India, Bangladesh and Thailand and on narrow-terraced hill fields in Nepal, indigenous farmers have developed techniques of using draught animals under these difficult conditions. Like most other resources in smallholder systems, provision of draught power is often one of several functions of the animals; the functions of providing manure or milk may be equally if not more important to the farming household. Where farmers have deliberately not adopted animal traction promoted by outside agencies, investigation of the farmers' perceptions of soil suitability and erosion risks can point to adaptations of the technology required to render it appropriate to the specific ecological conditions.

Complex systems involving several of the above-mentioned linkages between crops and livestock have been developed by smallholders throughout the tropics and subtropics, e.g. on Ukara Island and Mount Kilimanjaro in Tanzania, in the Papua New Guinea highlands, in *campesino* farming systems in Chile, and in the intensive home garden systems found in highly populated parts of Asia as described in the section 'Vegetation design and manipulation'. In many of these intensive systems, the livestock component consists of pigs or smaller animals such as rabbits, poultry and fish. The indigenous techniques and strategies of integrating these animals into their production systems manifest the farmers' awareness of the value of livestock not only in economic but also in ecological terms.

Plant protection

Smallholders in many parts of the tropics and subtropics use biological methods to suppress crop diseases and pests. Many of the above-mentioned soil and crop management practices play a role in reducing incidence of diseases or pests, e.g. burning destroys weed seeds and helps control insects and other pests, intercropping hinders the spread of diseases or pests, retaining "good" weeds in the fields reduces insect pressure on crops, fallowing interrupts insect reproduction cycles. Some further measures of disease and pest control in indigenous farming systems are:

- choice of fields, e.g. avoiding areas where certain diseases are more prone, such as black pod disease of cocoa if planted in valley bottoms (ZEHRER 1985);
- choice of varieties which are more resistant, e.g. by virtue of their growth period, such as the use of traditional sorghum varieties in Togo which ripen in the early dry season, which is not so favourable for insects as the late wet season when "improved" cultivars ripen (ZEHRER 1985);
- land and crop rotation to avoid build-up of pests and diseases which thrive on a particular plant species, e.g. the Quechua Indians' rotation of potatoes, other tubers and cereals to prevent soil infestation by nematodes (FREEMAN & FRICKE 1980);
- treatment of seed, e.g. soaking seeds with ash or neem leaf extract to reduce bird attraction (ZEHRER 1985);
- including plants in the crop mixture which deter insects, such as in the Chagga gardens in Tanzania (MERGEN 1987).

STOLL (1986) refers to the combination of several measures as a key factor in indigenous systems of plant protection, as this reduces the capability of pests to adapt to the situation. Typically, the measures adopted are very site-specific and reveal a detailed knowledge of the attributes of often very localized plants and insects. For example, Brazilian Indians deliberately introduce one type of ant into their planted areas of the forest in order to repel leaf-cutting ants (POSEY 1985).

With respect to plant protection, ALTIERI (1985) stresses the importance of the high genetic diversity maintained in traditional systems, as this reduces the threat from pests and pathogens specific to particular strains of the crop. For example, farmers in the Andes grow as many as 50 distinct varieties of potatoes. Paddy rice systems in Asia have an even wider genetic base. Similar varietal diversity is found in African millet systems. Maintaining a wide genetic base also permits the farmer to adapt his production system by changing varietal emphases when he observes concentrations of certain pests. Growing a mixture of varieties in one field not only reduces the danger of disease spread; it can also allow a staggered harvest and consumption of grain. Because less of the harvest must be stored, the amount of grain subject to pest damage in storage is reduced.

This brief description of some indigenous ecofarming practices in the tropics and subtropics reveals that the farmers have typically developed measures which serve various purposes, e.g. not only to improve soil fertility or prevent soil erosion but also to yield useful products such as firewood, stakes for climbing plants, food and fodder. The multiple purposes of individual measures or components of the indigenous farming systems and the close integration of components are characteristics which increase stability, i.e. reduce annual variations in output of the system. The change in any one component could have far-reaching ramifications – and not only in a positive sense. It is unlikely that outside scientists could ever achieve the comprehensive understanding of the local environment and ecological interactions which indigenous farmers have attained through generations of experience and refinement of their farming methods.

It is, therefore, necessary that agricultural development agencies, rather than trying to impose methods developed elsewhere, give the farmers every opportunity to use their own detailed knowledge of their environment in developing their own farming systems and judging the ramifications of new techniques or inputs.

3.2 Indigenous experimentation

Indigenous farming systems are often called "traditional" with the connotation that they are relics which have been handed down unaltered over generations. However, the agricultural history of any

farming group will reveal that the production system has adapted to changing external conditions and incentives and has incorporated and developed new techniques and ideas. These have often been incorporated so thoroughly that a farmer may even initially refer to them as "traditional". If the crops, varieties, methods and technologies used by the present farmers are compared with those used by preceding generations, or if changes in production of even a single crop by a single cultivator over his or her lifetime are investigated, the dynamic nature of the indigenous farming systems becomes obvious. The existing farming system is the result of continuous efforts by local men and women to recombine their environmental knowledge and available resources in response to changing conditions and new ideas in order to maintain a viable form of production.

Farmers throughout the world conduct small-scale, low-cost, low-risk experiments: trying out a new technique, a new variety, a new crop mixture, often using ideas or materials (e.g. small quantities of seed) acquired on a trip, from visitors or from neighbours whose experiments they have already observed. The home garden often serves as a testing ground for new inputs, particularly new crops and varieties. JOHNSON (1972) offers several examples of experimentation in traditional agriculture, such as tobacco farmers in Puerto Rico trying out late transplanting to see if it improves yields. Farmers in Bangladesh used informal research methods to develop rice varieties and cropping systems suited to particular hydrological conditions (BIGGS 1980). Farmers in the mid-hills of Nepal discovered a cold-resistant rice variety and carried out trials in several villages to discover up to what altitude it could be grown (THRUPP 1987b).

RICHARDS (1985) describes the innovative vigour of West African smallholders. Where population increase is exerting pressure on the land-use system, farmers experiment to relieve these pressures. In southern Nigeria, farmers worried by reduced fallows and declining fertility have experimented with new intercrop mixes and have started to develop compound farms fertilized with household refuse. Even in more sparsely populated areas where changes within the farming system are not required by external pressures, farmers display inventiveness and adaptiveness. In a low-populated area of Sierra Leone, farmers were experimenting with double cropping, integration of tree-crop and rice cultivation, and intercropping in swamps.

These have been examples of largely autonomous processes of innovation within indigenous farming systems. Also the new technical packages which extension services try to introduce are subjected to experimentation by smallholders, who select and develop those aspects of the packages which they recognize as being potentially beneficial to them. They may even take up ideas discarded by the researchers. For example, farmers in Sierra Leone were found to be selecting within an "improved" variety of rice in order to obtain a plant type with awns or long outer glumes which they found useful in deterring birds. This trait had not appeared useful to the station-based plant breeders, who had even been selecting against it (RICHARDS 1985). Among agricultural scientists and extensionists, little is known of how farmers select, modify and adapt new technologies, of how they integrate modern agricultural knowledge into their traditional systems of knowledge. In RHOADES' (1987) words:

> "We, the non-farmers, lack even the basic understanding of farmers' own research methods, their schemes of information exchange, their informal farmer-to-farmer extension methods, and their approaches to generating new technology or designing new farming systems".

The foregoing account of indigenous ecofarming knowledge and of autonomous innovation processes is not intended to prove that the smallholders require no assistance from agricultural research and advisory services. The social cohesiveness, values and self-determination potential of smallholder communities have been affected by increasing interactions with the cash economy and with alien systems of education and land legislation. This has weakened traditional forms of environmental management and reduced self-confidence in indigenous systems of knowledge and experimentation.

Rates of population growth may exceed indigenous capacities to adapt the production systems to meet increased needs without degrading the natural resources on which they depend. The experimental approach of farmers tends to be slow and highly dependent on chance encounters with new ideas.

The indigenous capabilities of experimenting and generating new ecofarming knowledge need to be fostered by agricultural development programmes. Combining scientific and indigenous knowledge could speed up the process of finding ways to increase the productivity yet maintain the ecological sustainability of land-use systems in developing countries. For example, by combining the knowledge of ecologists, geneticists and agronomists with indigenous knowledge in managing local tree species in multistorey systems, techniques could be developed of selecting and managing faster-growing nitrogen-fixing tree species to provide more fuel, fodder and mulch from the trees as well as more crop and animal products. Similarly, combining formal and "folk" science could lead to the discovery of fertilizers which can best interact with local measures of enhancing soil fertility, and to the development of application techniques which make efficient use of both the additional fertilizer inputs and the farmers' labour resources. RICHARDS (1985) and other observant scientists have provided ample evidence that many smallholders possess the inventive curiosity, experimental creativity, skills and experience to collaborate with agricultural scientists in ecofarming research and development.

Combining formal and "folk" scientific knowledge and experimentation in ecofarming becomes increasingly important as the limitations to energy sources required for modern agrotechnologies become increasingly evident. Systems of indigenous knowledge and knowledge generation could make a much needed contribution to international efforts to manage natural resources in a productive and sustainable way.