2. Ecofarming in Technical Cooperation

2.1 Major techniques and principles of ecofarming

Thus far in projects of Technical Cooperation with an ecofarming component (see Annex 3), the emphasis has been on specific techniques of biological agriculture. These are aimed at achieving high and lasting productivity while maintaining or restoring a balanced ecosystem at a given site. The most widely applicable techniques which permit intensive plant growth (biomass production) and good humus management even with low levels of external inputs can be classified as vegetation design, use of biological symbionts, green manuring, mulching, composting, integrated plant protection and integration of livestock and/or aquaculture.

Classifying ecofarming techniques in this way does not do justice to the comprehensive and interactive nature of ecofarming. Ecofarming is much more than a technical package. It is an integrated, interdisciplinary approach to development at the farm level, and it is this approach which will be the focus of discussion in the following chapters. In this chapter, the major production techniques and biological principles involved in ecofarming are described only briefly; more detail can be found in MÜLLER-SÄMANN (1986). The main concern in the present context is how these techniques fit into smallholder farming systems.

Vegetation design: multiple cropping and agroforestry

Multiple cropping is a widespread practice in traditional farming systems in the tropics, but the introduction of European production methods has encouraged its replacement by sole cropping. Where land is not in short supply, sole cropping permits a higher degree

of labour productivity, particularly under mechanization. As land becomes increasingly scarce (in many regions of the tropics, the area of land available per capita is now less than 0.1 ha), output per unit area and yield stability become crucial and multiple cropping regains importance. In recent years, agricultural research has recognized this fact. Crop interrelationships have been analysed and various systems and concepts of multiple cropping have been recorded, as summarized in Table 2.

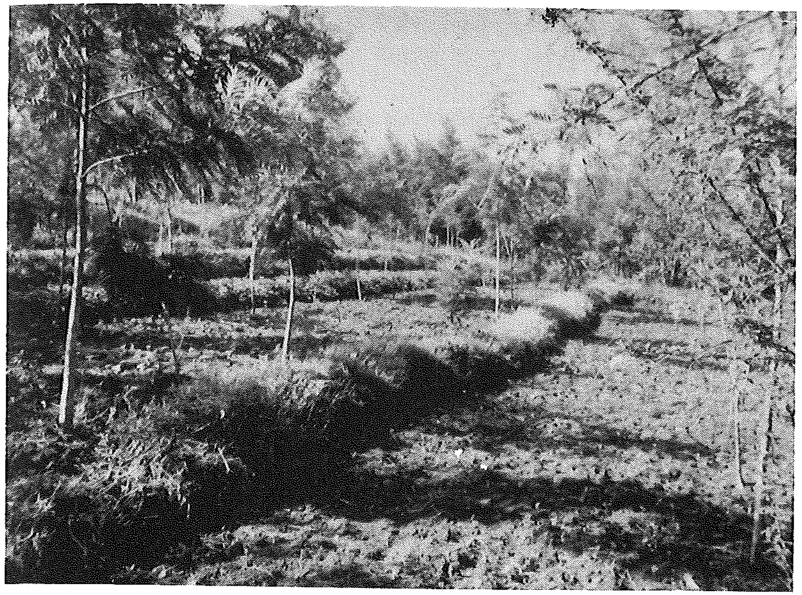
Table 2: Definition of the principle multiple cropping patterns

Multiple cropping: Intensification of cropping in terms of time and space. Growing two or more crops on the same field in a year.

1. **Sequential cropping:** Growing two or more crops in sequence on the same field per year. The succeeding crop is planted after the preceding crop has been harvested. Intensification of cropping is only in terms of time. There is no competition between crops, as only one crop is grown at a time in the field.
   - 1.1 **Double cropping:** growing 2 crops/year in sequence;
   - 1.2 **Triple cropping:** growing 3 crops/year in sequence;
   - 1.3 **Quadruple cropping:** growing 4 crops/year in sequence.

2. **Intercropping:** Growing two or more crops simultaneously on the same field. Cropping is intensified in terms of both time and space. There is competition between crops.
   - 2.1 **Mixed intercropping:** growing two or more crops simultaneously with no distinct row arrangement;
   - 2.2 **Row intercropping:** growing two or more crops simultaneously, with one or more crops planted in rows;
   - 2.3 **Strip intercropping:** growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough to achieve multiple cropping effects, e.g. alley cropping;
   - 2.4 **Relay intercropping:** growing two or more crops simultaneously over part of the growing period. The second crop is planted after the first has reached its reproductive phase but before it is ready for harvest;
   - 2.5 **Multistorey cropping:** association of tall perennials with shorter biennials and annual crops.

Source: after ANDREWS & KASSAM 1976, in STEINER 1982.



Plates 3, 4, 5 and 6:
In agroforestry systems, ground-level crops, shrubs and trees are combined in such a way that they compete as little as possible for nutrients, light and water (top left). A high yield per unit area can thus be achieved. The multi-storied vegetation provides not only food but also the fuel to cook it. The trees contribute to ecological stability; for example, planting trees and shrubs along contour lines on slopes is an effective means of erosion control (bottom left, top right). By means of decentralized on-farm nurseries, the farmers can provide themselves with the seedlings needed for agroforestry (bottom right).

Multiple cropping can involve crop succession (sequential cropping) or spatial co-existence (intercropping); the former emphasizes timing and the latter spacing. However, both aspects can be combined, e.g. in relay cropping or in cases where a ley crop (see Section 'green manuring') is sown with the final food crop before the ley period. Planting must be timed and spaced so that competition between the crops in the stand is minimized and synergism promoted. Essentially, multiple cropping should serve the following functions:

- provision of ground cover year-round or for a lengthy period of the year, in order to protect the soil from dessication through evaporation and from erosion;
- reduction of seasonal labour peaks as a result of different sowing and harvesting times of the individual crops;
- prophylactic plant protection through diversification of species and varieties (increasing the antiphytopathogenic potential in the stand);
- increased output per unit area, particularly with low levels of external inputs, as a mix of species makes better use of available nutrients and water in the soil;
- an evenly distributed provision of food supply over the year and lower production risks: if one crop fails, e.g. as a result of bad weather, the other crops still use the field and provide a harvest.

In smallholder agriculture, the aspect of risk reduction is the primary attraction of multiple cropping, for a bad harvest can endanger the very survival of the farm family. The results of numerous trials also confirm the superiority of multiple cropping over sole farming in several other aspects (STEINER 1982, BEETS 1982). However, findings in one area do not yield widely applicable "recipes" for multiple cropping. Optimal crop combinations are site-specific and must be developed through local experimentation.

Agroforestry or multistorey farming is a form of multiple cropping which essentially involves a vertical arrangement of crops (plants growing one above the other), whereas the dominant concept of intercropping is one of horizontal arrangement (plants growing be-

Plate 7:
In many locations, such as here in Tanzania, traditional multiple cropping systems can be further developed in the light of new scientific knowledge. Maize, sweet potato, soyabean and cassava thrive in a complex horizontal and vertical pattern. Multiple cropping permits land-intensive production, provides a more steady supply of food and reduces production risks compared with sole cropping. The longer or even permanent ground cover protects the soil from erosion.

side each other). The integration of trees and shrubs with field crops eliminates the spatial separation between field and forest. A structural diversity of vegetation is sought which approaches the optimum for that site (structure of the climax vegetation). As in intercropping, the plants are combined in space and time in such a way that they compete as little as possible for nutrients, water and light, but rather complement each other in their differing requirements so as to achieve an optimal output per unit area. Scientific research in interrelationships and practical methods of agroforestry is still in its infancy. The main ecological functions of trees and shrubs on cropped land which are known thus far are:

Erosion control. Trees and shrubs provide protection against erosion and preserve agricultural land. This applies not only to mountainous regions with heavy precipitation but also to low-rainfall areas such as the Sudano-Sahel zone.

Improved water balance. Trees and shrubs increase the water absorption and retention ability (infiltration rate and field capacity) of the soil. As a result of the greater availability of water to the plants, the growing period can be extended into the dry season, total plant production increased, and the soil protected by vegetative cover for a longer period of the year. Competition between individual crops for water cannot be avoided; however – in relation to total production – water utilization is generally more efficient: less water is consumed per kilogramme of dry matter produced. Losses resulting from evaporation, seepage and surface runoff are reduced.

Improved nutrient cycling. Plant residues (e.g. fallen leaves) from trees supply organic matter to the soil. Mulch cover promotes nutrient cycling by favouring the development of symbiotic root fungi (*mycorrhiza*) and reducing nutrient losses from leaching or fixation. Moreover, deep-rooted trees draw nutrients from deeper soil layers and recycle them through litter-fall and wood production.

Improved microclimate. The presence of dispersed trees in fields and pastures also changes the climate within the plant communities. Slight shading increases air humidity and reduces diurnal

temperature fluctuations; reduced heating of the soil slows down humus decomposition. At sites with high solar radiation and/or high temperatures, multistorey cropping can result in better utilization of solar energy and prevents excessive generation of heat within the stand.

Trees not only preserve soil fertility; they also make an important **contribution to the economy of the farm household.** As trees provide various products such as firewood, timber and fodder, the integration of trees into farming systems can reduce household expenditures for these products or can provide an additional source of cash income. If trees and shrubs are planted in home gardens and adjacent fields, their products can be collected quickly at the convenience of the household members. This considerably reduces the time and energy that particularly women and children must spend collecting firewood and increases the flexibility of timing this activity. The contribution of trees to improving working conditions should also not be underrated: the physical efficiency of workers under the climatic conditions created by trees is considerably higher than in the open field.

As cropping is intensified in densely settled areas, horticultural techniques based on intercropping and multistorey cropping (including shrubs and trees) become increasingly important. The concentration of diverse vegetables, grain legumes and fruits in home gardens can result in an extremely high output per unit area and can make a substantial contribution to the income of smallholder households. Home gardening helps above all to eliminate the major causes of malnutrition: deficiencies in protein, vitamins and minerals.

Use of biological symbionts

Nitrogen is often the nutrient in plant growth which most limits yields. It is present in the earth's atmosphere as a pure element N_2 but cannot be absorbed by plants in this form. Plants are dependent on fixed nitrogen. Fixation is achieved biologically by bacteria, fungi and algae, i.e. microorganisms which live in soil or water either freely or in symbiosis with plants.

The development of chemical ammonia production on an industrial scale led to a waning of interest in biological nitrogen fixation and a concentration of efforts on extending the use of mineral fertilizers. Not till the onset of the energy crisis in the 1970s was it realized that nitrogen obtained by chemical means can make only a very limited contribution to increasing agricultural production. According to data given by CZYGAN (1971) for 1959, only 6% of the nitrogen present in the world's harvests is derived from industrial products. Even if this proportion has doubled in the meantime, it provides – at least in quantitative terms – an indication of the relative significance of mineral nitrogen. More important, however, are the qualitative aspects. Mineral nitrogen is often applied incorrectly; doses which are too high and too one-sided have a counterproductive effect on soil fertility and hinder biological nitrogen fixation. Seen in this light, application of mineral nitrogen requires utmost caution and a great deal of experienced judgement.

In the meantime, there has been a resurgence of interest in biological means of making nitrogen available to plants. The large group of plants known as the legumes, many of which live in symbiosis with nodule bacteria (*rhizobia*), are the focus of attention. The tropics in particular contain a wide range of leguminous species and thus have a great potential for biological nitrogen fixation. These include trees such as the widespread acacias, shrubs such as *Leucaena* and *Calliandra*, and ground-covering food and fodder crops such as groundnuts and *Desmodium* spp. The diversity of existing legumes offers numerous development possibilities in agroforestry, multiple cropping, green manuring etc.

Another important group of biological symbionts are the blue-green algae in irrigated rice which, living either freely or in association with the water fern *Azolla*, can fix enormous amounts of nitrogen. A third group consists of the *actinomycetes* (ray fungi), which live in symbiosis with trees (casuarina, alder) and other lignifying plants, and a fourth consists of free-living bacteria such as *azotobacter* and

azosperillum. The role of mycorrhiza in nutrient cycling is discussed in the section 'Mulching' .

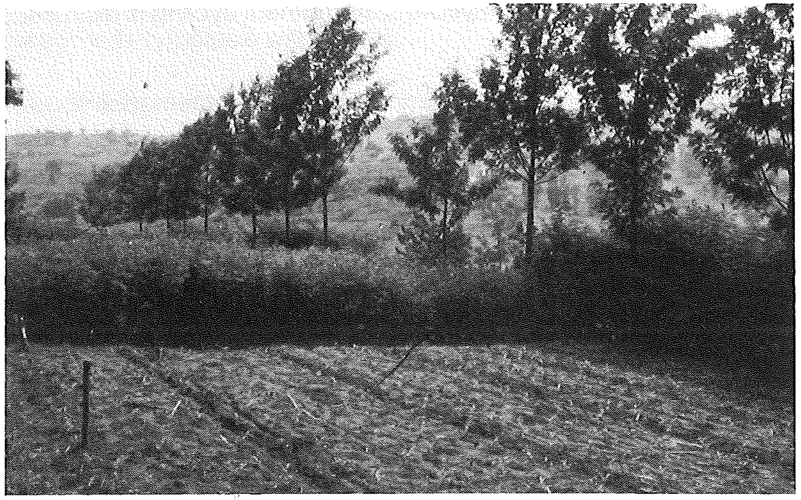
Green manuring

Where permanent cropping is increasing, green manuring techniques gain considerably in importance, particularly in the tropics. Incorporating sizable quantities of biomass, preferably from nitrogen-fixing legumes, into the soil is an extremely important way of maintaining soil fertility. Two basic forms of green manuring are possible:

Single-season or multiseason fallowing. Particularly after bush fallowing over several seasons, the biomass growth has a high proportion of lignified plant parts which, when incorporated into the soil, mineralize relatively slowly and have a correspondingly long-term effect. This form of green manuring can lead to a gradual build-up of humus, but has the disadvantage that no food crops can be grown during this period. Therefore, green manure fallow is often impracticable in areas where land is in short supply. However, when soil fertility is completely degraded, a green manure fallow may be the only possible means of building up new humus.

Green manure fallow which simultaneously regenerates soil fertility and provides pasture or fodder for livestock is the central feature of ley farming. Grazing of grass fallows may reduce the amount of organic matter which can be returned to the soil. In the case of mixed grass/legume leys, however, initial selection by grazing animals for grass reduces competition for light and nutrients for the legumes and, thus, promotes legume growth. Under such conditions, grazing of fallows can even enhance soil fertility regeneration, particularly the supply of nitrogen.

Green manure undersowing. In order to maintain soil fertility in spite of permanent cropping, ground-covering legumes are grown in association with crops. The results of numerous trials show that this can be done without detriment to the main crop and can even increase its yield (cf. MÜLLER-SÄMANN 1986). Undersowing gener-



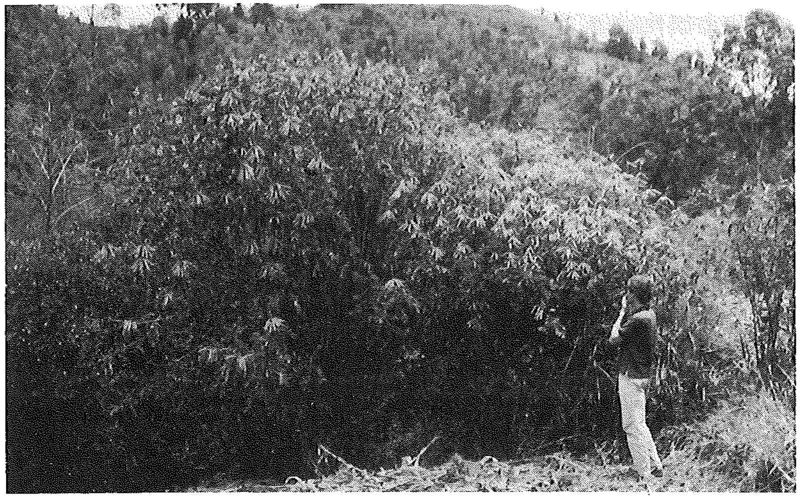


Plate 8 and 9:
Balanced crop rotations including green manure (top, in background) help maintain soil fertility. Popular green manure crops are quick-growing legumes which not only produce a large amount of biomass but also fix considerable quantities of nitrogen. For example, within a period of 10 months, the shrub *Tephrosia vogelii* (bottom) grows in Rwanda to a height of 3 m and produces 14 t dry matter of above-ground biomass which, when worked into the soil, can increase the yield of subsequent crops as much as fivefold.

ally has a short-term effect; it stimulates soil organisms and can lead to increased decomposition of organic matter without additional organic manuring (priming effect). Therefore, the undersowing technique must be applied with care so as not to produce the opposite effect, i.e. a decrease in soil fertility.

Agroforestry systems can also include an element of green manuring, e.g. when trimmings from hedges such as *Leucaena* and *Sesbania* are worked into the soil.

Proper use of green manuring leads to increased yields and long-term improvement of chemical and physical properties of the soil; at the same time, the technique requires little in the way of external resources and capital. However, the introduction of green manuring is often difficult because:

- in comparison with fallowing, more work and higher costs are involved, and the direct benefits are often not sufficiently obvious to farmers;
- if mechanization is not available, as is often the case, working the biomass into the soil involves heavy physical labour.

A particularly attractive proposition in economic terms is the green manuring of fields some distance from the homestead and livestock enclosures, as substantial costs would be incurred in transporting other farm-produced fertilizers (dung, compost) to such fields.

In the permanently humid tropics, where soils are generally poor in minerals and have a low sorption capacity, one function of green manuring is to reduce nutrient leaching. Large amounts of biomass can be produced quickly and need not be worked into the soil; under these favourable climatic conditions, microorganisms quickly decompose the mulch layers. In the subhumid savanna, choice of green manuring techniques is determined by the seasonal fluctuations in water availability. In most cases, only the long rainy season is suitable for undersowing, while the short rainy season can be used as a period of pure green manuring. In the semiarid savanna, possibilities for green manuring are very limited (high utilization costs for water consumption). Most suitable here is leaf dressing with foliage of drought-resistant tree and shrub species. In tropical highlands with well-balanced rainfall distribution, green manuring has greater potential, although low temperatures at high elevations can be limiting in that they prevent adequate mineralization.

Mulching

Mulching is an agricultural and horticultural measure which involves spreading organic or inorganic matter on the soil surface so as to cover it to the greatest possible extent. This is done either by leaving crop residues on the field or by bringing matter from elsewhere to the field.

The main function of mulching is to create a microclimate (temperature, air humidity) in the topsoil which is fairly independent of the weather. The mulch layer protects the soil from dessication and excessive heating and thus optimizes the conditions for the decomposition and mineralization of organic matter; at the same time, it protects the soil from erosion through heavy rains and wind. In this respect, it fulfils the same functions as undersown plants, cover crops or green manuring crops, which are also referred to as "living mulch".

Over time, the mulch layer is decomposed, and mineralized by small animals and microorganisms. In this environment, the root fungi mycorrhiza can develop particularly well. They live in symbiosis with the plants and provide them directly with a large proportion of the nutrients from the dead plant matter (direct mineral cycling). As the soil plays no role here as intermediary, no nutrients are lost from the soil as a result of leaching or fixation. At the same time, humus is formed, which is worked into the soil by the soil fauna (earthworms etc.). For this reason, mulching is also referred to as "surface composting".

The cheapest and easiest method is to use crop residues for mulching. Alley cropping also provides mulch on the spot: fast-growing trees and shrubs (e.g. *Leucaena, Gliricidia*) planted in strips between rows of crops are lopped at regular intervals to mulch the crop rows, and also serve numerous other useful functions as agroforestry elements. However, transporting mulch from elsewhere can also be an economical proposition, whether it be by cutting wild reeds in swampy flats or by actually growing mulch material. In the case of coffee growing in Kenya, it is even recommended to fertilize not the coffee itself but rather the mulch areas.

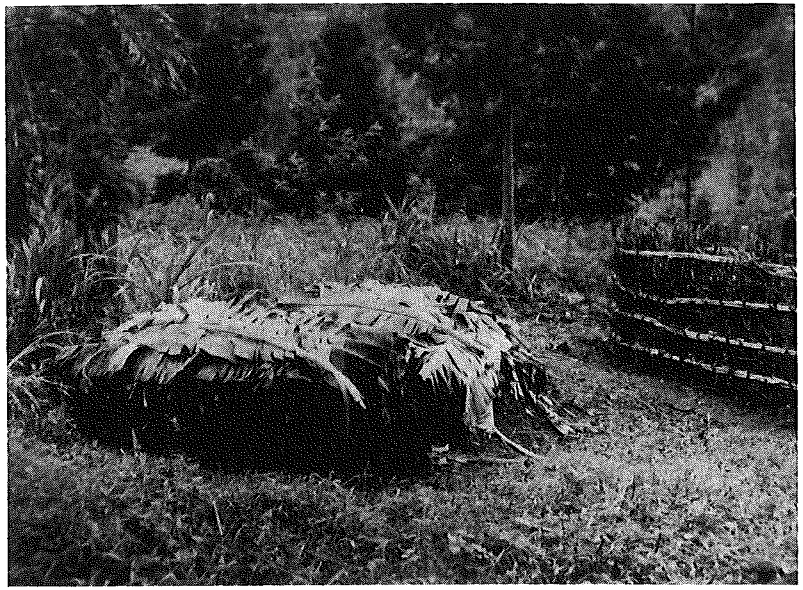
The great advantage of mulching is that it is a relatively simple technique to learn and apply, although incautious application can lead to problems. The mulch material can transmit plant diseases (for this reason, maize stalk mulch should not be used in maize fields), and it must also be ensured that rodents (mice, rats) do not multiply as a result of mulching techniques. Alternative uses of potential mulch material must also be considered. For each location it must be established which materials are suitable for use as mulch and how they can be used most efficiently on the farm.

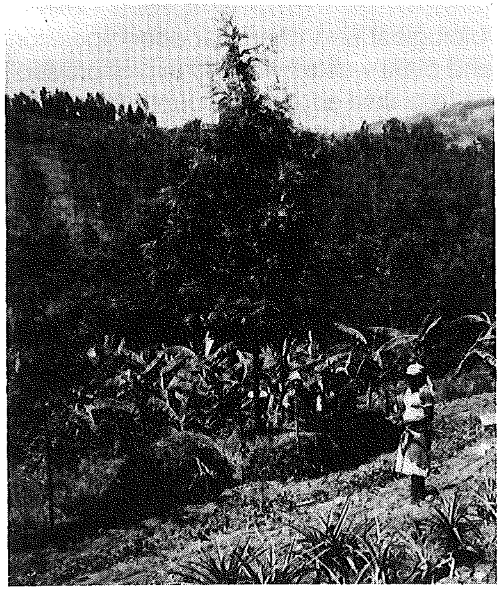
Composting

Composting is controlled biological and chemical decomposition and conversion of animal and plant wastes with the aim of producing humus. Mineral fertilizers (e.g. lime and rock phosphate) can be added if available and necessary. This waste treatment by means of a fermentation process is of major importance in many respects:

Hygiene. Harmful substances and toxic products of metabolism are broken down, while pathogenic agents, weed seeds and root weeds are destroyed by the heat generated within the compost heap (up to about 70°C).

Nutrient balance. Soil fauna and microorganisms develop a high level of activity which contributes substantially to the decomposition of organic wastes and formation of humus. Proper composting leads to an increased proportion of humic substances which are of high molecular weight, i.e. longer lasting (stable humus). Therefore, manuring with compost results in an enduring increase and qualitative improvement in the humus content of the soil. This is of cru-





Plates 10 and 11:
The composting of plant and animal wastes is an important way of maintaining nutrients and energy within the farm cycle and making them available again for future production. Regular application of compost not only raises the humus content in the soil but also improves its quality. Compost preparation demands, however, well-founded knowledge and practical experience. In Burundi (top), banana leaves cover the compost heap to protect it from dessication and leaching. In Tanzania (bottom) compost is heaped mainly on field boundaries to avoid having to transport it.

cial importance for most tropical soils, as here the organic matter, rather than the clay minerals, assumes the functions of storing nutrients, protecting them against leaching and fixation, and making them available to plants. At the same time, increased biological activity helps to make nutrients which are not readily soluble, e.g. phosphate compounds, available to plants and increases assimilation of atmospheric nitrogen.

Soil structure. Intensification of microorganic activity and abundant soil fauna promote the biological stabilization of soil particles and improve soil structure. This is reflected in reduced erosion, increased water absorption and retention capacity, and improved soil aeration.

Resistance to diseases and pests. Numerous experiments have demonstrated that all forms of organic manuring increase the capacity of plants to resist diseases and pests. The cause-effect relationships are largely unknown.

All these effects make it clear that, in terms of its quality as a fertilizer, compost differs fundamentally from the materials from which it is derived. Important factors to ensure a good rotting process are sufficient moisture (yet not water excess), warmth, air supply and a carbon/nitrogen ratio of about 30:1. The art of composting consists of creating these conditions for the specific site and with the basic substances available. Whether composting is done in heaps or pits depends primarily on the prevailing temperature and precipitation. At high-rainfall sites, compost heaps are preferable; they must be covered carefully to protect them against leaching. In hot, dry locations where water is scarce, pit composting is to be recommended; in this case, covering protects against dessication.

Composting can greatly improve soil productivity with little capital investment. However, a number of factors can hinder its widespread acceptance. The organic wastes on farms generally have several alternative uses: animal dung can be used as fuel, and plant residues can serve as fodder, fuel or mulch. Furthermore, composting demands a considerable amount of work. Not so much making the compost heap as rather spreading the compost on the fields involves heavy physical labour and often has to be done at times when there is already a labour peak. A partial remedy is to set up decentralized compost points in the fields to be fertilized. The degree of difficulty involved in compost preparation should also not be underestimated. Proper compost making requires well-founded knowledge and, above all, practical experience. Therefore, the introduction of composting must always be accompanied by thorough training.

Integrated plant protection

The concern with ecological degradation of the environment in industrialized countries and the role of agricultural chemicals in this process has lead to the development of the concept of "integrated pest management" which has now become a part of "integrated agronomy". This approach makes use of traditional cultivation methods such as crop rotation or green manuring and combines them with modern methods, including any external inputs considered useful in optimizing the factors of crop production. The first principle of plant protection in this approach is not to take action until infestation by diseases, pests and weeds surpasses a defined level of damage (economic threshold). This can be done on the basis of good diagnosis of infestation and intensive observation of its development. Furthermore, the attempt is made to reduce the use of chemical pesticides to an economically and environmentally acceptable level by supplementing them with:

- physical or mechanical methods such as hoeing, trapping insects, and treating seeds with warm water;
- biological methods such as releasing natural enemies;
- biotechnical methods such as using pheromones or hormonal chitin synthesis inhibitors;
- breeding for pest tolerance or resistance.

This is supported by the development of more selective chemicals; these, however, are expensive and difficult to obtain in the Third World.

Many elements of this integrated agronomy approach are also propagated within the ecofarming approach. Yet, the two should not be confounded. Basic to the former is still the philosophy of maximizing profits within a highly specialized system (monocropping, etc.) with open cycles, and plant protection in this context has the task of protecting a crop against its enemies.

In contrast, in an ecological approach as described in this volume, all organisms – including insects, fungi, weeds, etc. – are considered to be integral parts of the farm ecosystem. Here, plant protection involves seeking regulating factors which influence the development of a crop within the farm ecosystem, rather than combatting enemies. The major prerequisites for such regulation have already been described in the preceding sections: vegetation design, green manuring, mulching, composting, and a system of more or less closed cycles.

Any climax vegetation is necessarily a self-regulating system at its specific energy level. In the tropics and subtropics, the vitality and virulence of insects and microorganisms are generally higher than in temperate areas. Therefore, regulating efforts are often required which go beyond the self-regulating potential of even the most sophisticatedly designed cropping systems. Since many natural regulating techniques are laborious or forgotten, the recourse to cheap and easily available chemicals – and, with them, to the "enemy attitude" - is, of course, tempting or considered inevitable. Even so, selective chemicals for use in intercropped systems are rare, expensive and often difficult to obtain. Therefore, the use of chemical protectants in cropping should be considered at best a compromise and must, in the long run, be overcome. Analysis of traditional farming techniques reveals that highly efficient natural regulants exist and often are still being used by farmers (cf. STOLL 1986).

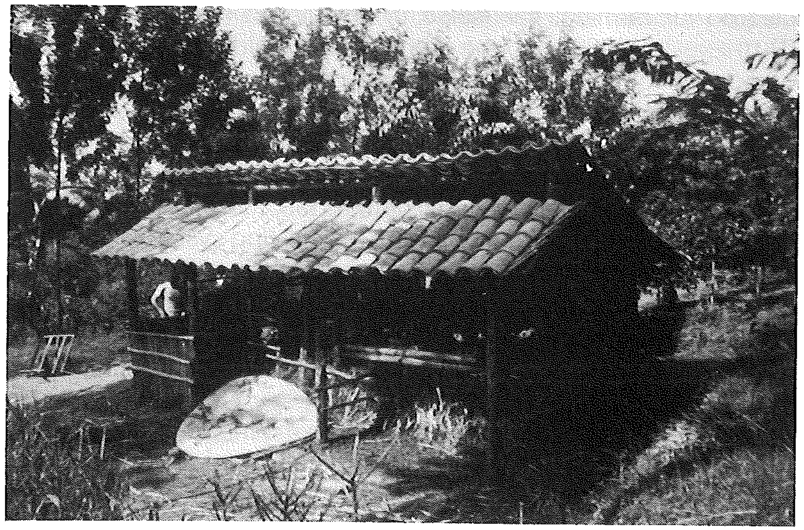
The use of chemical plant protectants cannot be recommended for ecofarming. Already for very obvious ecological reasons, they must be treated with caution. Their long-term effects on the ecosphere, like those of biotechnical methods, are often not detected until it is too late. The ecological balance in the tropics is more delicate than in temperate areas: pesticides, for instance, will pollute groundwater tables much faster where no humus or clay minerals hold them in the place where they are meant to act or where microorganisms and sunlight might help to decompose them. For example, it could be demonstrated that grammoxone virtually cannot be degraded under certain conditions and that regular use leads to reduced soil fertility. Here, the conventional calculations of economic feasibility become absurd, if the ecological basis is destroyed.

Consequently, the discovery or rediscovery of natural regulating strategies and techniques as well as the development of practical methods to apply those already known and available is increasingly necessary and must form the focus of research in a redefined concept of plant protection.

Integration of livestock

Livestock play a vital role in most smallholder systems in developing countries. Cattle, sheep and goats graze areas which can be cultivated only temporarily or not at all. In this respect, resource use for cropping and livestock-keeping is complementary. Apart from providing milk and meat, animals can provide manure for fertilizing cropland, draught power for cultivation, means of transport, e.g. water transport, and a savings account out of which larger expenditures for household or farm can be financed. Livestock can play a particularly important economic role for smallholders in semiarid areas where cropping risk is high, as animals provide security in case of crop failure and can be sold to buy cereals and other staples when the family's harvest is insufficient.

Direct application of manure as fertilizer, also in combination with other forms of fertilizer, or the use of manure in composting is a key element of integrated animal husbandry in ecofarming systems. Although manuring does not create new nutrients, it transfers nutrients from rangeland to cropland, concentrates nutrients on selected areas of land, and recyles nutrients more quickly than through natural decay of vegetative material. The use of livestock



Plates 12 and 13:
In densely populated areas, little land is available for livestock husbandry. Land which has been used for extensive grazing, as above in Rwanda, is increasingly needed to cultivate food crops. Livestock husbandry must then become more intensive, with stall-keeping (bottom) combined with forage production and collection of manure to fertilize crops.

for draught can be a further important link in ecofarming, in the sense of producing with few external inputs. However, rather than intensifying production on small plots of land, this often leads to preparation of larger areas than could be cultivated by hoe. Animal traction is likely to make a greater contribution to increasing agricultural production for both subsistence and sale where human population density and, thus, labour availability is low. In more densely populated areas, its primary value lies in reducing human labour inputs and permitting more timely cropping operations.

Crops and livestock can interact not only within a farm but also between different production units, as illustrated by the examples of traditional manure/forage linkages given in the section 'Crop-livestock integration'. Particularly crop residues are an important source of fodder. In addition, cropping can create a more favourable environment for livestock production than nonmanipulated (natural) areas. Where savanna woodland has been partially cleared for farming, the tsetse fly population has been reduced (RUTHENBERG 1980) and the higher grass yield on fallow fields as compared with natural savanna provides more forage for grazing ruminants (POWELL & WATERS-BAYER 1985).

Such interfarm integration of crops and livestock is found mainly in areas where land availability still permits fallow systems. In areas so densely populated or degraded that the existing system of resource use can no longer support the human population, a shift in emphasis from large ruminants to smaller species such as sheep, goats or rabbits may be necessary. Larger animals (cattle, buffalo, camels) may nevertheless have to be retained for draught purposes.

A change then becomes necessary from extensive grazing to systems of zero-grazing involving fodder collection and/or intensive forage production. In supporting such changes, it is important to recognize that smallholders tend to use potential fodder resources for several other purposes as well, e.g. woody plants provide not only fodder but also food (leaves, fruits), fuel, fibre etc. Also soil conservation and amelioration can be achieved by promoting forage production via multipurpose measures. The possibility of

using foliage as fodder to increase animal production can be a decisive incentive for smallholders to invest in planting trees and shrubs which control erosion, or in planting fallows which speed up the process of restoring soil fertility as in the case of ley farming.

Integration of aquaculture

In recent years, aquaculture – the keeping or breeding of organisms which live in fresh or salt water – has become a subject of growing interest. Within the framework of smallholder agriculture at issue here, attention must be focused on fish farming in ponds and fish breeding in rice fields. Fish provide protein which is of exceptionally high quality from the biological point of view; they are also highly efficient in converting feed. Moreover, fish production is an enterprise that – in contrast to many other forms of animal husbandry – competes little or not at all with the production of food for humans. All these factors give pond-based fish farming a position of considerable importance as an enterprise in smallholder agriculture.

Fish breeding in rice fields, as has long been practised in Southeast Asia, is a close to ideal form of land use, with cereal and animal protein being produced from the same area of land. Depending on the way the rice is grown, the following production methods can be used:

- one generation of fish following a single rice harvest per year (rice-fish rotation);
- fish farming between two cultivation periods, in the case of 2-3 rice harvests per year;
- fish farming simultaneously with rice growing (rice-fish culture).

In all cases, the fish culture remains secondary to the rice culture.

However, other forms of fish breeding have gained considerably greater importance. These range from extensive management in natural waters (stocking with young fish, no additional feeding) to intensive fish farming in specially created ponds (high stocking

Table 3: Terms used in aquaculture

MONOCULTURE	Only one species is kept (e.g. trout); the fish are generally very demanding in terms of nutrition and environment
POLYCULTURE	Various species with differing nutritional and environmental requirements are kept together; competition should be avoided.
INTENSIVE FARMING	High stocking rate (10 kg fish/1000 l water), high investments in technical facilities and exclusively artificial feeding permit intensive production; problems include waste water disposal and high susceptibility to disease.
SEMI-INTENSIVE FARMING	a) Stocking rate of 1-2 kg fish/1000 l water; some supplementary feeding (fodder plants); omnivorous fish (especially plankton, algae and higher plants) are most suitable (this system is appropriate for low-input smallholder farms). b) Young fish are bred on an intensive basis, e.g. in cages or tanks, then released and reared on an extensive basis without supplementary feeding.
EXTENSIVE FARMING	The fish feed on the natural food supply in the pond.

rate, artificial feeding only). An interesting and important example is the carp polyculture of China. Various carp species with different feeding habits live in different zones of a pond fertilized with domestic refuse and sewage and animal excrements. The water plants floating on the surface as well as any green feed added are eaten by the grass carp. Silver carp filter the plankton out of the water, and common carp eat the insect larvae, worms and snails on the bottom of the pond. This system can also be combined with the keeping of ducks.

Although various techniques of low-external-input agriculture have been described here separately, it is essential to recognize that ecofarming involves the complex integration of several of these techniques in a manner which makes the most efficient use of locally available resources. The combination of techniques which is most suitable for a particular farm at any point in time depends on the specific situation of that farm, in terms of not only the natural conditions but also the sociological and economic situation of the farm family. As these conditions change, so too do the appropriate ecofarming techniques.

2.2 Current research activities and development approach

Ecofarming research activities

To gain an overview of ecofarming activities within Technical Cooperation, the GTZ made a worldwide survey of organizations, working groups and individuals involved in agricultural development. The survey is described in more detail in Annex 1. Here, only a brief summary of the main emphases in ecofarming research and development in Technical Cooperation is given, together with examples of particular activities mentioned in the survey responses.

The survey revealed that by far the majority of ecofarming activities were being carried out in the more humid rather than the arid and semiarid zones. The comparatively favourable climatic conditions in the humid forest, derived savanna and subhumid savanna seem to offer more opportunities for applying ecofarming methods. The most frequently mentioned measures involved manipulation of vegetation geometry (agroforestry and multiple cropping) and improvement of soil fertility (nitrogen fixation, composting, mulching). A classification of respondents according to function (research, development project, information service, extension/training) revealed an exceptionally high proportion in the realm of research.

Possibly the most valuable product of the survey is the list of contact addresses of survey respondents who are presently involved in ecofarming activities. Highlights among the activities mentioned are:

Green manuring. In Africa, IITA (60)[1] has been investigating legume undersowing in maize stands for several years. In Rwanda (138) one-year green manuring periods with *Crotalaria, Cajanus* and *Tephrosia* were being successfully propagated.

In South America numerous legumes are being tested to determine their suitability for undersowing in maize in Cochabamba, Bolivia (4). *Vicia villosa, Medicago sativa* and *Trifolium alexandrinum* have yielded good results; the performance of some varieties was very site-specific. For more than 30 years in Brazil, Schaafhausen (115) has been investigating the suitability of various legumes for improving soil fertility. Here, *Dolichos lablab* has gained central importance as a combined fodder, cover and food (bean) crop which, being highly resistant to drought, can survive dry spells relatively well and whose deep roots provide increased access to soil nutrients.

In the rainforest zone of Nicaragua (48) in Central America, ways of undersowing legumes in rice, maize and beans are being tested, as are pure green manuring mixtures with legumes and legume/grass combinations. Similar work is also being done by World Neighbours in the Honduras (132).

In Hawaii the Nitrogen Fixing Tree Association (96) is examining the performance of nitrogen-fixing trees and shrubs, particularly the species *Leucaena, Sesbania* and *Prosopis.* The investigations cover fodder yield, quantity of nitrogen fixed, wood yield, calorific value and leaf drop.

Mulching. In Africa, IRHO (72) is investigating the mulching effect of oil cake from oil palm stands in the Ivory Coast and Benin, and

1) Figures in brackets refer to the lists in Annexes 2 and 3.

coconut seedlings are mulched with coconut fibre and fertilized with nutshell ash in Togo, Cameroon, Ghana and Tanzania. IITA (66) in Nigeria has carried out numerous experiments which confirm the beneficial effect of mulching. The trials involve essentially the burning of crop residues versus mulching with or without mineral fertilizer and lime. A hand-pushed implement for sowing into stubble or mulch has been developed for smallholder agriculture (see below). In Liberia (102) a training course covering mulching techniques, among other things, is being run as part of an afforestation programme (rubber, coffee, cocoa, oil palm).

In South and Central America, the Hospicultura Horticultural Project (119) in Peru's rainforest zone is growing food crops on ridges, between which are water ditches with fish. The crops on the ridges are mulched with algae and water plants. Also in Nicaragua (48) various mulching materials are being tested.

In India, systematic mulching is done with weeds and crop residues in Pondicherry. A particularly positive effect is the proliferation of earthworms beneath the mulch layer which work the organic matter into the soil. In the Far East, IITA and IRRI (81) have cooperated in developing a hand-pushed sowing implement (rolling injection planter) which, instead of making a seed furrow, penetrates the soil surface or mulch layer and makes a separate hole for each seed. The main advantages of this implement are that it reduces labour time and energy requirements and preserves soil moisture. AVRDC (10) in Taiwan is investigating different mulching materials with regard to yield and plant protection in vegetable growing. In Thailand (87) nutrient dynamics and soil microbiology are being compared in areas which have been cleared and burnt in shifting cultivation and areas which have been cleared and mulched.

Composting. In Africa, various composting methods are being tested in a small agricultural training centre in Kenya (19); also cut-up twigs and wood are composted. GROW (55) runs a training and demonstration centre in Soweto, where groups of black South Africans are instructed how to form self-supporting production units.

In South America, CENTEP in Ecuador (24) is conducting composting trials in different climatic zones. EMBRAPA/CPATU in Brazil (31) are studying the influence of compost on physical and biological properties of the soil. Agruco in Bolivia (4) is using compost in an attempt to solve the problems of low humus content, poor soil structure and high propensity for erosion. Methods of pit and stacked composting are being tested and compared, and field trials conducted to investigate the effects of organic manure. In Argentina, Chase (32) is investigating the possibility of using seaweed as mineral additive in composting sugar cane bagasse. CET (30) in Chile holds seminars on biological farming, produces extension pamphlets on different composting methods and plans to train "grassroot" extension workers.

A large number of projects are attempting to introduce composting techniques in Central America (48, 132, 141), particularly World Neighbours (132) in Honduras and Mexico. Composting is reportedly now a fairly widespread practice on farms. INCAP (69) is carrying out composting trials in Panama, Guatamala, El Salvador, Costa Rica and Honduras, and CSAT (37) is doing the same in Mexico. ACORDE (1) in Honduras runs courses on health, nutrition, arable farming, animal husbandry and ecology. Composting and the breeding of earthworms are important features of this programme.

In the Middle and Far East, the Centre of Science for Villages (26) is conducting trials with compost, biogas sludge and mineral fertilizers in India. The Asian Institute of Technology (8) in Thailand is working on the composting of human faeces, rice straw and water hyacinths. AVRDC (10) in Taiwan is investigating the decomposition rate of compost and dung in the soil, and their manuring effects.

Supraregional training centres are located in the Dominican Republic (according to 112), the Netherlands (67) and England (16). Emerson College (112) in England offers three different courses for foreign students, already attended by participants from over 20 countries.

Plant protection. In several countries in Africa, IRHO (72) is working on phytosanitary methods using ground-covering legumes. IITA in Nigeria (66) is investigating the effect of multiple cropping as compared with sole cropping on pest infestation; trials relating to smallholder storage practices revealed that seed (cowpea) treated with groundnut oil was almost free of pest infestation *(Callosobruchus maculatus),* while 68% of the untreated control was infested.

In a number of West African countries, GTZ, IITA and others (56, 66) are working on biological control of the cassava louse. A research programme in integrated plant protection to control the greater grain borer *(Prostephanus truncatus)* is being prepared by GTZ (153). Another programme is studying the possibilities of obtaining natural insecticide from the neem tree (154).

In South and Central America, research programmes aimed at biological pest control are in progress at CIAT in Colombia (33); the mealy bug *(Phenacoccus herreni)* is being kept under control by natural enemies *(Kalodiplosis cococidarum, Ocyptamus stenogaster* and *Chrysopa* spp). GTZ (158) has established several projects involving breeding for resistance to coffee rust. CIP in Peru (35) is breeding potato cultivars resistant to pests and diseases (thrips, aphids, late blight virus) and is investigating possibilities of controlling nematodes *(Meloidogyne)* by promoting growth of the fungus *Paecilomyces lilacinus.* CIMMYT in Mexico (34) is testing mechanical control of weeds (particularly *Avena fatua* and *Phalaris minor)* in cereal stands. CENDA in the Dominican Republic (23) is working on an integrated plant protection programme for rice growing, in cooperation with the University of Wageningen in the Netherlands.

In the Middle and Far East, AVRDC in Taiwan (10) and IRRI in the Philippines (81) are studying the influence of multiple cropping and other cultural practices on the spread of the bean fly. In several GTZ projects (56) the rhinoceros beetle in coconut plantations is being successfully controlled by means of parasitic fungi and viruses.

Aquaculture. The most interesting work programmes are to be found in the Middle and Far East. The Marga Institute in Sri Lanka

(90) is studying integrated fish farming and poultry raising. In addition, work is being done on tilapia breeding and the adaptation of saltwater fish to freshwater conditions. CODEL (36), also in Sri Lanka, is implementing several projects involving pond-based fish farming; training programmes for farmers form an important component of their activities. AIT in Thailand (8, 143) is investigating the suitability of composted water hyacinths, rice straw and human faeces for use as fish feed.

Prevailing approach to ecofarming development

Many of the ecofarming concepts presently being promoted in Technical Cooperation, e.g. soil fertility improvement measures and forms of crop-livestock integration, derive from experiences in the industrialized countries in temperate areas. The specific measures mentioned in the survey have been adapted to the natural conditions of the tropical or subtropical locations, but this has been largely by means of on-station or researcher-controlled trials. It is more rare that the ecofarming measures have been successfully integrated into the existing farming systems.

Farmers with similar production goals, using similar techniques and operating in a similar environment can be regarded as part of a distinct farming system. Each farm is, in itself, a complex and interconnected system, and any specific question related to agricultural production is but a single element within a greater whole which forms the framework for decision-making by the farm family. The family evaluates innovations in terms of compatibility with their resources, needs and production goals. These usually include risk avoidance and subsistence security but also almost invariably relate to production for exchange or sale.

The constraints and opportunities as perceived by the farm families will ultimately determine the appropriateness of ecofarming measures.

Table 4 gives a number of examples of station-based experimentation which show that yields can be increased substantially by ap-

Table 4: Effects of fertilizing and mulching on crop yields

a) Fertilizing and maize yield – Nyabisindu, Rwanda 1982 / 83 (1600 m above sea level, 1500 mm rainfall, oxisol)

Fertilizer (per ha)	None	15 t manure	Green manuring	10 t manure + green manuring[1]	NPK 120 / 100 / 10
Maize yield (kg / ha)	581	1254	2834	3312	3044

Source: NEUMANN & PIETROWICZ 1983.

b) Mulching[2] and maize yield – Oxkutzcab, Mexico 1984 (1100 mm rainfall, 27°C annual mean temperature)

Treatment	4th year after clearing by fire: Pure stand	4th year after clearing by fire: Mult.cropping+mulch	After 10 years of traditional bush fallow
Maize yield (kg/ha)	200	1324	ca. 1300

Source: NEUGEBAUER 1984.

c) Mulching[3] and yields (kg / ha) of maize and cowpea – Pará, Brazil 1984 (Eastern Amazon Region, 250 m above sea level, 1600 mm rainfall, latosol)

Treatment	Without mulch	With mulching material: 2-3 year old trees, bush vegetation	With mulching material: 4-5 year old trees, bush vegetation	Pueraria phaseoloides
1st season maize				
– without mineral fertilizer	78	1560	1807	3342
– 120 / 80 / 60 NPK	3539	4462	4479	5697
2nd season cowpea				
– without mineral fertilizer	7	35	95	114
– 30 / 80 / 60 NPK	1169	1191	1397	1187

Source: SCHÖNINGH 1984.

1) Green manuring after 10-month growth period – utilization costs!
2) Mulching with *Canavalia ensiformis*
3) Mulching 4 months before sowing of maize

Table 5: Productivity (per ha) of a multiple cropping system without trees compared with a system involving erosion control and tree cover in Rwanda

	Unit	Without trees	With erosion control[1] + tree cover Absolute	Relative
Sweet potato/ soyabean	t	3.2	2.9	—
Maize/beans	t	2.2	2.0	—
Goat doe	head		+ 1	—
Wood	t	—	8.6	—
Leaves	t	—	2.3	—
Grass	t	—	5.0	—
Gross margin	FR	65000	85000	ca. 130
Labour requirement	man-hr	3000	3400	ca. 113
Return per man-hour	FR	22	25	ca. 114

Source: Neumann & Preißler 1985

1) 0.9 multiple cropping; 0.1 ha erosion control strip + tree cover – Year 10.

plying biomass and that extremely high crop yields can be achieved by combining biomass and mineral fertilizers. More detailed assertions would require an analysis which also takes account of situation-specific utilization costs for the land needed to produce green manure. The ultimate proof of the appropriateness of the measures for the specific conditions of the smallholders concerned is attainable only through trials conducted by the farmers themselves.

Not only isolated measures but also complex ecofarming systems have been developed which have functioned well in biological terms under research conditions. However, attempts to extend such systems among smallholders revealed that especially the element

Table 6: Tasks involved in multiple cropping with erosion control measures[1] according to year of implementation (X)

Tasks	Year 1	2	3	4	6	10
Creation of erosion control strips	X					
Grass planting	X	(X)	(X)	(X)	(X)	(X)[2]
Tree planting (number)	80	50	50	20	20	20
Building shed for goat		X				
Goat from own livestock			X			
1st yield, wood / branches			X			
1st yield, goat / goat dung				X		
Final stage, wood yield						X

Source: derived from Neumann & Preißler 1985

1) 0.9 ha multiple cropping, 0.1 ha erosion-control strip + tree cover.
2) Grass planting necessary each year but only 1/3 of area.

of time until benefits emerge had not been given due consideration. Ecofarming measures with a start-up period lasting several years cannot be extended in the same way as improvements in annual cropping. Table 5 shows an example of this relating to a traditional multiple cropping system without trees as compared with a new system involving erosion control and tree cover. The comparison reveals that the system involving trees yields about 30% more output per unit area. Labour requirements are about 13% higher, which means that the returns to labour are still 14% higher (last line of the table). Why, then, have so few farmers opted for this innovation?

A possible explanation can be found in the footnote: the comparative data apply to Year 10! In other words, the entire start-up phase after changeover to the new system is disregarded and consequently also the possibilities for designing the individual components in such a way that losses in yield and income are kept as small as possible, if they cannot be avoided altogether. Considera-

Table 7: Productivity (per ha) of a multiple cropping system without trees compared with a system involving erosion control and tree cover including start-up phase.

	Unit	Without trees	With erosion control[1] + tree cover Yr1	Yr 2	Yr 3	Yr 4	Yr 6	Yr 8	Yr 10
Sweet potato/ soyabean (3.0/0.2)	t	3.2	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Maize/ beans (1.5/0.7)	t	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Wood (on 0.1 ha)	t	—	—	—	0.3	0.4	1.5	6.0	8.0
Leaves (on 0.1 ha)	t	—	—	—	0.1	0.2	1.3	2.0	2.5
Grass (on 0.1 ha)	t	—	—	3.0	5.0	5.0	5.0	5.0	5.0
Gross margin, crops	1000 FR	65	59	59	59	59	59	59	59
Gross margin, wood	"	—	—	—	1	1	5	18	24
Gross margin, goat	"	—	—	—	1	2	2	2	2
Investments, fixed costs	"	—	1	3	1	1	1	1	1
Income	"	65	58	56	60	61	65	79	85
Labour req., multiple cropping	100 man-hr	30	27	27	27	27	27	27	27
Labour req., erosion control	"	—	4	1	2	2	2	2	2
Labour req., goat/dung	"	—	—	2	2	3	3	3	3
Total labour req.	"	30	31	30	31	32	32	33	34
Return per man-hr	FR	22	19	19	19	19	21	24	25

Source: derived from NEUMANN & PREIßLER 1985.

1) 0.9 ha multiple cropping; 0.1 ha erosion control strip + tree cover.

tion of the individual tasks which the family must carry out (Table 6) permits specification of the labour requirements and income to be expected in each year of the start-up phase. This reveals that the new system is fairly complex, and additional yields (last three lines

in the table) are not obtained until quite some time after its adoption.

Table 7 represents an attempt to estimate the development of income and labour requirements during the start-up phase. The first five lines represent the output components. The gross margin per individual component, less investments and fixed costs, yields the income. On account of the "loss" of land (0.1 ha) for the erosion-control strip, the income initially drops before starting to rise again gradually as subsequent yields are obtained, and does not approach its original value again until Year 6.

In areas at risk from erosion, the decline in yields to be expected in the treeless system would naturally improve the competitive position of the new system. The question is, however, whether the farmers are fully aware of this fact in their decision-making. The return to labour is calculated from the income and the labour requirements, which increase only slightly at first but considerably later on. The figures in Table 7 indicate the "lean period" quite clearly. With regard to project work, the questions to be asked are: Can the drop in income be reduced by better combination and scheduling of components? To what extent might it be appropriate to provide the families with assistance in the case of erosion control measures which initially reduce income?

These examples emphasize the fact that the development of ecofarming measures and systems in Technical Cooperation projects may yield impressive results, but these results are often achieved and presented in isolation from the existing farming systems. An important aspect which has thus far received insufficient attention in developing ecofarming measures is the question of production risks. Research results and extension content tend to be based on average values. However, results may fluctuate widely in high-risk locations, particularly in areas of low rainfall.

As subsistence security is vital to the survival of smallholder families, ecofarming measures should be promoted which show low variability of production and which minimize risk.

Another major weakness of most project-based ecofarming activities has been the poor exchange of information between researchers and farmers. Ecofarming research has been largely isolated from the wealth of experience and knowledge of the indigenous people meant to be the beneficiaries of the innovations. Ecological science is poorer as a result, and important potentials for the development of smallholder farming systems have been overlooked.

Even where ecofarming projects have included on-farm trials, these have involved the testing of methods which project personnel have designed and/or decided to promote. The farmer's role has been to provide feedback about the scientists' ideas, which are based on the latter's interpretation of – above all – the biological problems they perceive in the farmer's setting. The project scientists determine how the trials are managed. If a farmer attempts to add his own variation to the trial on his field, in keeping with his own ethnoscience or perception of constraints, the project scientists generally regard this as interference.

Not only in the research and development of ecofarming measures but also in their extension, the approach in Technical Cooperation has tended to be top-down: outsiders disseminate scientific knowledge which they regard as superior to that of the local farmers. Even the demand for "farmer participation" fundamentally reflects a top-down approach. Outsiders decide which problems have top priority and which solutions are required, and then summon the participation of the villagers – to build contour bunds, to plant tree belts (e.g. in food-for-work programmes), to "adopt" and "accept" measures which are necessary and appropriate in the view of the scientists and extensionists. Judging by repeated reports of villagers' failure to maintain bunds, tree belts etc., the necessity and appropriateness of these measures were often not obvious to the villagers. The project workers then tend to attribute the rejection of these innovations to the villagers' ignorance (lack of formal schooling), passivity, conservatism etc., instead of questioning the viability of the measures for the situation of the village community and the individual farm families.

Referring specifically to integrated plant protection, ZEHRER (1985) points out that this is not the type of measure which can be "brought" from outside into smallholder farming systems. Plant protection systems are locally developed and adapted to a specific area and group of inhabitants. He refers to traditional systems as "starting points", out of which improved plant protection measures can evolve through collaboration of the agricultural scientists and the indigenous farmers. This is also emphasized by ALTIERI (1985):

> "The ensemble of traditional crop protection practices used by small farmers represents a rich resource for modern workers seeking to create pest management systems that are well-adapted to the ecological and socioeconomic circumstances of peasants. Clearly, not all traditional crop protection components are effective or applicable; modifications and adaptations may be necessary, but the foundation of development should be indigenous."

This also applies to all other efforts within Technical Cooperation to promote ecofarming.

The farming systems and techniques which smallholders have developed to suit their particular circumstances must form the starting points for improving ecofarming measures.

Instead of calling for the participation of farmers in ecofarming projects, the call should be for the participation of research and development workers in the continuing efforts of the farmers to meet their subsistence needs and maintain their resources for their heirs.