TROPICAL AGROECOLOGY |5|

ECOFARMING PRACTICES

for tropical smallholdings

Johannes Kotschi (Editor)

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I. Introduction

Johannes Kotschi

Smallholders in tropical countries constitute by far the majority of the rural population. Most of them face problems of land scarcity, low soil fertility status and limited availability of external inputs (e.g. mineral fertilizers). At the same time, because of the rapid rates of population growth in the Third World, smallholder families are obliged to produce their food, energy and income from increasingly less land. This often leads to severe soil degradation or even erosion and environmental destruction in rural areas, sometimes to the point of complete impoverishment. Long–term considerations of sustaining the productivity of the available land are sacrificed for immediate and short–term needs.

Since recently, several movements have been promoting the concepts of "ecologically sound agriculture", "biological husbandry", "organic farming", "ecofarming" etc. The aim is to maintain or establish a high and lasting level of soil productivity (ADELHELM & KOTSCHI 1986) by applying methods which require a minimum of external inputs, because these are, in most cases, economically and ecologically not feasible. In this reader "ecofarming" is used to refer to these related concepts.

In development agencies, there is a growing consciousness of the pressing need for sustainable forms of agriculture in the tropics. In the early 1980s, it therefore became possible to obtain financial support for ecofarming research. The programmes from which preliminary results are presented in this reader have been supported not only by the countries in which the research was conducted but also by the European Economic Community (EEC), the West German Ministry of Economic Cooperation (BMZ) and the German Agency for Technical Cooperation (GTZ). Their support is gratefully acknowledged.

In view of the wide range of tropical farming systems which exist in greatly differing agroecological and socioeconomic settings, there can be no single answer to the problem of environmental degradation. This reader concentrates on ecofarming under rainfed conditions. Throughout the world, the most common cropping systems are rainfed. These provide a livelihood for the majority of people dependent on agriculture, most of whom are smallholders. The key problem in rainfed cropping systems, whether in Africa, Latin America or Asia, is decreasing soil fertility. In order to understand this problem and to find possible solutions, it may be useful to take a brief look at the "history of soil fertility" under rainfed cropping in the tropics.

Soil fertility in tropical smallholder agriculture was originally maintained in a wide range of cropping systems by shifting cultivation. Bush or grass land was cleared, burned and cultivated for a short period of time. After 2–3 years of cropping, the land was again left fallow. Sufficiently long fallow periods (7–16 years in the humid tropics, 27–67 years in semiarid areas; YOUNG 1976) permitted a regeneration of organic matter and nutrients in the topsoil. During this fallow period, deep–rooting shrubs and trees mobilized nutrients from the subsoil, produced enormous quantities of biomass, and "fertilized" the topsoil with litter fall and root biomass. According to NYE and GREENLAND (1960), by the end of the fallow period approximately 20% of the nutrients in the upper biomass and in the topsoil had been mobilized from deeper soil layers during the fallow period.

Almost more important than the supply of nutrients by fallowing was the accumulation of organic matter in the topsoil:

- in most tropical soils, this is a main factor for cation exchange capacity (CEC) and thus helps prevent nutrients from leaching;
- it improves porous volume and pore size, leading to a higher rate of water infiltration and a better water–holding capacity:
- it further improves aggregate stability of the soil through biotic engineering and thus effectively reduces susceptibility of the soil to erosion.

Thus, fallowing regenerated soil fertility in a very comprehensive way. Nutrient balance and water balance were restored and the

danger of soil erosion was reduced. In addition, the shading effect of trees and shrubs over many years "cleaned the soil" from dominating weed flora.

As long as farmland was abundant, labour was limited and external farm inputs were next to nonexistent, shifting cultivation was the optimal way of ensuring sustainability in an ecological sense and a high productivity of labour in economic terms. With increasing population, the area under cropping expanded and fallow periods were shortened. In some cases, they were replaced by animal manure as a measure of soil fertility maintenance. Today, all over the world, shifting cultivation is in transition to permanent cropping or has already reached this stage.

Over a long period of time, agricultural research and extension had hoped to halt the decrease in soil fertility by regular application of mineral fertilizer. It was assumed that the nutrients applied not only replaced those extracted through cropping but also increased biomass production to provide the urgently needed organic matter. However, long–term field trials could not verify this hypothesis. With regular application of mineral fertilizer, organic matter content and, with it, soil fertility continued to decrease.

Today, the key questions are:

- How can soil fertility be maintained under permanent cropping?
- What measures can be applied to replace the valuable but disappearing fallowing practices?

It has been shown that mineral fertilizer alone cannot maintain soil fertility as defined comprehensively above. Organic manures (cattle dung, compost etc.) – although better suited than mineral fertilizers – are, in most cases, far too limited in supply to offer a real alternative. Consequently, only plant matter itself remains as a possibility. The idea is to replace the succession of fallowing and cropping over time by a coexistence of plants in space: plants which "accumulate" and others which "consume" soil fertility. In this spatial arrangement, the accumulators are deep–rooting perennials (trees or shrubs) and the consumers are annual field crops. Agroforestry, multistorey cropping and multiple cropping are based on this principle.

In accordance with this idea, research interest has been focused on the question of soil fertility maintenance by integrating perennials into existing cropping systems in the tropics. In this reader, initial results are presented of research into newly developed ecofarming practices, mainly involving agroforestry. The results are derived from small–scale experimental programmes which form part of rural development projects. The close connection with agricultural extension and the experimentation on farmers' fields and in cooperation with farmers make this type of research highly applicable to local farming systems.

After a general overview of the role of agroforestry in soil fertility maintenance (KOTSCHI, Chapter II), results from small–scale experimental programmes in Benin (FLOQUET), Colombia (MÜLLER–SÄMANN), Rwanda (RAQUET) and Tanzania (PFEIFFER) are presented and discussed in Chapters III–VI. The work in Burkina Faso (EGER, Chapter VII), although it involves the same type of research, covers a different aspect: soil and water conservation by erosion control measures. Finally, WATERS–BAYER (Chapter VIII) discusses methods of farmer–scientist collaboration in ecofarming research and the extent to which the experimental programmes combined scientists' and farmers' knowledge to generate improved techniques for the existing farming systems.

The findings presented in Chapters III–VII are introduced by a description of the research location, followed by a brief analysis of the major problems. Based on this, the main aims of the research and the methods applied are outlined. The discussion of results is limited to the main findings, which already indicate the perspectives for future research. Deeper analyses of the data are still underway and final results were be presented in more detailed publications.

It is hoped that this reader will make a useful contribution to the discussion of ecofarming in general and will provide some ideas as to how ecological principles can be translated into techniques that are applicable within smallholder farming systems. To this end, the methodological approaches are particularly important,

and it is hoped that ways are indicated here as to how ecofarming research can be continued.

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II. Agroforestry for soil fertility maintenance in the semi-arid areas of Zimbabwe[1]

Johannes Kotschi

1. Introduction

Countless farmers all over the world have been taught to remove every tree or shrub in the field or along field borders. Extension workers explained that trees were merely competitors for light, water and nutrients, and were obstacles to agricultural mechanization. With increasing environmental degradation, the importance of trees in land use is slowly being rediscovered. Today trees are being rehabilitated. Agricultural scientists are becoming aware that trees can be useful. They not only supply much demanded fuelwood; their usefulness in maintaining soil fertility, controlling erosion and supplying fodder may be just as important, not to mention numerous other functions of trees and shrubs.

Researchers, fieldworkers and administrators are now proclaiming "agroforestry" – a term which is becoming more and more fashionable. Agroforestry can be defined as a technique

> "of land use in which trees are combined with crops or pastures or with both. The combination can be simultaneous in terms of time and space or it can be phased. The objective is sustained optimization of total production per unit area" (HEUVELDOP & LAGEMANN 1981).

This principle is not new. Trees and field crops have always been combined in traditional land-use systems. Introduction of the new term agroforestry reflects, however, a change in attitude among agricultural scientists. The "experts" have finally become

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[1] Paper presented at the Workshop on Cropping in the Semi-arid Areas of Zimbabwe, Harare, 24–28 August 1987

aware that trees must be integrated into agriculture and that tree planting must be seen in a multifunctional context.

In land–use plans for the Communal Lands in the semi–arid areas of Zimbabwe (SAAZ), virtually no thought was given to agroforestry until now, even though land degradation has reached immense proportions. The natural vegetation has been extremely overexploited. Gutu District gives a good example of the situation. It contains large areas with some of the highest levels of human population pressure relative to carrying capacity in all of Zimbabwe (WHITLOW 1980). The cattle population density is correspondingly high. The four main ways in which the natural resources are being overexploited are, in order of importance:

- overstocking with cattle, especially in Regions III and IV (according to the classification by VINCENT & THOMAS, 1960); browse in the late dry season can comprise up to 50% of the diet;
- extension of rainfed cropping into marginal lands and continuous cropping of arable land where fallow cycles used to exist;
- deforestation in response to high demand for fuel, timber and fencing material, particularly in Regions III and IV;
- removal of litter/leaf mulch for manuring purposes from the remaining small forests leads to reduced growth and/or regeneration of trees and shrubs and also increases soil erosion at sites with steep slopes and thin soil cover; this type of vegetation use appears to be confined, however, to Regions IV and V.

As an overall result, devegetation and, linked to it, erosion is highest in Region III, declining with increasing aridity.

The problems have been analysed but no solution can be seen. The only answers experts offer for the Communal Lands is to reduce drastically the area under cropping, to ensure food supply via the commercial farms, and to create alternative sources of income in these densely populated areas. However, as there are no promising conceptions of how to bring this about, such changes cannot be expected in the near future. Population and the area under cropping will increase further, and the environment will continue to deteriorate.

Pursuing one goal – e.g. finding alternative sources of income – does not exclude the simultaneous pursual of another goal, and this must be to find ways of sustaining land productivity even under continued arable cropping. In this context, the role of trees in soil fertility maintenance is of key importance. The following considerations will therefore be focused on the soil fertility aspect of agroforestry.

2. Soil fertility maintenance in the Communal Lands

Soil fertility in the Communal Lands was originally maintained by a well–functioning system of shifting cultivation. Sufficiently long fallow periods regenerated the level of organic matter and nutrients in the topsoil. With increasing population pressure, fallow periods were shortened and gradually replaced by animal manure as a soil fertility maintenance measure. The area under cropping expanded further and, today, quantities of animal manure are grossly insufficient to restore soil fertility[2)], and cattle population already exceeds carrying capacity. Again the question is: how can land productivity be maintained? The only extension message given by AGRITEX is to apply mineral fertilizer and, consequently, smallholders regard it as a substitute for organic manure, which is becoming increasingly scarce. But is it really a substitute?

[2)] According to ROBINSON (1953) 10 tons of kraal manure/ha every 4 years would be necessary to sustain the system. Thus, approximately 2.5 livestock units/ha arable land would be required. The present ratio in Gutu District is ca 1.25 livestock units/ha on average (CARD 1985). However, there is a high variation between farms. About 35% of all farmers do not own any cattle. Their only sources of organic manure are leaf mulch from forests and compost consisting of household litter, plant residues and fuelwood ash which is collected in pits near the homestead. The utilization of these different manures is an impressive demonstration of how highly the farmers value organic materials.

Examination of the yield response to fertilizer in Gutu District (KOTSCHI 1986) reveals a wide range of situations. For the sake of simplicity, only two situations from Region IV are presented in Figure 1: A) the master farm with sufficient cattle to fertilize the

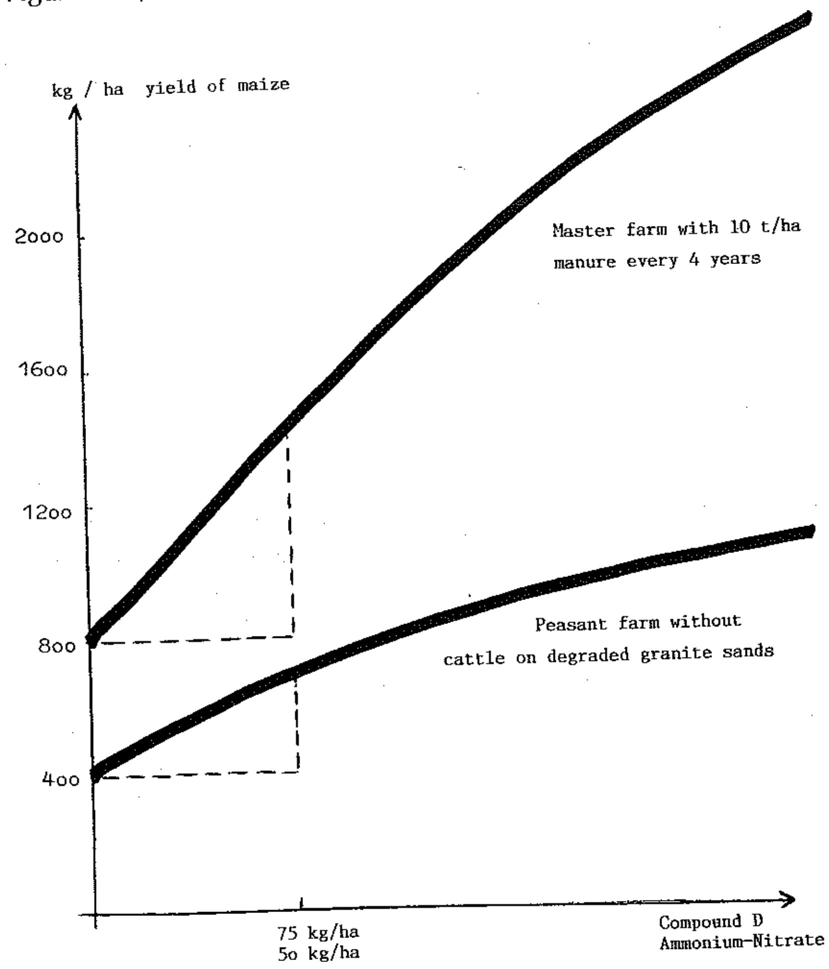


Figure 1: Estimated fertilizer response of Communal Lands (Region IV) with different soil fertility status

Compound D contains 8% N, 14% P_2O_5, 7% K_2O, 6,5% S
Ammonium Nitrate contains 35% N

Source: KOTSCHI (1986)

fields with the required 10 t/ha every 4 years; and B) the peasant farm without cattle, on degraded granite sands. The yield responses in the second situation are much lower than in the first. The following general conclusions can be drawn:

- in situation B, the rate of return per unit of fertilizer applied is low and may be insufficient to meet additional costs, especially in years with low, irregular rainfall;
- an increase in soil fertility (a shift from the lower to the upper curve in Figure 1) requires an increase in organic matter content and also a qualitative improvement in humus composition; this can be achieved only by incorporating organic matter, whereas mineral fertilizer can have only a supplementary effect;
- it can be expected that the cropped area in the Communal Lands will increase further and availability of organic manure per unit of land will decrease further; accordingly, the areas with low soil fertility status will expand and the economics of mineral fertilizer application in the Communal Lands will deteriorate further.

The decrease in soil fertility is the core problem in the Communal Lands, and there appears to be no choice but to increase biomass production to fill the gap. But where and how can this biomass be produced in areas which are already intensively cropped? Agroforestry offers some answers. However, before seeking appropriate answers specifically for the situation of the Communal Lands in the SAAZ, the methods and performance of existing agroforestry systems will be discussed. In the following, several examples are presented.

3. Peformance of an agroforestry system: an example

Location. In Nyabisindu in the tropical highlands of Rwanda, an agroforestry system is presently being assessed by a research programme. The site lies 1700 m above sea level, receives 1100 mm annual rainfall in two rainy seasons, and has a mean annual temperature of 19°C. The population density – ca. 200 persons/km² – is high; farms are characterized by a severe shortage of land. The average farm size in the district is 0.93 ha, supporting 6 persons on average. This area is used for arable cropping, coffee and banana production. As virtually all fields are situated on slopes, soil erosion is a permanent danger. Soil fertility is low, and fields are left fallow only if crops will no longer grow. The fallow serves as a ley pasture, and has little impact on restoring land productivity. In this area, a German–funded project of agricultural development is seeking methods of intensifying husbandry and introducing communal forestry. Practising agroforestry on arable land is one recommendation among many others, and an appropriate method has been developed over the past 15 years.

Agroforestry method. Trees, shrubs and perennial grasses are planted along contour lines spaced 10–30 m apart, depending on steepness of slope. In order to minimize root competition with field crops, lateral roots of trees in the soil layer 0–50 cm are cut regularly. These contour strips serve several purposes:

- to reduce soil erosion and induce terraces (see Figure 2),
- to produce substantial quantities of biomass for use as fuel, fodder, mulching material etc.,
- to mobilize nutrients from deeper soil strata via the trees' deep roots and to fertilize the field with nutrients and organic matter via leaf fall,
- to improve the microclimate and, with it, water use efficiency and crop yield.

Trial design. Various contour strips with different plant combinations have been tested. The following trial follows a very simplified pattern: 250 *Grevillea robusta* trees/ha were planted on contours (10 m apart); the cropping cycle of the trees is 9 years, i.e. each year about 28 trees/ha are felled and replaced; below the trees, mixed cropping is practised according to the crop rotation in Table 1. The control is a system without trees, intended to represent a "traditional" land–use system. In reality, the existing production systems display various degrees of land–use intensity,

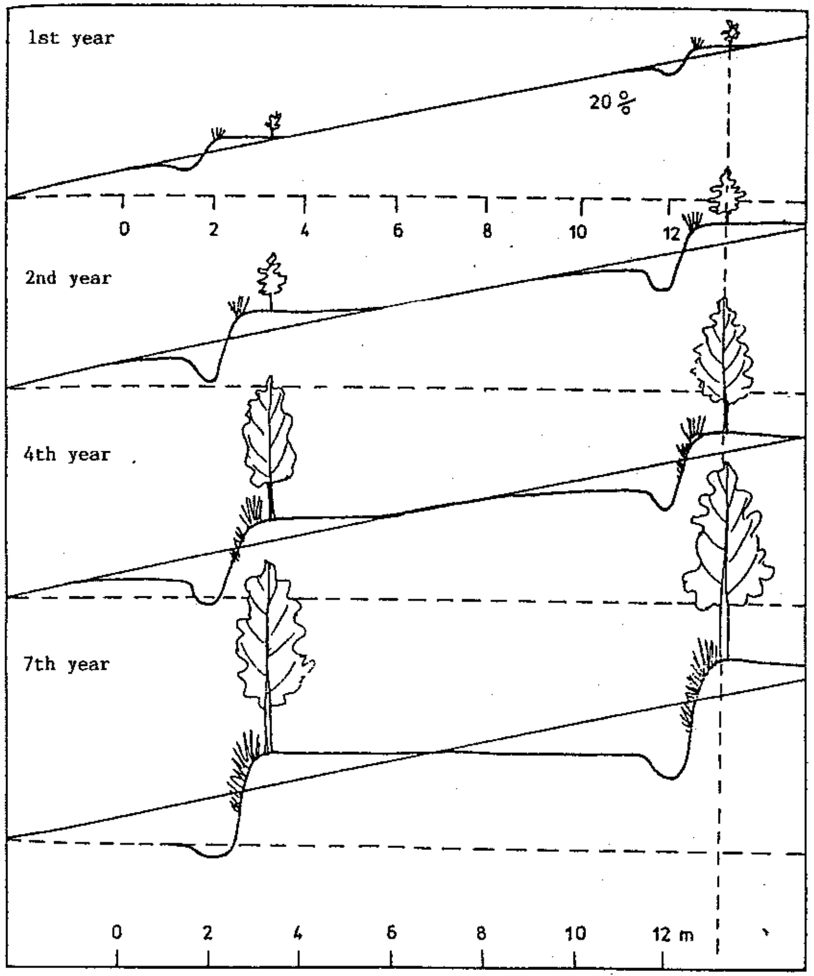


Figure 2: Terrace formation and reinforcement of terrace embankments with the aid of trees – an example

Source: (Egger 1981)

but with a general tendency towards decrease in number of trees with increasing cultivation density.

The trial was carried out over 2 1/2 years with a fully functioning agroforestry system, i.e. the oldest Grevillea trees were already 9 years old. Field crops were grown right up to the tree trunks. However, a 10% reduction is calculated for field crop area in

Table 1: Design of agroforestry trial in Nyabisindu, Rwanda

Treatments:	A	without trees
	B	with 250 trees/ha *(Grevillea robusta)*
Replicates	3	over growing periods
Crop rotation	Year 1:	green manure crop (mixture of *Tephrosia, Cajanus, Crotalaria* etc.)
	Year 2:	1st season, maize/soybean/sweet potato; 2nd season, maize/beans *(Phaseolus vulgaris)*
	Year 3:	as Year 2

plots with trees: the yield figures were multiplied by the factor 0.9 in treatment B.

Trial results. Table 2 presents the yields attained with and without trees, giving average values over replicates and seasons. Despite the presence of trees and the 10% reduction in area for field crops, a marked increase in the yields of sweet potato (25%) and maize (10%) could be observed, whereas the yield was 30% lower in soybean, probably because of its sensitivity to shading. The 32% reduction in weed growth was probably also due to

Table 2: The effect of trees on yields of food crops, green manure and weed growth (kg/ha)

Treatment / Field crop	A without trees	B* with trees	Significance (p≤)
Maize	1 204	1 328 (+10%)	0.01
Beans	798	797	
Soybeans	312	220 (−30%)	0.05
Sweet potatoes	2 439	3 038 (+25%)	0.05
Green manure mixture	14 560	13 743 (− 6%)	0.05
Weeds	221	151 (−32%)	0.05

Source: NEUMANN & PIETROWICZ (1985), modified.

* To account for 10% reduction in crop area due to trees, crop yields were multiplied by the factor 0.9.

shading. The *Grevillea* trees yielded annually 5.9 m³ of stem wood, 4.8 t of branches[3] and 2.1 t of fresh leaves (PREISSLER 1985). Thus, the wood from 1 ha was sufficient to supply fuel for 10 people[4].

In Table 3, the gross margin is given for both treatments to indicate land productivity. Although the trees reduced the area for annual cropping by 10%, the gross margin for food crops alone decreased only slightly, and when the revenue from the trees (fuelwood, timber, and leaves for fodder and mulching coffee) was added, the gross margin was 30% higher than in the treatment without trees.

Table 3: Land productivity expressed as gross margin (Rwanda Franc/ha) with and without trees

Treatment	A without trees	B with trees
Food crops	96 291.00	92 754.00
Leaves of Grevillea trees	–	8 580.00
Fuelwood and timber	–	23 564.00
Total (%)	96 291.00 (100)	124 989.00 (130)

Source: calculated from NEUMANN & PIETROWICZ (1985) and PREISSLER (1985).

This increase in productivity can be explained by a better use of existing nutrients, water and sunlight. The assessment of soil water and nutrient balances in this trial was not sufficiently intensive to give reliable results. Nevertheless, the deep–rooting trees with their ability to mobilize additional nutrients from deeper soil layers might be the main reason for increased biomass production not only of trees but also of some food crops through leaf litter fallen from the trees[5]. Competition between

[3] 1050 kg fresh weight of branches is equivalent to 1 m³ (NEUMANN & PIETROWICZ 1985).

[4] Assuming a wood consumption of 1 m³/person/yr

[5] NEUMANN & PIETROWICZ (1985) calculate that an average leaf fall of 3.8 t dry matter/ha/yr supplies the topsoil with 32.7 kg N, 0.3 kg P, 15.2 kg K, 53.2 kg Ca and 4.7 kg Mg/ha/yr.

trees and food crops for water cannot be avoided, but water use efficiency can be increased considerably because trees reduce potential evaporation[6]. This is associated with lower maximum temperatures and higher relative humidity. In addition, a higher rate of water infiltration can be expected. With regard to sunlight for photosynthesis, the 250 *Grevillea* trees gave a crown cover of approximately 20%, which led to an average light extinction of 38.2% as compared with the treatment without trees. The remaining radiation was sufficient to permit even higher yields of the major crops under the trees. Only soybean appeared to react negatively to shading.

The next question which needs to be answered is: how does the agroforestry system affect labour input and labour productivity? According to the summary of results in Table 4, although labour input was 13% higher in the agroforestry system, productivity of labour was increased by 14%.

Table 4: Labour input and productivity (Rwanda Franc/hour) with and without trees

Treatment	A without trees	B with trees
Labour input:		
Hours of work/ha	3000	3400
%	100	113
Productivity of labour:		
Rwanda Franc/hour	32.1	36.7
%	100	114

Source: calculated from PREISSLER (1985) and ADELHELM et al. (1986).

Implications for implementation. Tree planting along field borders, roads and even in the fields is now becoming quite popular, even on farms with only 1 ha of arable land. However, constraints to introducing the method of agroforestry described above must not remain unmentioned. The above calculations apply to the fully developed agroforestry system, but the establishment costs are considerable. At least for some time, part of the crop area (10%) must be relinquished to the trees, and additional labour input is required for planting, weeding, root trimming, pruning and harvesting the trees (see Table 5). The reduction in crop area initially causes a reduction in gross margin; this and the additional labour input cause a reduction in productivity of labour, which is about 10–12% less in Years 1–3 of the agroforestry system than in the treeless system. Only after Year 6 does the new system become competitive. Full productivity of land and labour is not reached until 10 years after establishing the trees on the contour lines.

[6] Over a period of 49 weeks in 1983, potential evaporation measurements (class A pan) showed a 36% reduction under trees as compared with the treeless treatment.

Table 5: Investment phases during establishment of agroforestry system

Treatment	A without trees	B with trees				
		Year 1	Year 2	Year 3	Year 7	Year 10
Productivity of land (1000 Franc/ha)	96.3	86.7	86.7	86.7	108.5	124.9
Labour input (100 hours/ha)	30.0	31.0	30.0	31.0	32.7	34.0
Productivity of labour (Franc/hour)	32.1	28.0	28.9	28.0	32.9	36.7
		(−13%)	(−10%)	(−13%)	(+2%)	(+14%)

Source: calculated from PREISSLER (1985) and ADELHELM et al. (1986).

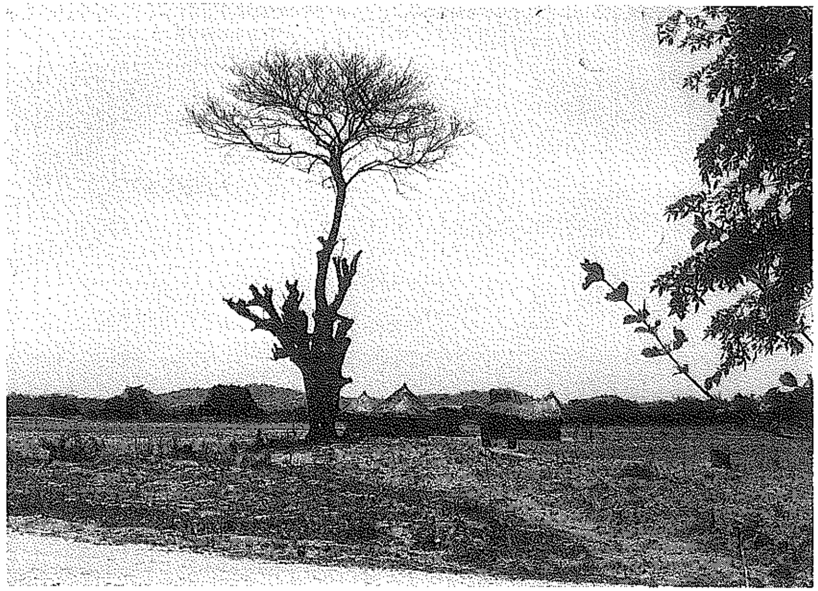
On the other hand, it cannot be assumed that productivity of land and labour remains constant over 10 years in a traditional system without trees. In actuality, productivity would decrease as a result of land degradation and erosion. If this were taken into account, the agroforestry system would become competitive in a shorter period than 6 years.

This time required (start-up period) until full productivity of land and labour is reached is quite typical of attempts to introduce new technologies. Improvement of the resource base requires initial investments (that can, in other cases, be much higher than here) which often exceed the means of the people concerned. In such situations, external support is needed if innovations to prevent environmental degradation are to be adopted.

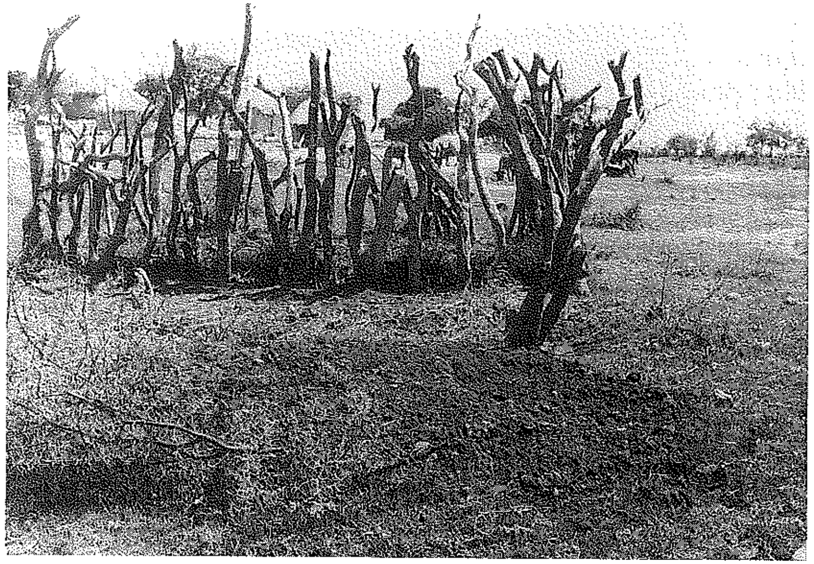
4. Experiences in semi–arid areas of West Africa

With decreasing availability of water, the natural vegetation becomes less not only in terms of biomass production but also in terms of number of trees. The options for agroforestry are reduced accordingly. Nevertheless, even in semi–arid areas, trees play an important role in sustaining land productivity.

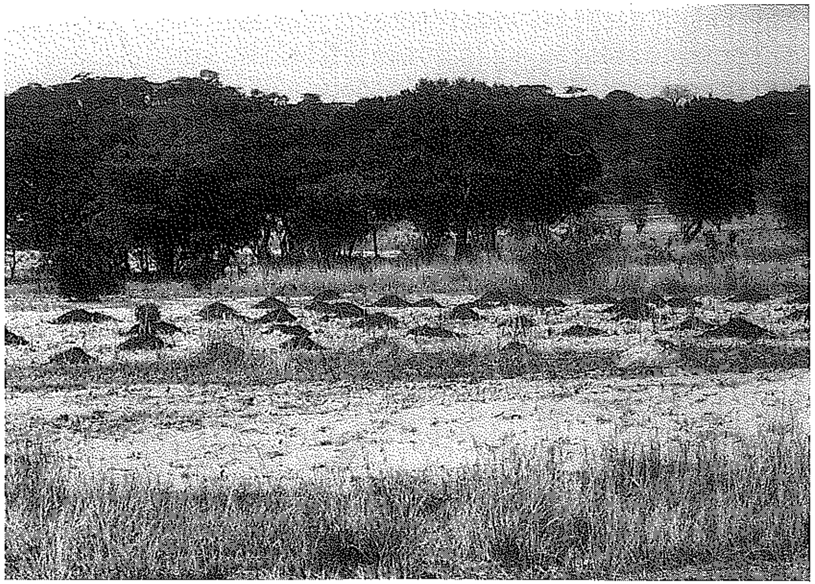
A traditional agroforestry system in the West African Sahel is based on the leguminous acacia tree *(Faidherbia albida)*. The deep roots of this tree enable it to tap lower sources of water and nutrients inaccessible to field crops. It drops its leaves during the wet season and, therefore, does not compete with crops for light. It produces leaves during the dry season, a phenomenon known as "reverse foliation". The leaf litter contributes nitrogen, other nutrients and much needed organic matter to the fields. This soil improvement leads to considerable increases in crop yields. CHARREAU and VIDAL (1965) measured millet yields at different distances from single trees and found enormous differences (see Table 6). Near the trunk, millet yield increases of 150% were measured in comparison with millet grown beyond the tree canopy. Even more marked are the differences in protein yield: an increase of 245% under the trees. Based on these measurements, it was calculated that crop yields could be increased by at least 50% with a tree density of 30 adult acacia trees per hectare (Advisory Committee on the Sahel 1984). Additional benefits were 50–100% increases in soil organic matter, improved soil structure, increased water–holding capacity and a marked increase in soil microbiological activity beneath the trees (FELKER 1978). Last but not least, the pods are a valuable source of fodder at a critical time of the year – the late dry season – when other local sources of animal feed are scarce or of poor quality.



The natural vegetation in the Communal Lands has been severely damaged by overutilization, as drastically shown by this tree which has been reduced to a stump by lopping.



Cattle are kept overnight in such kraals. The dung which collects there is highly valued as fertilizer for the fields.



Fertilizing a field with dung: only the larger farmers own enough cattle to be able to apply larger quantities of kraal dung to their cropland regularly.

Such contour ridges cover 5–10% of arable land, but they are left idle. They offer a good potential for planting trees and shrubs for agroforestry purposes.

Table 6: Millet yield under and near *Acacia albida* in Senegal (ca. 600 mm annual rainfall)

Location Yield		Near the trunk	Edge of tree canopy	Outside of tree canopy
Grain	kg/ha	1669	983	600
	%	253	149	100
Protein	kg/ha	179.9	84.2	52.2
	%	345	161	100

Source: CHARREAU & VIDAL (1965).

These results illustrate that integrating trees into arable land does not necessarily reduce and can even increase crop yields. However, *F. albida* has very site–specific requirements; as it grows well only on deeper alluvial soils, its distribution is restricted.

A new agroforestry practice which is gaining in importance in the Sahel is the installation of shelterbelts and windbreaks along field borders and in the fields. A shelterbelt is generally wider and denser than a windbreak. An example of using trees as windbreaks comes from the Majjia valley in Niger. Neem trees (*Azadirachta indica*) have been planted in "hedges" 8 m wide (i.e. in triple rows with tree spacing of 4 X 4 m) and 120 m apart. BOGNETTEAU–VERLINDEN (1980) measured wind velocity and

Table 7: The influence of windbreaks[1] on microclimate and millet yield (kg/ha), Majjia Valley[2], Niger (1979)

		Without windbreak	Distance behind windbreak (m)				
			7	35	60	84	112
Relative wind velocity	%	100	78	47	60	72	63
Millet yield	kg/ha	854	1106	1332	1043	1070	944
	%	100	130	156	122	125	129

Source: BOGNETTEAU-VERLINDEN (1980).

[1] windbreaks: 120 m apart, 8 m wide, planted with neem 4 × 4 m, 7 m high

[2] location: Garadome (453.5 mm mean annual rainfall)

millet yields in fields with and without windbreaks. The most interesting results are summarized in Table 7. Wind velocity was reduced by 22–53% and millet yields were 22–56% higher in fields with windbreaks. At distances up to five times the height of the planted trees (7 m) on the leeward side, yields were 56% greater than in unprotected areas. This might be explained by lower evaporation. Total millet yields in protected fields were 123% of those in unprotected fields, taking into account a loss of production due to 10% reduction in crop area and competition effects between trees and adjacent crop plants. This example demonstrates impressively that, even at sites with extreme water scarcity such as in the Sahel, additional trees can lead to more efficient use of water.

5. Implications for the Communal Lands in the SAAZ

The above examples may have given an indication of the potential of agroforestry practices, but they must not be considered as recipes directly applicable to the SAAZ. Site-specific solutions must be found. Technical questions (e.g. choice of suitable tree species) are involved, but primary consideration must be given to the socioeconomic question: how can tree planting and raising be integrated into the existing system of land use and become a normal activity of the rural population? Until now, almost no thought has been given to possibilities of agroforestry in Zimbabwe. Therefore, the following recommendations can be of only a very general and preliminary nature.

Present activities in agroforestry. To date, the Forestry Commission is the only institution which has the mandate and which runs activities to combat deforestation (Rural Afforestation Programme). In Gutu District, for instance, it maintains 5 nurseries, each of which raises 6000 Eucalyptus seedlings per year as well as seedlings of pine, Casuarina, Leucaena and fruit trees (guava,

peach, pawpaw, citrus) in small quantities. Eucalyptus is used to establish 5 ha village woodlots intended to supply fuelwood on a 5–year rotational basis (1 ha/yr) and to last for about 30 years.

The future objective for agroforestry/forestry. In view of the different causes of devegetation discussed in Section 1, it is obvious that measures to counteract devegetation must be seen in a multifunctional context of resource use. It is not sufficient nor is it of primary importance to propagate village woodlots with fast–growing fuelwood trees. A much more comprehensive approach is needed in which the different purposes of trees and shrubs are taken into account. The present concepts of spatial segregation (woodlots) and exclusively planting one species (e.g. Eucalyptus) must be overcome. Instead of being a sectoral activity, the planting and raising of trees and shrubs must become an integral part of the entire land–use system. How could this be achieved?

Two levels of decision–making must be considered: the household–based production system, i.e. pertaining to the arable land of the smallholdings; and the community–based production system, i.e. pertaining to the pasture and forest land.

Measures on the farm level. The arable land is presently being used almost entirely for annual cropping. Virtually no trees are left in the fields or along field borders. The same applies to the contour ridges, which are 3–5 m wide and take up 5–10% of the arable land, but are left idle except for some extensive grazing in the off–season. Agroforestry practices on arable land could raise land productivity considerably. The first step would be to plant trees and shrubs (preferably nitrogen–fixing species) on top of the contour ridges. Farmers in Gutu District, who were asked their opinion about this, thought it a good idea but did not know how to do it and lacked tree seedlings; some mentioned that they were not allowed to use the contour strips. There seems to be a promising potential to encourage, train and advise innovative individuals/families in tree planting and care.

They could become key persons for community activities. The ecological and economic benefits of applying agroforestry practices to contour strips on arable land are obvious:

- the additional biomass produced (estimated 0.3–0.5 t/ha/yr) could make a valuable and, in some cases, desperately needed contribution to fodder and fuelwood supply,
- insofar as legumes can be included, these would add nitrogen to the system,
- the vegetation strips could improve microclimate by serving as windbreaks; evaporation in the fields would then be reduced and, thus, the amount of water available to the crops could be increased.

A second step in intensifying agroforestry systems on arable land would be to integrate trees into the fields themselves.

Measures on the communal level. On communally used land, a process of land–use planning together with the local population should be commenced, aimed at achieving an agreement with the village/ward community on afforestation of certain areas of land and on forms of grazing management. This decision–making process requires a great deal of time, but any physical activities (e.g. installation of further woodlots) should be done only as an outcome of this process of communal land–use planning.

Existing constraints and how to begin. Until now, little scientific knowledge is available about suitable tree and shrub species. An observation trial at Makaholi and off station in Gutu District was started in 1984 by the Forestry Commission and a Communal Land "on–farm" screening trial is planned to begin in 1987. This trial should certainly be given continued support, but there is not time to wait another 20 years until results may be available. Forestry activities in addition to the existing ones should commence at once, as they are of vital importance to halt soil erosion and to increase land productivity. Even if not all species propagated will be successful, the measures can still have a positive impact. For a start, a selection of trees/shrubs which appear promising are recommended (Table 8). For the contour lines, the recommended species are Cassia, Casuarina, Grevillea, Leucaena and Sesbania. Species which are promising for afforestation on communal areas are Casuarina, Grevillea and Gmelina. For live–fencing – in addition to the existing sisal and Euphorbia hedges – Caesalpina, a thorny climbing shrub, should be propagated.

Table 8: Recommended species for multiplication and propagation in Gutu District

Species	Site		Purpose					
	Contour line	Live fence	Arable land	Wood-lot	Fodder	Fuel	Soil fert.	Tim-ber
Faidherbia albida			x		x		x	
Caesalpina	x	x			x		x	
Cassia siamea	x						x	
Casuarina cunn.	x			x		x		x
Casuarina glauca	x					x		
Gmelina arborea				x		x		x
Grevillea (glauca?)	x			x		x		x
Leucaena leuc.	x				x		x	
Sesbania sesban	x		x		x		x	
S. grandiflora	x		x		x		x	

Source: Kotschi (1986).

More important than proper selection and combination of tree or shrub species is the protection of newly planted seedlings from cattle. With regard to the arable land, it is recommended either to keep cattle out of the fields year–round or to restrict residue grazing to a very short period during which the herds are strictly controlled. At the same time, crop residues should be more completely collected to serve as fodder and bedding in the kraals. Regular pruning of the vegetation strips on the contour ridges would provide additional fodder and bedding. Thus, the linkages between arable cropping and livestock–keeping would be strengthened: more fodder would be available, and both quantity and quality of manure would be improved.

Without doubt, it will be difficult to keep cattle away from arable land. Crop residue grazing is a common practice and sometimes still a right of the community. However, as a result of the increasing scarcity of land, this grazing pattern is already yielding to more pronounced use by the individual families. It would also be feasible to start with protection of individual trees until grazing is completely controlled on arable land. Protecting trees on communal grazing land is much more difficult. Here again, the long–term perspective must be to develop patterns of controlled land use, particularly with respect to browsing and fuelwood collection. To begin with, there may be no other possibility than to protect selected areas for some years by fencing and guards. However, the final decisions as to the means of protecting and utilizing trees should be made by the community concerned, who should have the final responsibility for implementing their decisions. It is conceivable that, by being encouraged to draw on past traditions of resource use and management, communities can develop new forms of management suited to the changing conditions.

Implications for AGRITEX. As soon as possible, agroforestry should become a new and top–priority activity of the extension service. Tree planting on contour ridges should be the first step. Seedlings should be given to all farmers interested in planting them. The farmers' investment would be the small amounts of manure which must be applied at planting and the labour inputs for planting, weed control and protection against grazing.

Concluding remarks. Major intentions of this paper have been to introduce some general concepts about agroforestry, to indicate its potential in controlling erosion and enhancing soil fertility, and to stress the necessity for applying agroforestry techniques in the Communal Lands of the SAAZ. Above all, it is meant to encourage colleagues in agricultural research, advisory services and administration to follow new paths toward conservation, management and development of resources.

We need to free ourselves from the conventional concepts of development and extension activities as passing along experimentally validated results to farmers. At present, we – the scientists – must admit that we have only very limited knowledge about appropriate agroforestry (or other) techniques to prevent land degradation in the SAAZ. To gain the necessary knowledge, we must work together with the rural people concerned in joint research and development efforts. We need to exchange ideas with farmers about the possibilities of using trees. We need to give them the opportunity and the responsibility to manage these resources. Besides making tree seedlings available to farmers and advising them in techniques of tree husbandry,

this would include, for example, clarifying farmers' rights to use contour strips as part of the farm enterprise and encouraging patterns of communal resource management which permit non–destructive utilization. Through trying out new ideas in cooperative trials on smallholdings and communal areas and through joint discussions of the results, researchers and farmers can learn together how trees can be best integrated into present land–use systems.

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III. Conservation of soil fertility by peasant farmers in Atlantic Province, Benin

Anne Floquet [1]

1. Description of location

Natural conditions. Atlantic Province (6°N–7°N, 2°E–2°30′E) consists of a gently undulating plateau dissected by few valleys without steep inclines, sloping gradually down to sea level at the Atlantic coast. The plateau soils are slightly ferralitic alfisols. The natural vegetation, formerly equatorial forest, is now degraded tree savanna. The mean annual rainfall of ca 1 000 mm falls in two rainy seasons (600 mm / 400 mm). The mean annual daytime temperature ranges from 25°C to 27°C.

Population and landuse. Population density is more than 125 persons/km^2 in the rural areas. The ethnic composition, comprising related Ewi groups, is relatively homogenous. The dominant form of landuse is bush fallowing: the landscape is a mosaic of small fields with scattered palm trees interspersed with fallows covered by dense bush 1–4 m high. These bush fallows are being partially supplanted by derived savanna with tall grasses *(Andropogonaceae spp, Paniceae spp).*

The Province's inhabitants can be subdivided into "pioneers" who cleared the virgin forest, "conquerors" who received landuse rights from the Abomey kingdom, and more recent "immigrants". The formerly strong rural exodus is slackening off, as unemployment rises in urban areas and in neighbouring Nigeria.

The major crops are maize, oilpalm, cassava, groundnut, cowpea, teak and vegetables (tomatoes, chillies, okra). The most

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Landscape in the Province Atlantique: fields with scattered palms and shrub fallows.

On fields which have been cultivated for several years, weeds (especially grasses) develop and compete with maize.

common crop combination in various different rotations involves oilpalm, maize and cassava.

Livestock husbandry is of minor importance. Mainly goats, poultry, and some sheep and pigs are kept. They are basically scavengers and are slaughtered for celebrations or serve as financial fallback in times of need.

2. Problem analysis

Rapid population growth and the establishment of large state–owned oilpalm plantations have led to land scarcity for peasant farmers. As a result, the traditional fallowing system is disintegrating: fallow periods are being shortened and cropping periods lengthened. This leads to declining soil fertility, falling yields and a serious problem of weed invasion into cropland. The farmers are compelled to develop more intensive yet sustainable forms of landuse, and this process must occur quickly enough to avoid irreversible ecological damage. On numerous research stations, scientists are trying to develop suitable measures (improved varieties, alley cropping, intensive fallow with fast–growing legumes). Although some interesting production techniques have been developed in this way, the question remains fully open as to whether the smallholders are willing or able to adopt these innovations. For each specific target group with different access to land and availability of labour and cash, the question constantly arises whether an innovation is appropriate and acceptable.

3. Aims

The programme ESYCTRA (Etude des Systèmes de Culture Traditionels et de leur Maitrise de la Fertilité) within CARDER Atlantique (Centre d'Action Régionale pour le Développement Rural, Province Atlantique) has the aim of supporting farmers in the development of more intensive yet ecologically sustainable landuse systems. The research team works with the assumption that some particularly progressive farmers have already developed methods of intensification ("indigenous innovations"), which are not yet generally known. At the same time, it is necessary to investigate the extent to which cultivation methods developed on research stations, e.g. alley cropping or intensive bush fallow with *Cajanus cajan*, are suitable for adoption by the farmers. The ESYCTRA team therefore set itself the following tasks:

- to define the problems and basic needs from the viewpoint of the farmers,
- to identify and assess innovations which farmers have already developed to solve their agricultural problems,
- to investigate the extent to which innovations developed on research stations are useful within the smallholder setting.

4. Methods

4.1 Basic considerations

The research team comprised Beninian agronomists, a sociologist and the author, working in close collaboration with village extensionists. At the outset, the team had little knowledge about the target group. No data were available about the farms' resources or the households (size, composition, labour force, etc). In addition, no proven methods were known of identifying and assessing indigenous innovations; here, the team was breaking new ground.

The development of more intensive cropping techniques means that other aspects of the farming system must be changed considerably. This is a very complex process which can be promoted successfully only by working directly together with the farmers. The team's close collaboration with farmers in the research and development process was an iterative process which

led to increasingly precise results. This demanded that the team have not only a solid base of agronomic experience and good local knowledge but also, above all, a new understanding of relating to farmers. In order to gain knowledge about both the farmers' problems and their efforts to solve them, the researchers had to assume the role of learners. This was a basic principle of the methodological approach, and a prerequisite for building upon the knowledge and skills of the farmers in developing intensification techniques appropriate to their particular situations.

4.2 Phase I

In the first phase of research (April–August 1986), two surveys were made. The first survey involved questioning one group of farmers in each of the 80 communities in the Province. The groups consisted of voluntary participants encountered in the fields and villages. The team used a discussion guideline focused on agriculture but tried to remain open to the farmers' ideas. Each evening, a summary of the days' findings was written up and discussed. A report was compiled for each of the seven districts in the Province.

The socioeconomic topics included land (ownership, use rights, farm size), labour (availability per farm, rural–urban migration, distribution of labour inputs over the year), and description of economic activities according to gender and wealth class. Furthermore, the primary limiting factors of these activities were analysed, as well as the frequency and causes of bottlenecks. The major agronomic aspects covered were soils, fallow vegetation, present crops and varieties, and cultivation techniques. In discussions with the farmers, their views of the primary agronomic constraints were elicited.

In the second survey (September 1986 – February 1987), an attempt was made to obtain more detailed quantitative data on the most important topics which emerged during the first survey. A total of 100 farms were covered. The survey was spread over three interviews for each questionnaire.

This survey permitted classification of the different farm types and validation of the qualitative statements made by the farmers during the first survey. The local conditions were analysed more precisely, different land types were defined, and new hypotheses emerged for identifying indicators which could be used in future monitoring of production technology development. Differences between cropping methods were determined, and new key questions were formulated.

In addition, access to land, landuse rights, household structure and labour availability were investigated. Farmers' opinions were sought about constraints to expanding or intensifying cultivation, and the aims, income and limiting factors of different production techniques were compared. With respect to crop agronomy, yield development (emergence, flowering, time of harvest) and yields of maize were investigated in relation to location and cropping methods.

4.3 Phase II

The second phase of research (April–December 1987) was devoted to seeking indigenous innovations. Because only few of the farmers in the surveys suffered so acutely from land shortage that they were compelled to develop more intensive forms of landuse, the aid of village extensionists was sought in identifying farmers who knew how to ensure family subsistence and maintain yield levels despite growing land shortage. Thirty farms were selected as a representative cross–section with respect to soil characteristics and vegetation. Despite its small size, this sample was sufficient to complete the basic analysis as planned. In discussions and field observations, it was verified whether land scarcity was indeed a problem and the farmer's attempts to find solutions were identified. The investigation was then focused on techniques of intensifying landuse. The innovations were classified according to type, and farmers representative of each type were selected, on whose fields the innovations could be studied in more detail.

Farmers were also encouraged to try out in their own fields some of the methods of landuse intensification which had been developed on research stations. The research team made measurements and observations in the farmers' trials.

5. Results

As this research entailed seeking a new methodological approach, the following discussion refers not only to the findings but also to the methods of investigation.

5.1 Discussion of methods chosen

As a point of entry, the method of open interviews proved extremely valuable. It could thus be avoided that potentially important aspects were excluded prematurely. Rather, the iterative group conversations brought the problem analysis progressively closer to reality. It was also favourable that the form of questioning was simple and caused little disturbance to the farmers. By comparison, initial interviews with individuals selected as a random sample (e.g. ticked off on a list) were regarded by the farmers as threatening. It was disadvantageous, however, that the self–image presented by the farmers tended to distort reality (glossing over social differences), that fringe groups could not make themselves heard, and that the research team influenced the choice of topics to some degree.

The 100 farms selected for the second survey were already involved in CARDER's on–farm testing of new maize or groundnut cultivars. This had the advantage that the farmers took active part in the discussions and field observations. Similarly gratifying was the participation of the village extensionists, who were simultaneously assisted by the team in monitoring the maize plots. However, the question must be raised whether this sample was appropriate for attaining the defined aims. It represented that part of CARDER's target group which felt itself addressed by CARDER: primarily full–time farmers. It did not include the poorest rural families, who also work for wages on other farms and are most seriously affected by land scarcity. Also women were not included in the survey, as they were not involved in the on–farm programme. The question thus remains whether those who are already caught up in the vicious circle of insufficient yields – therefore wage labour – therefore labour–extensive farming of their own land – therefore insufficient yields are at all in a position to alter their situation. Without doubt, the quantitative composition of the sample was not representative of the total farming population in the Province, but it included all other groups except the above-mentioned and thus permitted a classification of the different farm types in the Province.

Of greatest interest for the next phase of the work, the search for indigenous innovations, were those families found between the marginalized farmers and the full-time farmers, i.e. those experiencing pressures but still having possibilities of altering their situation. The 30 farms in which indigenous innovations were studied in detail were selected accordingly. Retrospectively, the question arises whether it would not have been possible to work with these 30 farmers from the beginning. The team members came to the conclusion that the preceding steps in the work enabled them to identify the target group more precisely and to become sufficiently familiar with their problems to be able to examine more purposefully the problem of intensifying landuse.

5.2 Discussion of findings

5.2.1 General trends in agricultural development

As a result of population growth and the establishment of large oilpalm plantations, the farmland available to smallholders has been greatly reduced within a relatively short time. Table 1 gives an overview of the situation. It can be seen that the available land per inhabitant has decreased by one third within 25 years, and that this trend is accelerating. The portion of land fallowed has sunk correspondingly from 75% to 57% and will probably be ca. 33% by the year 2000. At the same time, the cropping period is extended from 2 to 3–5 years.

The second survey revealed that the average farm family of 13 persons had access to 7.3 ha[2] land, of which 4.7 was devoted to arable crops. In other words, land scarcity is not yet a problem

[2] However, the smallest farms (type VIII in Tables 2 and 3), comprising ca 20% of all farms, were not included in this survey.

Table 1: Indicators of the intensity of landuse in Atlantic Province

Indicator	1960	1976	1985	2000*
Arable land per inhabitant in the farming population (ha)	1.23	1.00	0.81	≤0.53
Cultivated land per inhabitant (ha)**	0.31	0.30	0.35	≥0.35
Landuse:				
Fallow	75%	70%	57%	≤33%
Tree crops not included in fallow systems	5%	8%	7%	≥66%
Seasonal and annual crops	20%	22%	36%	

Sources: 1960 and 1979 census, farm survey (FAO 1976), partial survey of farms (CARDER 1985).

* Projection assuming that population growth and rural emigration remain constant and no appropriation of land by city dwellers is occurring.

** Assumption: Yield level stabilizes.

for these farms. Extension of cultivation is constrained, rather, by declining soil fertility and insufficient labour during labour peaks. Where land is ample, it is common to lease fields which have been fallowed for 3–4 years for 1–4 seasons of cropping. With increasing land scarcity, however, this is becoming more seldom.

The major arable crop is maize. In order to ensure family nutrition, most farmers expand maize cropping to the greatest possible extent [3]. Any additional production is sold.

Crops grown primarily for sale are oilpalms, groundnuts, vegetables and cowpeas. Cassava is grown for both subsistence and sale. The reason for growing a crop is not necessarily reflected in its importance for subsistence or cash income: maize is most important in both domains. In the second growing season of 1987,

[3] To provide all family members with maize, 0.15 ha of maize per season and person must be grown in an average year on soils of average fertility (consumption 185 kg/person/year; yield 1 t/ha in the first growing season and 0.65 t/ha in the second, 20% storage losses). However, because of the relatively high cropping risks associated with irregular rainfall, more than this is usually cultivated.

an average of 85% of the cropped land was devoted to maize, 66% of this as a sole crop and 33% in mixtures with cassava. As generators of cash income, oilpalms and groundnuts were second and third in importance.

5.2.2 Farms types in relation to land availability and landuse rights

In most farms, production methods have developed out of a situation of ample land and scarce labour. The farms surveyed could be classified into different types according to land availability and intensity of landuse (Table 2).

An important distinguishing criterion is the labour supply of the farms. In the **large farms** (types I and II), labour is still the main limiting factor. Correspondingly, the land is worked very extensively and the portion of fallow is high. In contrast, farm types VI–VII suffer from acute land shortage; their R–values are already 0.52 and 0.73, respectively. Farm types III–V occupy an intermediate position. They still try to lease land wherever possible to be able to continue extensive cropping. However, this is becoming increasingly difficult, as land scarcity becomes more acutely felt.

Table 2: Farm types according to form and intensity of landuse

Farm type		Farm area (ha)	Family labour (per ha)	Duration of cropping (years)	Duration of fallow (years)	R-value*	Tree crops (% area)
I	very large	30.0	0.27	3.1	5.5	0.36	6
II	large, with tree crops	15.9	0.14	2.7	7.8	0.26	30
III	medium, extensive	7.9	0.25	3.6	6.0	0.31	6
IV	medium	5.2	0.56	3.5	4.9	0.42	10
V	medium, with tree crops	7.4	0.28	4.5	4.2	0.52	36
VI	medium, intensive	6.1	0.51	4.3	3.9	0.52	7
VII	small, intensive	2.4	1.04	8.2	3.0	0.73	17
VIII	marginalized			not surveyed			

Source: Own survey in 100 farms, 2nd growing season 1986.

*Including leased land but excluding areas with tree crops.

The importance of tree crops within the farm is a further distinguishing criterion of the farm types. Tree crops are found on farms with more land than needed to ensure family subsistence from maize and other annual crops. In addition, the farmers must own the land. Only in rare cases does a lease contract permit the planting and utilization of tree crops, e.g. oilpalms. Land ownership is, among other things, dependent on age. Usually only older farmers own land, but not younger ones or women. The farms of type II have a large percentage of tree crops because the farmers own rather than lease the land.

In the **medium–sized farms** (III–VI), two extremes can be distinguished: because farm types III, IV and VI are worked mainly by leaseholders, tree crops are lacking, or palms are integrated into fallow and are felled toward the end of the fallow period to produce palm liquor (see section on palm fallow). In contrast, farms of type V have greatly reduced their fallow in order to plant palms on almost 40% of the total area, while the remaining area is greatly overused.

These oilpalm stands are established either because the site is too marginal for arable cropping (coastal strip) or because, at good locations (northeast), the farmers can still continue to sow maize in juvenile as well as in thinned–out mature oilpalm stands. This substitution of bush fallow by oilpalms represents a form of intensification.

The **small farms** with acute land shortage (VII) have next to no tree crops. These farms are cultivated above all by immigrants, so–called "cooperants", young farmers and women. The immigrants, who arrived after the land had already been distributed, are dependent on lease in kind, i.e. they usually have only medium–term usufructory rights to the land, must give the landowner a third of the harvest as lease payment, and are not allowed to establish any tree crops (southwest).

The "cooperants" come from areas where land was expropriated for the establishment of commercial palm plantations. They have been granted landuse rights to 2 ha per family within the "ZOCA" (zone de cultures annuelles) to grow food for the family as a supplement to their wages from working on the plantation, but are not allowed to plant trees on the land.

The young farmers are those who want to set up an independent household but come from families which no longer have any fallow land available for them. When the first sons are old enough to marry, the father still has a large family to feed. He therefore tries to obtain fallow land for the son on short-term lease. This has become particularly difficult in the vicinity of cities, where increasing numbers of urban dwellers are buying up land to improve their income or old-age security (south and southeast).

The women cultivate small plots allocated to them by relatives, but their landuse rights are insecure. Through the sale of their crops, they try to meet their own and their children's cash needs.

The farms of type VII have an average of 2.3 ha land and a labour force of 2 units, but must support 8 household members. Two thirds of the area is sown to seasonal crops. This leads to degeneration of the bush fallow system, e.g. with a cropping period of 6 years, only 3 years remain on average for fallow. If the entire area could be sown to maize, family food needs could barely be met. As maize monoculture without fallow is impossible, the farms must diversify – in the southwest and west with cassava, in the south with legumes, and in the southeast with both. Some farms seek additional off-farm income. If innovations to intensify landuse are not introduced, this system cannot be sustained.

As the marginalized farmers (VIII) were interviewed only in the qualitative survey, they are not described in quantitative terms in Table 2. This group is already operating below the subsistence level and can survive only by working as day-labourers. Because they must work on other farms during labour peaks, they have difficulties in timely cultivation of their own fields, where the productivity per unit area is consequently low.

Table 3 gives a summary of the main production constraints in the different farm types. Except the large farms (I and II), all other farms (ca 90% of the total) suffer from a shortage of labour and, in most cases, also of land. In other words: availability of land and sufficient labour are not alternative lacks. To the contrary, the problem of labour scarcity increases with the problem of land scarcity. Shortage of land can be partially compensated by higher labour inputs, but as soil fertility decreases, so too does the productivity of labour. Although the yields decrease, the labour inputs required for preparing the fields, sowing and weeding remain the same or even rise. The small and smallest farms (VII and VIII) therefore find themselves in the situation of having access to less and less land and simultaneously being less and less able to cultivate it carefully.

Table 3: Main constraints of the different farm types

Farm types	Distribution (estimate)	Main production constraints		
		Scarcity of labour	Scarcity of land	Inability to intensify landuse
I + II (large)	ca. 10%	(+)	–	–
III + IV (medium, extensive)	ca. 25%	+	+	++
V + VI (medium, intensive)	ca. 25%	+	–	+
VII (small)	ca. 20%	++	+	++
VIII (very small)	ca. 20%	++	++	+++

Source: Estimate by author; BREMER et al. (1986).

5.2.3 Farming intensity and fallowing

The different farm types can be regarded as steps in an overall process of intensification: from a situation with ample land and long fallow periods to a situation with extreme land scarcity and transition to permanent cropping. Figure 1 shows how the natural or fallow vegetation changes according to farming intensity and location.

Only two generations ago, the prevailing cropping system involved 7–8 years of fallowing. After clearing, maize, cowpea and cassava were sown, partly in mixed cropping, and scattered oil-palms were planted. This cropping without soil tillage – the only implement was the machete to clear the bush – was practised only 2 to 2 1/2 years before renewed fallowing. According to the farmers, the fallow was long enough to maintain the long-term productivity of the soil. This system is rarely encountered today, except in some remote areas.

As land became more scarce, the farmers first reacted by shortening the fallow period. Most farmers think that the duration of fallow can be reduced to 3–4 years at average sites, but must be longer at sites where soils are low in fertility or poorly drained. The shrubs need at least 3 years to develop enough vigour to create the desired positive effects on a subsequent maize crop, as well as to produce branches of economic use to the farmers. For this reason, land is leased only if it has been fallowed for 3–4 years. The next step in intensification is to lengthen the cropping period but still to retain the fallow of 3–4 years. As the market value of wood, which is a product of fallow land, is rising constantly, few farmers are willing to abandon fallowing completely.

When the fallow lasts less than 3 years, fundamental changes occur in the vegetation. This does not necessarily have negative consequences for soil fertility. With reference to a new plant, *Eupatorium odoratum*, which has aggressively invaded fallow areas, the farmers concerned say: "God has sent us fertilizer". However, because this species "only" ameliorates the soil but has no economic use, the farmers are not yet prepared to plant it. *Panicum maximum*, which has become widespread at less impoverished

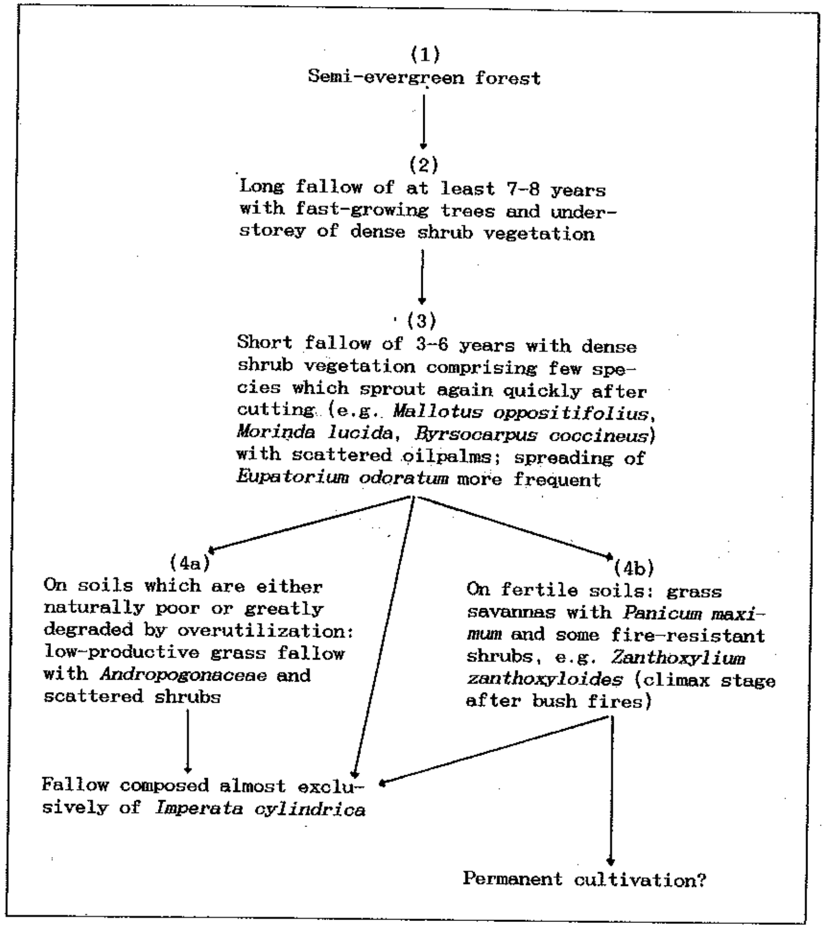


Figure 1: Composition and development of natural vegetation in relation to farming intensity and soils

sites, is also recognized as an effective and rapid soil-ameliorator, but is nevertheless regarded as a plague because it demands longer land preparation for cropping and higher weeding inputs. All in all, it therefore appears desirable either to maintain a shrub fallow of 3–4 years in order to produce wood or to shift completely to permanent cropping.

The situation on the individual farms can be summarized as follows. Only a few farms are at Stage 2, where sufficient land is still available. The vast majority are at Stage 3, where the old system reaches its limits. Most fields in the Province are fallowed for 3–6 years, and only a few for 1–2 years. At average sites, 3–4 years of fallow is the minimum. Some farmers try to stabilize this system with its fallow component; others replace the fallow with dense palm stands to produce liquor. However, such forms of further development of the cropping system are found on only few farms. In most cases, the old cropping system is continued until the land is completely degraded, at which point a changeover to more intensive and productive alternatives is difficult. It was therefore of particular interest to take a closer look at the indigenously developed alternatives and to consider how they could be made accessible to other farmers.

5.2.4 Indigenous farmers' innovations

Intensification of landuse is not limited to shortening the fallow or lengthening the cropping period. As land has become more scarce, farmers have developed numerous other innovations, the most important of which are described below.

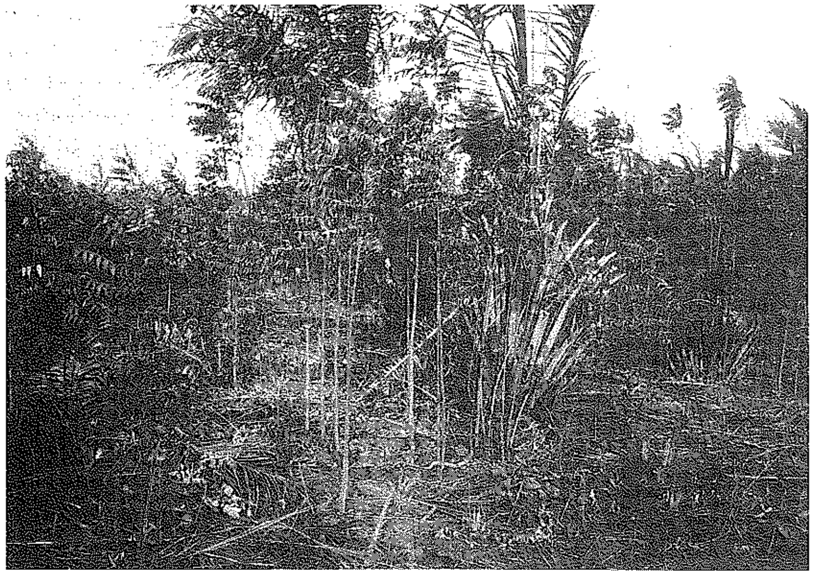
Cassava as component of the crop rotation. Also in bush fallow systems which are still fairly intact, cassava planted at low density already serves as a transition crop to the fallow. In the meantime, cassava is being grown increasingly to extend the duration of cropping. Pure maize cropping is followed by maize/cassava intercropping in the long wet season. After maize harvest, the cassava continues to grow over the short wet season until the next long season. The cassava is harvested when needed, i.e. the harvest stretches over 8–18 months, after which a maize crop is sown. The regenerative effect of cassava is attributed to its deep rooting, which mobilizes additional nutrients from lower soil layers. The deep tillage associated with harvesting of the roots permits incorporation of organic matter and deeper rooting of the following crop. The considerable leaf drop of the cassava plants fertilizes the topsoil. A dense cassava stand may also shade the soil sufficiently to suppress weeds. However, the question remains whether cassava really contributes to a regeneration of the soil for sustainable cultivation or only exhausts the soil more completely.

Deeper tillage and incorporation of organic matter. Deep tillage developed gradually from a traditional system of "zero–tillage". Originally, cropland was prepared only with the machete, i.e. the above–ground plant parts were cut and burnt. This permitted rapid regrowth after a short cropping period. With the spread of weeds, i.e. plants not originally in the fallow vegetation, the hoe was adopted to scrape the field clean; the weed vegetation was then burnt. The gradual transition to deeper tillage with the hoe began with digging a planting hole so that the soil around the seed was loosened. This gradually changed to deep tillage (15–20 cm) over the entire field, which permits simultaneous incorporation of organic matter and makes burning superfluous. As there are scarcely any woody plants in the fallow by this phase, incorporation of organic matter does not present problems. The next step in intensification is ridging (see below).

Grain legumes as component in the crop rotation. Like cassava, also legumes such as groundnut (*Arachis hypogaea*), niebe (*Vigna sinensis*) and Bambarra groundnut (*Voandzeia subterraea*) were sown as transition to fallow. Today, groundnut and niebe have often become a regular component in the rotation. They are grown either alone or in sequence (groundnuts, then niebe) in the long wet season. These crops have such a beneficial effect on the soil that maize can be grown for several seasons afterwards. In the case of groundnut, this is due to the deeper tillage, in the case of niebe to the good ground cover and leaf fall. The farmers themselves regard niebe as more effective in this respect than groundnut. However, the niebe is very susceptible to pest infestation.

Ridging and incorporation of organic matter. In some regions the development of deeper tillage techniques has progressed to the making of ridges, particularly in sandy locations which have been farmed for a very long time (southwest and southeast). Ridging for maize cropping is practised on impoverished or naturally poor soils, even at sites which are marginal for maize, i.e. only a few plants can be grown in mixtures with groundnut and niebe and, more rarely, also vegetables. Ridging is often employed to prolong maize cropping at a given site. It permits better

Ridging and thus concentrating organic matter: on soils where maize can no longer be grown on the flat, ridging becomes an alternative.



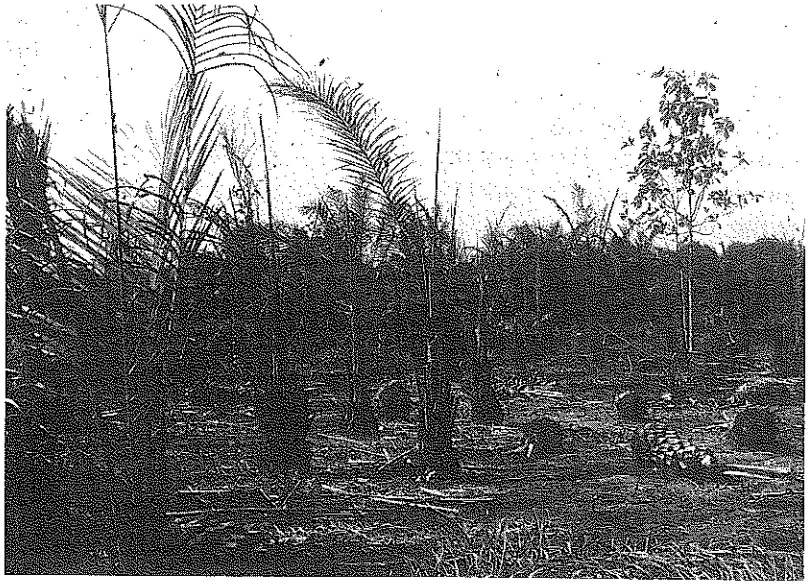
A common practice is planting neem trees as a fence or, as shown here, because the field has been invaded by *Imperata cylindrica.*

and deeper incorporation of organic matter. Plant residues are laid in the furrows which form the basis for new ridges in the following year. However, the only sources of organic matter are crop residues and weeds in situ; no organic matter is introduced from elsewhere. The farmers consider this to be too labourious. The yield–increasing effect of ridges can be explained not only by the addition of organic matter but also by the spatial concentration of topsoil. The effects of this technique on water balance are not clear.

Farmers who practise ridging had already done so elsewhere before coming to Atlantic Province, or they learned the technique from migrants. Migrants who had grown exclusively on ridges in their place of origin initially practised zero tillage at their new location and waited until the soil was impoverished before they resumed their old ridging practices. For their neighbours who are "trying out" the technique for the first time, it is a real innovation.

Cultivation of sweet potatoes. Sweet potatoes are grown in the southwest of the Province, the only area where there is a demand for this root crop. They are planted when hardly anything else can grow (after ca 7 years' cropping). Ridges are made, on which the sweet potatoes grow from May to December. The effect on subsequent crops is due partly to the deep tillage associated with ridging, but also to the dense ground cover and the above–ground biomass which is worked into the soil at harvest when the ridges are broken down.

Retaining fallow shrubs and introducing tree crops. During the cropping phase (ca 7 years), various fallow shrubs are selectively cut back and retained, whereas others are completely removed. This leads to a selective fallow vegetation which the farmers regard as more productive for the shorter fallow period (3–4 years) and which still provides the economic products of a "normal" fallow: timber, fuelwood, fodder, etc. As these farmers experience increasing land scarcity, they begin to include tree crops in the cropping system. Teak and neem trees are planted, either around fields or on small separate plots. The step to planting tree crops is connected with the question of land rights: fallow vegetation is



In very densely populated areas, dense palm groves are alternated with seasonal crops. These groves are first planted in association with seasonal crops and grow later in pure stands. They play the role of bush fallows.

Besides *Cajanus cajan*, other species are being tested for sown fallow to improve soil fertility, provide fuel and forage, and suppress *Imperata cylindrica*. One example is *Mucuna utilis* as 1–year green manure, as shown here.

common property, whereas planted trees manifest land ownership, and only the landowner may plant them. With a view to land availability, this would be a form of intensification possible in all medium–sized farms (types III–VI), but it is practised by only few farmers. Although the majority are interested in retaining the fallow, few farmers have consciously dealt with the question of how the fallow could be intensified.

Palm fallow. With the so–called "palm fallow", the spontaneous spread of oilpalm seedlings has been developed into a systematic form of landuse. A wide spectrum of intensification steps by the smallholders can be observed. Young palms are deliberately protected during the 3–4 years of cropping, and some are also transplanted to create a uniformly dense stand (up to 600 palms/ha). After the cropping period, a mixed palm/bush fallow vegetation develops. The palms are retained until palm liquor (*sodabi*) can be made, at the earliest when the trees are 6–7 years old (after 3 years of fallow). However, because the palms serve as a savings bank, they are felled only when money is needed. As the palm juice yield increases proportionally with the age of the tree (up to the 14th year), this system remains profitable also with longer fallow periods. The effect of palm fallow on soil fertility has not yet been investigated. A positive effect is expected, although, as the palm fronds are used as fuel, a large part of the biomass is removed from the system.

5.2.5 Exogenous innovations in intensifying landuse

Parallel to the work in the smallholdings, new possibilities of maintaining soil fertility have been tested on research stations. From a broad spectrum of legumes including the shrubs Glyricidia, Leucaena and Cajanus and ground–covering legumes like Mucuna and Pueraria, a technique involving the local variety of *Cajanus cajan* exhibits the greatest promise for introduction into smallholdings. *Cajanus cajan* is sown with a spacing of 100 x 50 cm together with maize, develops first as an understorey crop and, after maize harvest, continues to grow over a total of one year. Shortly before the next long wet season, it is cut and left on the fields as mulch for a subsequent maize crop. Initial research results with this "improved fallow" technique are shown in Table 4.

Table 4: One-year fallow with *Cajanus cajan* – production performance and fertilizer effect on subsequent maize yield

Production performance of *Cajanus cajan*	Above-ground biomass (kg/ha/year)
Leaves[1]	9 615
Stems[1]	6 166
Foliage litter[2]	12 191
Fertilizer effect of *Cajanus cajan*	**Maize yield (kg/ha)[3]**
Cajanus as preceding crop	1 815
Control	890

Source: Trial D7–8, I+II/85–86 at Calavi (AKONDE & KÜMMERER 1986)

[1] Fresh matter.
[2] Air-dried.
[3] Original values given as cob yield converted to grain yield with the factor 0.64

Even though the biomass yields vary greatly between locations and years, the facts remain that the high level of leaf litter and associated mulching fertilizes the soil and the shade cast by the Cajanus stand reduces weed growth. Even *Imperata cylindrica*, which propagates itself via stolons, can be temporarily suppressed by Cajanus fallow. Still more decisive for the suitability of this technique for peasant farms is the fact that the Cajanus fallow resembles the one–year cassava cropping (see Section 5.2.4), so that the "innovation jump" is relatively small and, thus, easy to make, provide that Cajanus is really superior to cassava.

The results of initial on–farm trials with Cajanus fallow are shown in Table 5. Because yield records made by the village extensionists were not very precise, the margin of error is wide. Nevertheless, in the first season, all variants differed significantly from the control. As a mean of 32 farmers' fields, *Cajanus cajan* had a relatively low effect if compared with the results under

Table 5: Fertilizer effect of one-year *Cajanus* fallow compared with mineral fertilizers (average values of 32 farmers' fields)

	Maize[1] yield (cobs with husks)			
	Long season 1986		Short season 1986/7	
	(kg/ha)	(rel.)	(kg/ha)	(rel.)
Maize with maize as preceding crop (control)	2170	(100)	1250	(100)
Maize after *Cajanus*	2570	(118)	1220	(98)
Maize with 100 kg/ha NPK[2] and 50 kg/ha urea[3]	2930	(135)	1430	(114)
Maize with 200 kg/ha NPK and 50 kg/ha urea	3000	(138)	1540	(123)

Source: CARDER, n. d.

[1] Maize cultivars: Pirsaback and Poza Rica.
[2] NPK = 15% N_2 + 15% K_2O + 15% P_2O_5.
[3] Urea = 46% N_2.

controlled conditions. However, numerous individual results revealed yield increases of 80–120% on areas previously planted to Cajanus, even when the initial yield level was above average.

Questions still to be investigated are how the performance of Cajanus fallow compares with that of indigenous innovations such as cassava, and how the farmers judge the difficulties and benefits associated with this new technology.

6. Proposals for continuation of work

Thus far, the farm types could be identified in which further development of cropping methods to intensify landuse are most probable, and the most important indigenous innovations could be discovered and described. The next step is to study the efficiency of these innovations and their practicability in socioeconomic terms from the farmers' point of view. The next phase of research, to be carried out together with the farmers and on their fields, therefore has the following aims:

- to assess the efficiency of indigenous and exogenous innovations in the smallholder setting, comparing them with each other as well as with conventional smallholder practices; and
- to make corresponding comparisons in socioeconomic terms in order to clarify the advantages and disadvantages of these innovations, and their practicability or the obstacles to their adoption.

For the next three years, the following research is planned. A group of farmers, who have already made cassava a regular component of their crop rotations as described in Section 5.2.4, will compare this with Cajanus fallow. Another group will compare the innovation "cropping on ridges with incorporated organic matter" with Cajanus fallow. Numerous other innovations as described in Section 5.2.4 will be investigated with regard to their effects and performance as case studies on individual farms. The practices of "palm fallow" and "shortened bush fallow" are to be studied in greater detail to determine their contribution to regeneration of soil fertility and their economic role within the farming system.

As the research programme will continue, in collaboration with farmers, to build upon the innovations they developed themselves but will also investigate the appropriateness for smallholders of technologies developed in classical field trials under controlled conditions, the results are expected to be of great use to agricultural advisory services.

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IV. Green manuring with fast-growing shrub fallow in the tropical highland of Rwanda

Kurt Raquet

1. Description of location

1.1 Natural conditions

The mountainous country of Rwanda lies between 1°04'–2°51'S and 28°53'–30°53'E on the eastern slope of the Great Rift Valley. It is bordered by Uganda to the north, Tanzania to the east, Burundi to the south and Zaire to the west. With an area of 26,338 km², it is one of the smallest countries in Africa.

A transect from east to west cuts across five land formations characterized as follows by WERLE & WEICHERT (1987):

- the plateau zone of east Rwanda,
- the central highland,
- the edge of the Great Rift Valley (Zaire/Nile divide),
- the trough at Lake Kivu, and
- the Birunga volcano region.

The study area lies mainly at an altitude of 1650–1900 m a.s.l. in the central highland, and includes the municipalities of Nyabisindu, Kigoma, Rukondo and Karama (see Figure 1). The original vegetation of tropical montane rainforest in transition to tree savanna has been changed in the wake of settlement to a pure farming landscape.

The climate is influenced by the closeness to the equator. The mean monthly temperatures remain fairly constant over the year, but the mean annual temperature in the central highland is fairly

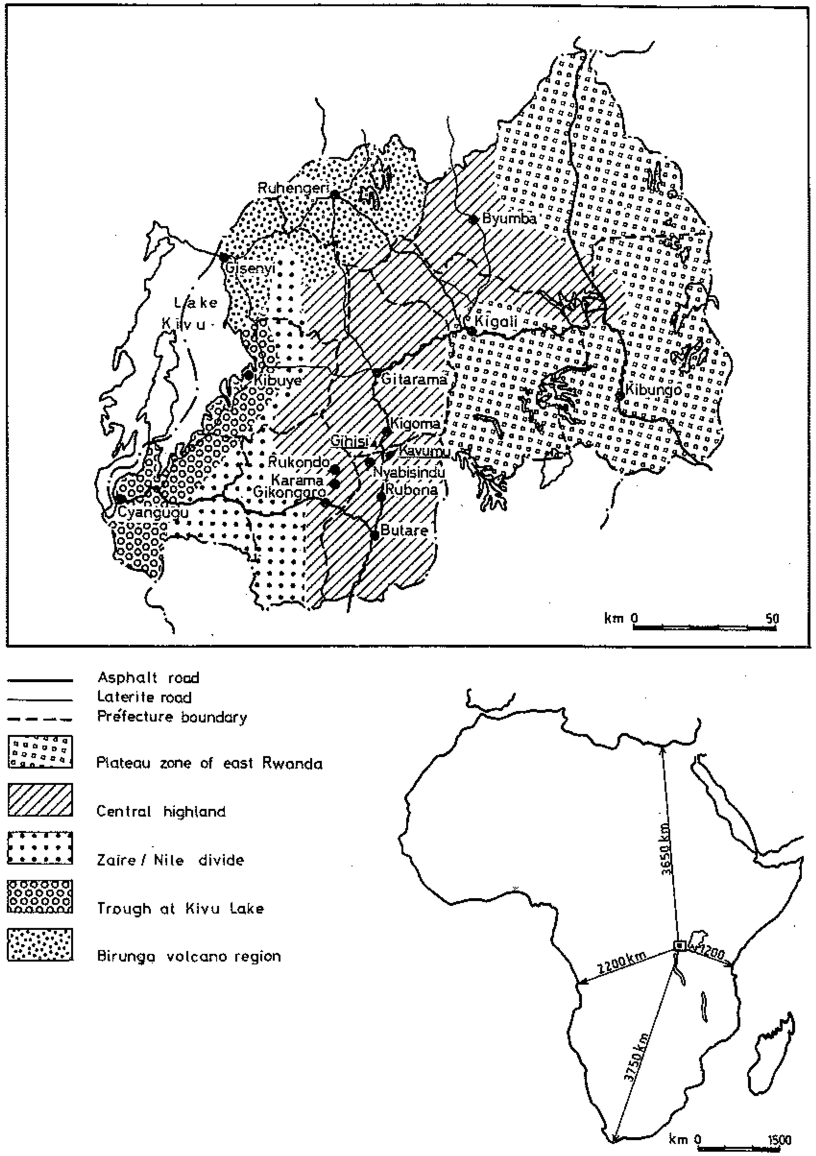


Figure 1: Geographical map of Rwanda

low (19–20°C, SIRVEN et al. 1974) on account of the high elevation. The mean annual precipitation of 1000–1400 mm in the Nyabisindu/Kigoma area (PAP 1984) is divided between a short rainy season from mid–September to mid–December and a long one from mid–February to late May/ early June. Whereas the short rains are characterized by an unreliable start and unreliable distribution and sometimes fail completely, the long wet season offers reliable and well–distributed rainfall.

Table 1: Annual precipitation and number of rain-days at Gihisi Station of PAP Nyabisindu, 1978–1983

Year	Precipitation (mm)	No. of rain-days
1978	1360	107
1979	1042	88
1980	1228	88
1981	1222	113
1982	1409	126
1983	1110	162

Source: PAP 1984.

The predominant soils in the study area are ferrisols and ferralsols. The former have deep fertile topsoils with good humus content, whereas the topsoil of the ferralsols is confined to a depth of 10 cm over a layer of low fertility. Further soil types which are widely scattered but fairly frequent in Rwanda are shallow lithosols of low nutrient content on quartzite ridges, histosols (boggy soils) and vertisols (dark clayey soils) in the valleys (HAAS 1984).

1.2 Population and landuse

With a human population of 6.2 million and a density of 234 people/km² as of mid–1985 (and already 390 people/km² cultivated land in 1982), Rwanda is among the most densely settled countries in Africa (SBW 1985). The population is growing at an estimated rate of 3.8% p.a. (NKULIYINGOMA 1987). The major ethnic groups are the Bahutu (90%) – primarily arable farmers – and the livestock–keeping Batutsi (9%). The original inhabitants

(Batwa) now make up only 0.5% of the population (WERLE & WEICHERT 1987). The vast majority of Rwandans – for 1987 a projected estimate of 89% (DELEPIERRE 1985) – live in dispersed peasant farming settlements.

In the project municipalities, the population density is 300–500 persons/km² (NEUMANN 1988). The average household in the Nyabisindu project area has just under 6 members and cultivates an area of 0.5 to 2 ha, depending on the municipality (BREITSCHUH 1985). According to DRESSLER (1984), the average farm size in the project area is already below 1 ha.

The farmers' primary aim is to meet their subsistence needs. Traditionally, mixed cropping is practised; the main crops in the study area are beans, plantains, cassava, sweet potatoes, sorghum, potatoes and maize. Very little forage is grown, and farm forest areas are decreasing rapidly (BREITSCHUH 1985). The major cash crop is coffee. Since the immigration of Batutsi cattlekeepers from the 14th century onwards and their attainment of political superiority, the possession of Watussi cattle has played an important role in Rwandan society. However, the expansion of cultivation and concommitant decrease in grazing area has led to a decrease in cattle holdings and an increase in holdings of smaller livestock (goats, sheep, pigs, rabbits and chickens). In the project area, 25% to just under 40% of the farms keep cattle (BREITSCHUH 1983) and over 40% keep goats (PIETROWICZ 1983).

2. Problem analysis

The rapid population growth in Rwanda has led to expansion of cultivation, deforestation and overgrazing. The removal of vegetative cover from unprotected slopes leaves the soil highly vulnerable to erosion during heavy rains. In view of the increasing scarcity of arable area relative to population, the long periods of natural fallow required for regeneration of soil fertility are no longer possible. The productivity of agricultural land is declining

rapidly. Possibilities of increasing soil fertility by applying mineral fertilizer are limited for both ecological and economic reasons. Ways must be found of combining intensive but sustainable use of locally available resources with the sparse use of external inputs in order to control erosion and to maintain or increase land productivity.

Over the past 13 years, the **Projet Agro–Pastoral (PAP) de Nyabisindu** has been designing, in collaboration with the Botanical Institute of the University of Heidelberg (Prof. Dr. Egger), a system of ecologically sound agriculture combining measures of vegetation design (agroforestry, multiple cropping) with measures of organic manuring such as using dung from stallkept livestock, composting, and sowing fallows to fast–growing nitrogen–fixing legumes. These so–called intensive fallows are meant as an alternative to the traditional grazed fallows, which take a long time to regenerate the soil and are, even then, of low effectiveness. In contrast, intensive fallows are of short duration, effectively suppress weeds, and produce much more biomass in the first year (above–ground biomass of up to 20 t DM/ha; PIETROWICZ & NEUMANN 1987). They also have a greater positive effect on subsequent crops (EGGER 1981, 1982; EGGER & ROTTACH 1984).

Two types of sown fallow for green manuring are being used: a herbaceous legume over one wet season, and a mixture of herbaceous and shrub legumes over at least two wet seasons. Before the start of a new cropping period, the fallow vegetation is cut, chopped up, and worked into the soil. The woody plant parts mineralize only slowly and lead to a long–term increase in the humus content of the soil.

In principle, the important contribution of intensive fallow in maintaining soil fertility has been established. However, it could not yet be widely disseminated to peasant farmers. One hindrance has been that few standard recommendations do justice to the diverse soil types and degrees of soil impoverishment in farmers' fields. For example, the standard mixture of *Cajanus cajan, Crotalaria lachnophora*[1], *Tephrosia vogelii* and *Desmodium*

[1] In identifying this species, different specialists came to different results: *Crotalaria lachnophora* and *Crotalaria lachnocarpoides*. The former was considered more probable.

intortum/D.uncinatum for one–year intensive fallow can lead to excellent yields of subsequent crops in one field, and only moderate results in another.

Also in other respects, the relative merits of intensive fallow and the traditional grazed fallow must be compared. The inclusion of natural fallow in the rotation on Rwandan smallholdings does not require any additional labour inputs, is possible on all types of terrain, at any season and for any duration desired, and partly compensates for the loss of cropping area by offering forage for cattle, goats and sheep. As intensive fallow is shorter than natural fallow, it need not occupy such a large portion of the farm, but additional labour is needed to establish it and to cut it. The secondary use of the biomass produced is limited to the extraction of large woody plant parts for fuel and the use of the *Desmodium* fraction and the green parts of *Cajanus cajan* as fodder, but these make up only a small part of the total vegetation. Leaves and thinner branches of the sown fallow could also be used for mulch or compost, but this might reduce the soil regenerative effect of the fallow.

3. Aims

The aims of the research were therefore to improve the intensive fallow so that it offers to the majority of farmers a real alternative to the traditional grazed fallow, and to investigate the performance of intensive fallow under farmers' conditions. Specific sub–aims were:

- on experimental plots, to test further plant species which could complement and improve or alter the existing standard mixture, in order to be able to offer intensive fallow types for a wide spectrum of sites and rotations, with particular attention to seeking plants which permit:
  - further reduction of the fallow period, and
  - multipurpose use (fodder, food, fuelwood);

- to test the growth performance and after–effects of the proven standard mixture for the shrub fallow under the varied agroecological conditions on peasant farms, so as to gain differentiated indications of general suitability and appropriate management;
- to make farmers better acquainted with the standard mixture;
- to collect and evaluate the experiences of farmers with intensive fallows.

4. Methods

The research was conducted primarily on peasant farms, supplemented by trials on the demonstration and seed multiplication areas of PAP on Gihisi Hill, Kigoma Municipality, and in Kavumu Sector. The natural conditions described in Section 1.1 apply to all trial sites. The research included screening new leguminous plants and recording the biomass development of intensive fallows and the effects on subsequent crops on farmers' fields at different sites. In addition, several surveys were carried out to investigate what farmers are presently doing with the intensive fallows.

4.1 Screening new leguminous species

To improve or alter the existing mixture for intensive fallow, a large number of new legume species were tested in simple screening trials on the PAP demonstration and seed multiplication areas and on a farmer's field on Kavumu Hill (Sept. 1985 – Mar. 1988). With one exception, this was done on small plots of 4–11 m^2 with 3–12 replications. Observations and measurements were made of growth behaviour, ground cover, weed tolerance, pest infestation, height and density of the stand and yield of above–ground biomass – both fresh matter (FM) and dry matter

(DM) – at the end of the fallow period and, in the case of some species, reproduction rate, nodulation and root weight.

Supplementary trials were conducted to investigate the effect of incorporating the shrub *Sesbania macrantha* into the standard mixture for intensive fallow.

4.2 Growth performance and subsequent effects of shrub fallow on farmers' fields

In this series of trials, different fallow mixtures and periods (2, 3 and 4 growing seasons) were investigated with respect to growth performance and effect on subsequent crops. At a farmers' meeting on Kavumu Hill, the experimental programme was explained and farmers were asked to participate. Material compensation for loss of crop area was promised to participants. On a total of 46 farmers' fields, the performance and effects of intensive shrub fallow could be investigated (Sept. 1985 – Mar. 1988). On each field, simple trials with 2–4 replications were laid out in block design or Latin square (plot size 4–30 m²). Depending on the area available, all 4 or only 2–3 of the following treatments were applied:

Factor A:

I Natural fallow; incorporation of all vegetation

II Shrub fallow with the mixture (for 100 m²): *Cajanus cajan (180 g), Crotalaria lachnophora* (150 g), *Desmodium intortum/D.uncinatum* (20 g) and *Tephrosia vogelii* (200 g); incorporation of all vegetation

III Shrub fallow with the mixture (for 100 m²): *Cajanus cajan* (180 g), *Crotalaria pallida* (150 g), *Desmodium intortum/D.uncinatum* (20 g) and *Tephrosia vogelii* (200 g); incorporation of all vegetation

IV Shrub fallow as in II but with incorporation of only the woody plant parts

Factor B: Different soil types (sites)

Factor C: Duration of fallow 2, 3 or 4 growing seasons.

The fallows were broadcast sown in Sept.– Dec. 1985 and cut, in accordance with Factor C, in Sept./Oct. 1986, Dec./March 1987 or June/August 1987. The subsequent effects were measured with maize, sorghum, beans, soybeans, peas and groundnuts (partly in mixed cropping). The following observations and measurements were made: growth behaviour, ground cover, phenological observations (start of flowering, incidence of disease and pests), height and density of stand and yield of above–ground biomass (FM/DM) at termination of fallow (percentage of stems, leaves, litter and weeds)[2], root weight, chemical analysis of fallow plants (C, N, P, K, Ca, Mg), yield of subsequent crops, and soil analyses before fallow, after incorporation of green manure and after cultivation of a subsequent crop. In addition, socioeconomic data were collected about farm size of the participating farmers, their social situation, and hours of labour for establishing, cutting and incorporating the intensive fallow.

4.3 Interviews about use of intensive fallows by farmers

Over the entire research period, the experiences of farmers who were testing intensive fallow in the municipalities of Karama, Kigoma, Murama, Nyabisindu and Rukondo were collected by means of questionnaires and interviews. In 30 farms to which seed had been distributed, a survey and simple measurements were made, focused on the growth of the fallow vegetation and its effects on subsequent crops. The experiences of the village extensionists were also evaluated. In 30 selected farms, an in–depth survey was made (KLAGES 1987), primarily to investigate the diffusion of intensive fallow.

5. Results

Only selected preliminary results are presented here. More complete and detailed results can be found in RAQUET (1988).

[2] Only in a small part of the fields.

One–year bush fallow of *Cajanus cajan*, *Crotalaria pallida* and *Tephrosia vogelii* in a Rwandan smallholding.

Already after 3.5 months, this *Crotalaria* bush fallow has developed strongly and provides a good ground cover.

5.1 Screening new leguminous species

A total of 64 leguminous species were screened. As expected, the majority proved unsuitable for intensive fallow. Table 2 gives an overview of the most interesting species with respect to their growth performance and their potential uses.

For the seasonal fallow, *Mucuna utilis* has been recommended until now. It is fast–growing and thus quickly provides a good protection against erosion, but it does not grow well at marginal sites and usually brings only mediocre yields. Several of the tested species offer alternatives (Table 3).

Table 2: New legumes for different forms of intensive fallow

Species	Potentially suitable for:
Canavalia ensiformis	Seasonal fallow; integration into fallow to supply fodder and food
Crotalaria agathiflora	Integration into multiseasonal fallow to supply leaves and fuelwood
Crotalaria podocarpa	Seasonal fallow at certain sites
Crotalaria retusa	Seasonal fallow at certain sites
Crotalaria zanzibarica	Seasonal fallow on moderate slopes
Crotalaria sp (Zaire)	Integration into seasonal or multiseasonal fallow to supply leaves and fuelwood
Crotalaria sp (No. 4)	Seasonal fallow at certain sites
Desmodium discolor	Integration into seasonal or multiseasonal fallow as fodder shrub
Desmodium distortum	Integration into seasonal or multiseasonal fallow as fodder shrub
Dolichos lablab	Seasonal fallow; integration into seasonal or multiseasonal fallow to supply fodder and/or food and as ground cover
Lupinus albus	Seasonal fallow
Lupinus angustifolius	Seasonal fallow
Mimosa invisa	Seasonal fallow; pasture; as ground cover in newly established forests
Stylosanthes guianensis	Pasture

Table 3: Growth performance of seasonal fallow plants

Species		Growth period (months)	Height (cm)	Fresh weight (t/ha)	Dry weight (t/ha)
Crotalaria	a)*	4.5	150	21.5	3.9
zanzibarica	b)	4	–	36.1	8.7
Dolichos lablab		5.5	40–60	14.2	3.2
Mimosa invisa		5.5	40	16.4	3.8
Mucuna utilis		3	30–40	10.1	2.1

* a) marginal site; b) average site.

The growth performance of *Crotalaria zanzibarica* shows it to be the best substitute for *Mucuna utilis*. This *Crotalaria* species normally becomes a shrub, but the relatively low proportion of dry matter indicates that, in a dense stand, it produces mainly delicate material which decomposes rapidly. Like *Mucuna*, it quickly covers the soil surface and thus also provides good protection against erosion on moderate slopes and suppresses weeds. Moreover, it is suitable for poorer soils. However, the pods of *C.zanzibarica* tend to be strongly infested by insects.

Also the yield of *Dolichos lablab* and *Mimosa invisa* is superior to that of *Mucuna*. However, these species are slower in their initial development and thus are more susceptible to competition from fast–growing weeds in the early weeks and form a closed stand later than *M.utilis*. Whereas *Mimosa invisa* exhibits strong and healthy growth, the leaves of *Dolichos lablab* usually suffer severe pest infestation. The plant also gives off an unpleasant odour. A local variety proved to be free of odour and more resistant to pests.

On average sites, *Crotalaria retusa, C.podocarpa, C.sp* (No. 4) and *Canavalia ensiformia* also appear to be suitable for seasonal fallow, and possibly also the two lupines (see Table 2). However, all these species exhibited site preferences which limit their use.

As additional species in the standard mixture for the multiseasonal fallow, *Crotalaria agathiflora*, the *Crotalaria* species from Zaire and possibly also *Desmodium discolor* and *D.*

distortum (with a view to increasing diversity) appear suitable, and also *Dolichos lablab* and *Canavalia ensiformis* as ground–covering undergrowth. *Crotalaria agathiflora* and the *Crotalaria* from Zaire are similar in growth habit to *C.lachnophora*, lignify quickly, and promise good production of fuelwood. However, both the leaves and the pods of the *Crotalaria* from Zaire are very susceptible to pests. Whereas the leaf damage does not appear to influence plant development, most of the grains are destroyed by parasites.

When integrated into the multiseasonal fallow, the fodder plants *Canavalia ensiformis, Desmodium discolor, D.distortum* and *Dolichos lablab* permit greater secondary use. The edible green pods of *Dolichos lablab* and *Canavalia ensiformis* can also contribute to human nutrition (SKERMAN 1977).

5.2 Development pattern of the multiseasonal fallow

One week after sowing, the species of both fallow mixtures germinated. During the short wet season, the shrubs grew in height slowly, even with good quantity and distribution of rainfall, and reached an average height of 20–30 cm after 3 months without providing satisfactory ground cover. *Crotalaria pallida* reached somewhat greater heights than the other shrubs. Both *Desmodium* species germinated later than the shrubs and grew even more slowly. During the first months, the fallow plants were probably striving mainly to establish their root systems.

With the first rains of the long wet season, both fallow mixtures grew vigorously and quickly achieved a closed cover and heights above 150 cm. Already in April, *Crotalaria lachnophora* and *C.pallida* formed their first flowers. Whereas further flowers of *C.pallida* opened in quick succession, flowering in *C.lachnophora* stretched over several months. By this time, the *Desmodium* species had begun to flower but *Cajanus cajan* and *Tephrosia vogelii* had not.

When the rains ceased (mid/late May), the pods of *C.pallida* began to ripen and those of *C.lachnophora* somewhat later. At flowering, *C.pallida* stopped growing, whereas growth of *C.lachnophora* continued (but much more slowly than in the wet season) despite flowering and dryness. After seed formation and accompanying shedding of almost all leaves, *C.pallida* usually died. In the dry season, *Cajanus cajan* lost over half its leaves and *Crotalaria lachnophora* lost most of them; the remaining leaves of *Crotalaria* turned yellow and were attacked by insects. As a rule, *Tephrosia vogelii* neither shed its leaves nor changed colour, and continued to grow throughout the entire dry season, although much more slowly than in the wet. *Desmodium intortum* and *D.uncinatum* were also affected by the dry period.

The first rains of the next wet season stimulated new vigorous growth in *Cajanus cajan, Crotalaria lachnophora* and *Tephrosia vogelii*. These shrubs became much fuller and gained somewhat in height, and the stems of *C.lachnophora* and *T.vogelii* lignified. *Cajanus cajan* and *T.vogelii* flowered and their pods attained milky ripeness in the third wet season.

Also in the next dry season, the fallows suffered high leaf losses, again much less in *T.vogelii* than in *C.cajan* and *Crotalaria lachnophora*. In the following wet season, *C.lachnophora* only partly replaced its lost leaves.

Immature intensive fallow – whatever its composition – is endangered above all by heavy rains which trigger off erosion and hinder development of the young plants, even displacing or destroying them, and by competition from weeds. Formation of channels after rainfall and, thus, considerable disturbance of the fallow stand was observed in several cases. During the first 3 months of the shrub fallow, ground cover was not sufficient to prevent erosion.

Weeds usually did not hinder the growth of the sown fallow, and weeding was seldom necessary. Quick–growing *Bidens pilosa* and *Galinsoga parviflora* (the closed stands of which had sometimes hindered or even prevented the further growth of young fallows on PAP experimental fields in earlier years), *Tagetes minuta, Ageratum conyzoldes* and other composites did not present serious competition, as all these species thrive well only on moderate to good soils. However, root weeds of the *Poaceae* (formerly *Gramineae*) family, particularly *Digitaria spp* and *Cynodon dactylon*, seriously endangered the sown fallow in some cases and had to be weeded out.

Once the shrubs began to grow vigorously, weeds had little effect. As the dense canopy cut out light, most weeds eventually died, at the latest in the dry season (but because of a deficiency of water rather than light). Those which lived longest and were most drought–resistant on account of their extensive root system were the so–called sweet grasses. They still survived after one year of shrub fallow and, when the fallow thinned out in the dry season, they received more light again, to which they are very sensitive. They grew vigorously as soon as the new wet season began, until the new canopy of leaves closed completely. Only fallows of 18–24 months could effectively suppress these grasses.

In addition to the consequences of heavy rains and weed competition, intensive fallows must also contend with pests of all types, above all with leaf–eating and parasitic insects. These attack especially *Crotalaria pallida* leaves and pods, *C.lachnophora* leaves and *Cajanus cajan* pods. The pod damage was usually so great that scarcely any seed could be harvested. The damage to *Crotalaria lachnophora* leaves did not seem to have a detrimental effect on plant development, and the pods of this species were completely free of parasites. This also applies to all plant parts of the *Desmodium* species and *Tephrosia vogelli*, with a few localized exceptions.

5.3 Composition of the fallow mixtures

Experimental results as well as initial observations on farmers' fields had indicated that the mixture of *Cajanus cajan, Crotalaria lachnophora,Tephrosia vogelii* and *Desmodium uncinatum/D.intortum* (hereafter: Mixture I) had great promise, likewise the variant with *C.pallida* instead of *C.lachnophora* (Mixture II). These two mixtures were to be further improved, with the intention of increasing biomass production by means of a multistorey vegetation structure and making more diverse use of the vegetation.

The addition of the taller shrub *Sesbania macrantha* to the fallow mixture led to reduced growth of the middle storey in favour of *Sesbania* growth. The overall result was poorer, as *Sesbania* has a much lower leaf:stem ratio than *Cajanus, Crotalaria* and *Tephrosia*.

Desmodium intortum/D.uncinatum did not form the desired understorey. The *Desmodium* species developed much more slowly than the shrubs and, after closing of the canopy, they were robbed of light and could not develop further. The proportion of *Desmodium* in all one–year shrub fallows was so small that it did not merit measurement. Table 4 shows the composition of Mixtures I and II after 11 months of growth.

Table 4: The composition of two proven fallow mixtures after 11 months of growth*

	Plants/m²		Above-ground biomass (t DM/ha)	
	Mixture I	Mixture II	Mixture I	Mixture II
Cajanus	3.9	3.7	1.44	1.49
Crotalaria	13.9	17.2	5.73	2.15
Tephrosia	11.6	12.3	3.04	4.52
Total	29.4	33.2	10.21 (5.69–15.45)	8.16 (3.83–14.96)

Source: Own measurements; mean values of 9 trials with 3–6 replications on farmers' fields in Kavumu.

* Mixture I: *Cajanus cajan, Crotalaria lachnophora, Tephrosia vogelii* and *Desmodium uncinatum/intortum*

Mixture II: as above, but with *Crotalaria pallida* instead of *C. lachnophora.*

The biomass yield of Mixture I (6–16 t DM/ha) confirms the results obtained by PIETROWICZ and NEUMANN (1987). Mixture II performed less well. Although *Crotalaria pallida* brought a higher plant density, its contribution to total biomass was small as it died early. It therefore does not offer an alternative to *C.lachnophora*, but should definitely be considered for seasonal fallow. According to POLHILL (1982), it can also be used as fodder. Plant density and biomass yield of *Cajanus* could be improved by

applying higher seeding rates and using seed with higher germination capacity.

With regard to the composition of fallow in terms of plant parts (Table 5), the high proportion of stems at the time of incorporation is striking: 75% and 71% respectively. At this time, most of the leaves had already fallen and most of the litter had mineralized. The values for litter given in Table 6 do not include the mineralized portion.

Table 5: Biomass compositon of 11-month intensive fallow and its performance compared with natural fallow[1]

Component	Mixture I		Mixture II	
	t DM/ha	(%)	t DM/ha	(%)
Stem	9.57	(69)	7.92	(66)
Leaves	0.71	(5)	1.45	(12)
Litter[2]	2.97	(22)	2.12	(17)
Weeds[2]	0.57	(4)	0.58	(5)
Total	13.82	(100)	12.07	(100)
Natural fallow	4.42 t DM/ha			

Source: Own data; mean values of trial with 4 replications on experimental fields in Nyirabanguka.

[1] Mixture I: *Cajanus cajan, Crotalaria lachnophora, Tephrosia vogelii* and *Desmodium uncinatum/intortum*

Mixture II: as above, but with *Crotalaria pallida* instead of *C. lachnophora.*

[2] Recorded only at time of harvest.

Comparing the two mixtures, the leaf portion was higher in Mixture II. The early senescence of *Crotalaria pallida* permitted stronger development of *Tephrosia*. The low values for litter in Mixture II are probably also due to the early senescence of *C.pallida*: by the time of yield measurement, a larger portion of the litter had already mineralized.

The longer the intensive fallow lasted, the more obvious are the differences in biomass production between Mixtures I and II and the greater the superiority to natural fallow (Table 6). Also the

Table 6: Biomass yields of intensive fallow after different durations of fallow*

	Biomass yield (t FM/ha)		
Duration of fallow	Natural fallow	Mixture I	Mixture II
2 growing seasons	5.77	26.62	24.97
3 growing seasons	14.42	42.90	41.41
4 growing seasons	6.34	46.21	32.80

Source: Own data; mean values of 9 trials with 3–6 replications on farmers' fields in Kavumu.

* Mixture I: *Cajanus cajan, Crotalaria lachnophora, Tephrosia vogelii* and *Desmodium uncinatum/intortum*

Mixture II: as above, but with *Crotalaria pallida* instead of *C. lachnophora.*

figures for litter in this table refer only to the time of harvest, i.e. do not include all litter. The values thus refer almost exclusively to standing biomass. In one case, this was less after 24 months than after 18 months because, by then, the plants had gone through a lengthy dry period. With increasing duration of intensive fallow, root weeds could be better suppressed and the proportion of material usable as fuelwood increased.

5.4 Effect of intensive fallow on subsequent crops

Previous results on PAP experimental plots had indicated great increases in crop yields after intensive fallows. PIETROWICZ & NEUMANN (1987) recorded 20–40% higher yields of crops in the first season after intensive fallow, and 125% and even 390% higher yields in exceptional cases. However, effects on yields in the second growing season were not so clearcut: the yield differences in comparison with the control lay between −46% and +28%.

The present study investigated this question on farmers' fields. From the multitude of data, examples are presented in Table 7. At an impoverished site, clear yield increases (25–46%) were found only in the second growing season. The results at an average site were considerably better. Here, yield increases of 75% and 86% were recorded already in the first season, but no residual effects

Table 7: Effect of one-year intensive fallow[1] on the yield of subsequent crops

Quality of site		Grain yield (kg/ha)		
Season/Crop		Natural fallow	Mixture I	Mixture II
Marginal site				
1st season:	mixed crop			
	maize	280	310	270
	beans	n.r.[2]	n.r.	n.r.
2nd season:	sorghum	610	760	890
Average site				
1st season:	mixed crop			
	maize	970	1700	1800
	beans	740	500	700
2nd season:	sorghum	750	890	810

[1] Entire vegetation incorporated.
[2] n.r. = not recorded.

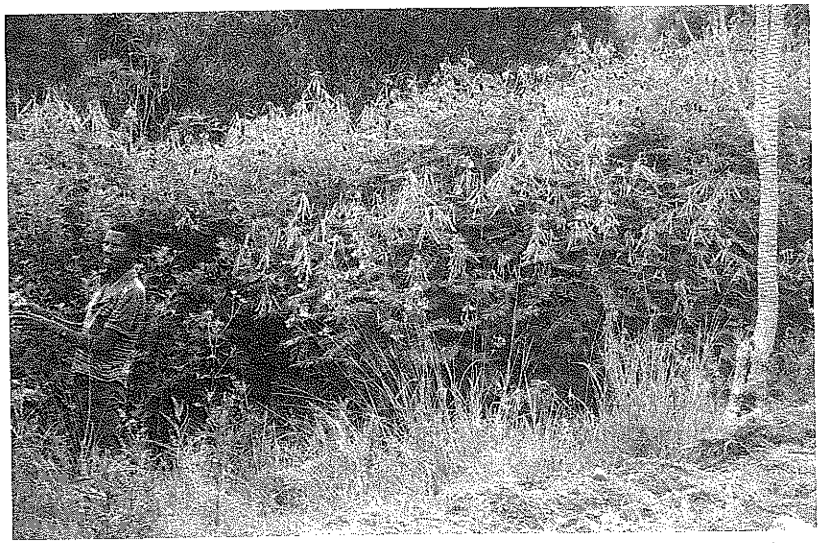
were evident in the second season. This essentially confirms the results of PIETROWICZ & NEUMANN (1987). It is interesting to note that Mixture II was not inferior to Mixture I in terms of its effects on subsequent crops, although much less biomass was produced and incorporated (cf. Tables 5 and 6). Crop yields after incorporation of only the woody plant parts instead of all the fallow vegetation did not differ greatly from the yields presented in Table 7.

5.5 Farmers' experiences with intensive fallow

The first survey addressed farmers' crop yield problems. Complaints were mainly about lack of fertile land and declining fertility of cropped land. Supplying sufficient manure and/or compost to the fields was deemed impossible as manure and compost production was insufficient or fully lacking. Any available manure/compost was applied almost exclusively to fields near the house, mainly to banana groves.

The farmers practise fallowing because they are aware that this is necessary for soil regeneration, but the duration of rarely more

The time of cutting and the way of incorporating the biomass is handled differently by the farmers than had been recommended by the project (see Table 8). Here, a 4.5–month *Crotalaria* fallow is being cut.



Multiseasonal bush fallow composed of a mixture of *Cajanus cajan*, *Crotalaria lachnophora* and *Tephrosia vogelii* after 15 months' growth.

and often less than 2 years is too short for the traditional natural fallow to fulfil the desired functions (soil improvement, pasture, mulch supply). Most farmers recognize that continuation of short–duration natural fallowing leads to a dead end, and are receptive to alternatives.

In managing the intensive fallow, the farmers often did not follow the recommendations of the extension service, following their own ideas instead (Table 8).

Table 8: Management of intensive fallow by farmers after the first distribution of seed

Criteria	Recommended by the extension service	Practised by the farmers
Quality of site	Medium	Marginal
Time of sowing	Short rains	End of short rains to long rainy season
Duration of fallow	1 year	2, sometimes even 3 years
Time of cutting	End of long dry season	End of long dry season; middle to end of short wet season
Incorporation technique	4 weeks after cutting, incorporation of hacked material without thick stems	After waiting several weeks till leaves fall, removal of stems and incorporation of leaves
Subsequent crops	Maize, beans	Sweet potatoes (beans, soybeans)

The farmers usually chose the poorest sites for the intensive fallow. In view of the scarcity of land, it is logical to select only those fields which are no longer productive.

The sowing time chosen by the farmers led to a – in part, considerable – delay in the development of the fallow but not to failure, even when sowing was not until March or April. By the end of the long wet season, the plants could barely grow to a height of 10–20 cm. They ceased growing at the beginning of the long dry season, but did not die. When the short wet season started in September/October, they began to grow again.

In some cases, the fallows had difficulties establishing as the seeding rate was too low. The farmers concerned had spread the mixture meant for 100 m^2 over a larger area. As a result, attainment of ground cover was greatly delayed and problems with erosion and weed competition arose. On the other hand, such fallows produced shrubs with strong woody stems or trunks. This considerable gain in fuelwood was extremely welcome, especially among the farmers in Karama and Rukondo, where the best growth performance of intensive fallow was recorded. Most of the farmers had chosen marginal land no longer usable for food production, where only eucalyptus trees or coffee shrubs could be grown. On these very fields, the biomass production of the shrub fallow was surprisingly high.

The farmers in Rukondo/Karama did not follow recommendations with respect to duration and termination of fallow. Rather than cutting the green material after one year, most did so after two years and some only after three. When asked why they left the fallow so long, they answered that even intensive fallow could be a success only if it lasted sufficiently long. The farmers regarded one year as too short. As a result of the long duration of the fallow, even dense stands could produce considerable quantities of fuelwood. Especially *Crotalaria lachnophora* wood is popular among the farmers, for it burns with hardly any smoke.

The following technique of cutting and incorporating the green manure was generally favoured: The green material was left to lie for several weeks after cutting until all the leaves had fallen off. Then the stems (trunks) and branches were removed, and the leaves were worked in with a deep hoe. If the leaves took too long to fall, the process was speeded up by beating the bushes with a wooden stick. Large roots were also removed from the plots and used as fuelwood.

After the intensive fallow, the farmers grew all known annual and perennial crops. However, first preference was clearly given to the sweet potato, the very crop which the extension service had advised against because of negative experiences in station trials. As the first crop after intensive fallow, sweet potatoes had produced much leaf material but extremely low tuber yields.

The sweet potato is traditionally the first post–fallow crop on peasant farms. For this reason alone, the farmers chose it as the first crop after shrub fallow. The choice appears to have been a good one. The farmers did observe an initial strong growth of stems and leaves, but afterwards – although with some delay – good tuber formation occurred. The farmers also found it noteworthy that they could obtain yields on land which, before green manuring, had not permitted the production of any crop whatsoever.

In summary, it can be said that the first distribution of seed was a success. The farmers expressed their satisfaction with the gain in fuelwood as well as the unexpected yields on land which they had already abandoned. This success can be measured by the great interest shown by the farmers during the second distribution of seed. Even though large amounts of seed were supplied, it was far less than the demand by interested farmers.

Finally, this study made clear that the farmer must be included to a greater extent than previously in the development of cropping methods. Both the experiences and knowledge of the farmers as well as their wishes must be given greater consideration. Development of new cropping methods should not mean merely developing methods **for** the farmers but rather developing methods **with** the farmers. Only then can acceptance by the farmers be ensured, without which even the best method has no value.

6. Prospects

The intensive fallow, as an important instrument to maintain soil fertility, should be regarded as a complement rather than an alternative to other forms of fertilization. In view of the predominantly positive results achieved thus far, intensive fallow appears to have high adoption potential among Rwandan peasant farmers. The further development and finetuning of the existing methods will have to be done by the farmers themselves, as is already happening (cf. Section 5.5). Trials under controlled conditions are of little use in this regard. The further development of methods by the farmers should be given outside assistance so as to speed up the process. To this end, supportive agronomic studies are necessary, particularly into the following questions:

- What are the causes of differences in fallow development (species composition, biomass growth) at different sites?
- To what extent does variation in sowing time and duration of fallow influence its productivity and effect on subsequent crops?
- What are the optimal rotations after intensive fallow?
- What are the possibilities of intercropping food crops and fallow plants, simultaneously or as relay crops?
- What are long-term effects on soil fertility of regular intensive fallowing?
- What are the possibilities of combining green manuring and mineral fertilizer?

Answering these and further questions can provide considerable potential for intensification of cropping in Rwanda.

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V. Investigating possibilities of combining fodder production with erosion control and agroforestry in the West Usambara Mountains of Tanzania

Reinhard Pfeiffer

1. Description of location

Natural conditions. The West Usambara Mountains form part of Lushoto District (Lushoto: 4°47'S, 38°18'E), a tropical highland area in northern Tanzania. The topography is hilly to mountainous with an elevation of 1280–2000 m. Predominant soil types are shown in Table 1. The mean annual precipitation of 600–1200 mm follows a bimodal pattern: short (warm) rains

Table 1: Soil characteristics in the West Usambara Mountains

Location	Prevailing soil types	Chemical features				Physical features		
		pH KCl	%C	%N	CEC	Sand (%)	Silt (%)	Clay (%)
Upper slopes	Chromic luvisol Rhodic ferralsol	5.1	3.3	0.37	15.0	–	–	–
Lower slopes	Chromic luvisol Chromic cambisol Chromic phaeozem	5.2	4.4	0.26	19.2	37.4	22.0	40.7
Foot-slopes	Chromic cambisol Pellic and humic vertisols	5.8	4.6	0.34	29.0	48.4	16.4	35.1
Valley bottom	Pellic vertisol Mollic gleysol	5.3	3.0	0.17	24.4	21.2	23.7	55.0

Source: Compiled from soil surveys conducted in 1979–1987 (Niemeyer 1979, Schaafhausen 1981, Ezaza 1985, own data).