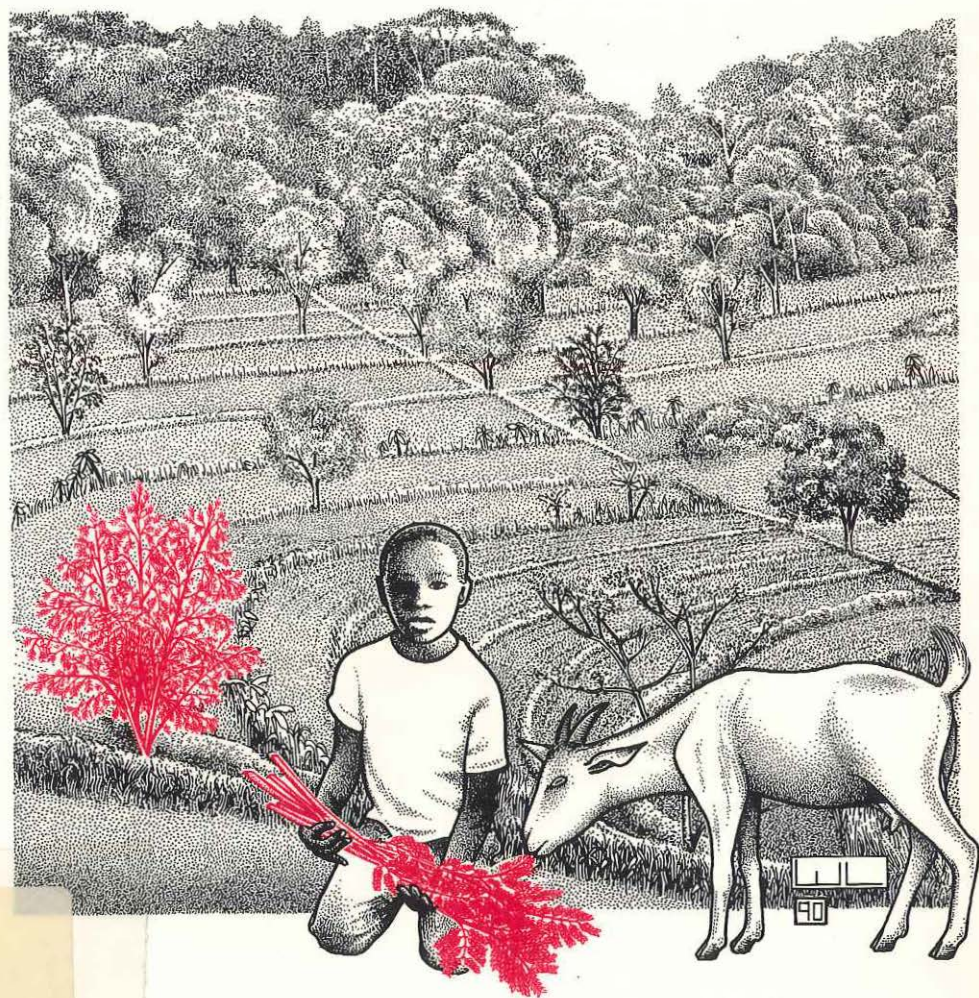


ECOFARMING PRACTICES

for tropical smallholdings



Johannes Kotschi (Editor)

Erhaltung tropischer Böden durch Intensivbrache. Dissertation, University of Heidelberg (in preparation); also to appear in: Etudes et Expériences. PAP, Nyabisindu.

- Skerman, P.J. 1977. Tropical forage legumes. Rome: FAO.
- Sirven, P., Gotanegre, J.F. & Prioul, C. 1974. Géographie du Rwanda. Editions A. de Boeck, Bruxelles/Editions Rwandaises, Kigali.
- SBW (Statistisches Bundesamt Wiesbaden). 1985. Statistik des Auslandes: Länderbericht Ruanda 1985. Verlag W. Kohlhammer, Stuttgart/Mainz.
- Werle, O. & Weichert, K.-H. 1987. Ruanda: ein landeskundliches Porträt. Görres-Verlag, Koblenz.

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, SCHAAPHAUSEN 1981, EZAZA 1985, own data).

from mid-October to mid-December and long (cold) rains from mid-March to mid-June. Mean annual temperatures range from 16° to 22°C, depending on elevation.

Population and land use. The West Usambara Mountains are densely populated (180–200 people/km²). All land legally belongs to the state, but the actual tenure system is derived from the traditional distribution and allocation practices of the Sambiaa people, with a recent tendency toward commercial land transactions. Almost 70% of the total agricultural area is cropped, 15% is classified as forest reserve, and 15% is pasture or unused land. Of the cropped area, 84% is devoted to dryland cropping, 11% to tree crops, and 5% is irrigated (TIRDEP 1977).

Mean farm size is 2.5 ha (range 0.7–5.1 ha) with scattered plots (mean 54/farm) at an average of 20 minutes' walking distance from the homestead. Ca 10% of the cropped area is on hill-tops, 20% in valleys and 70% on slopes. Average family size is 10–11 persons, 5–6 of whom are economically active. As a result of emigration of male labour, women outnumber men by 2:1 in the age group 20–30 years.

The major crops grown are maize and beans; minor crops include potatoes, cassava, wheat, tobacco, vegetables and temperate fruit trees (apples, pears, plums) in higher areas, and bananas, sugarcane and coffee in lower areas. The major livestock species are cattle and goats. The stocking rate in the District has been described by TIRDEP (1977) as 465 TLU/ km² of available grazing area; however, cropped areas also provide some animal feed, e.g. in the form of crop residues.

2. Problem analysis

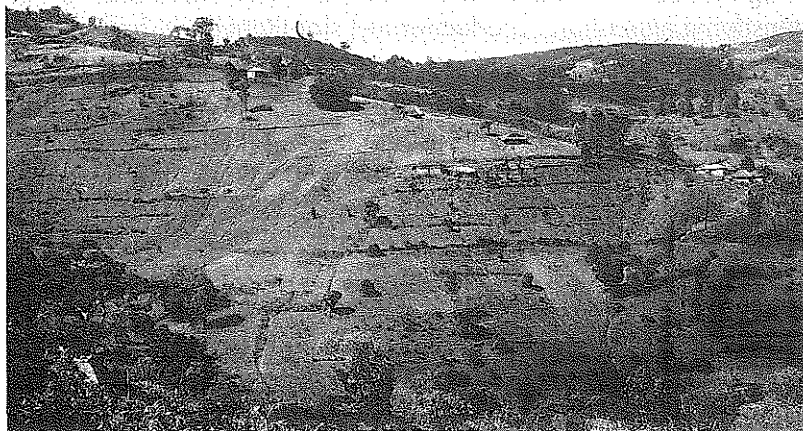
Human population growth has led to high cultivation density and shortage of arable land for further expansion. Livestock grazing has been shifted increasingly to the slopes as intensive horticulture spreads in the valley bottoms, formerly used for com-

munal grazing. Deforestation and grazing on the slopes has caused considerable surface runoff and soil erosion. As a result, crop yields are decreasing. Methods must be found of intensifying agricultural production yet simultaneously halting land deterioration.

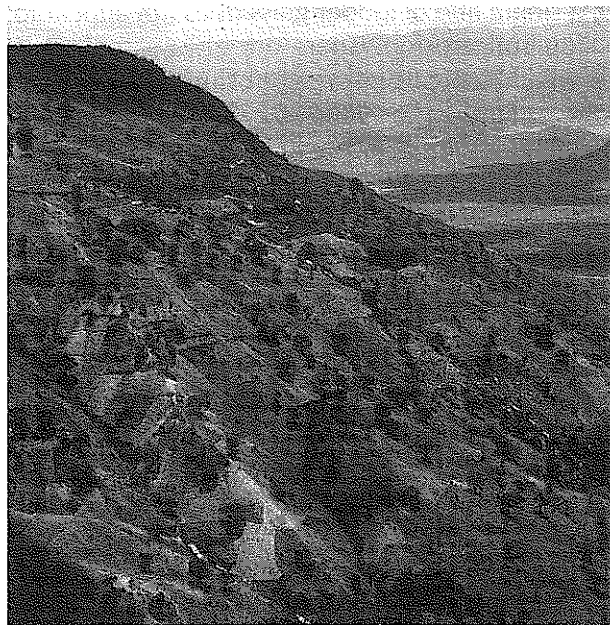
In 1980, a Soil Erosion Control and Agroforestry Project (SECAP) was established in Lushoto District to tackle the problem of land deterioration. The project started by propagating the already existing technique of planting the perennial Guatemala grass (*Trypsacum laxum*) along contours. These 0.7 m wide strips of grass are meant to control soil erosion and, at the same time, provide animal feed. The steeper the slope, the smaller the distance between the strips, varying from 5 to 20 m. The strips thus occupy 14–4% of the arable land. More than 1200 km of these strips ("grasslines") have now been established in the project area, and grass planting material has become a marketable item in several villages. Thus, the technique of planting permanent fodder grass along contour lines has been well adopted in the area.

However, a single line of fodder grass does not appear to be sufficient to stop soil erosion. There are always some gaps in the grasslines which can cause severe erosion as water is channeled through them. Furthermore, the root system of Guatemala grass strongly competes with adjacent field crops.

The vegetation strip was diversified by introducing creeping legumes, shrubs and trees. As this requires more space, the contour strip was widened and called a "macrocontourline". It has an average width of 2 m, is planted at a spacing of 5–20 m (depending on steepness of slope), and thus occupies 40–10% of the arable land. The macrocontourline is meant to serve multiple purposes: above all, to improve erosion control but also to reduce border effects between field crops and contour strips and to increase land productivity. However, little is known about the optimal composition of macrocontourlines for different ecological conditions.



Landscape in the West Usambara Mountains, showing severe erosion. Badly maintained grass contourlines, which are not diversified by fodder bushes and creeping legumes, might be even worse than no erosion control measures at all.



On account of high population pressure, even very steep slopes are cultivated.

3. Aims

The main target of SECAP is to raise or at least stabilize soil productivity on slopes. Central issues of the present study were to find ways of improving the macrocontourline and to provide detailed agronomic, ecological and economic data for different plant combinations. Within the contour strips, grasses should provide high biomass production, and creeping legumes should improve forage quality (protein content) and help control erosion by protecting the soil surface. Trees and shrubs should produce additional fodder, firewood and timber, and should improve the microclimate between the strips. As they root more deeply than grasses, they should also reduce competitive effects on adjacent field crops. As grazing possibilities are steadily decreasing, supplying fodder has become the most important function of the macrocontourlines. Screening and selection of fodder plant species was necessary to find suitable combinations for different agroclimatic sites in the project area.

4. Methods

In October 1984, field trials were established in three agroclimatic zones of the West Usambara Mountains. The trial sites are described in Table 2.

Table 2: Agroclimatic parameters of the trial sites¹

Site (village)	Agroclimatic zone	Annual rainfall (mm/yr)	Average daily temperature (°C)	Altitude (m above sea level)
Lushoto	Humid/warm	1087	19	1395
Ubiri	Humid/warm	805 ²	19	1280
Nywelo	Dry/cold	808	16	1820
Mbwei/Mlola	Dry/warm	732	22	1320

¹ Climatic data from October 1984 to September 1987.

² Due to topography, the trial site at Ubiri received only low rainfall although situated in the "humid/warm" agroclimatic zone.

The research programme consisted of several phases (see Table 3). During the first phase, promising perennials were screened simply by observing whether or not they grew. The yields of the 12 most suitable species were then compared in an "elimination trial". The next step was to compare the productivity of different combinations of the four macrocontourline components: grass, legume, shrub and tree ("productivity trial"). The effect of cutting frequency and cutting height on yield was investigated, as well as the influence of contour strips with different species compositions and spatial designs on adjacent field crops (root competition, shading, etc.). In addition, competitive effects of the contour strips on the field crops between them were studied ("interface trial"). Adjacent fields without contour strips served as control. Not only yields and growth habit but also cropping practices in these fields were recorded.

Table 3: Trials conducted, 1984-87

Trial	No. of treatments	No. of replicates	Plot size (m ²)	No. of sites
Screening trial	18	2	4	3
Elimination trial	12	4	12	4
Productivity trial	4-6*	6	18	5
On-farm trials	3	1	20	45

*Fodder plant combinations.

In order to assess the alley effects of the contour strips, ecological and microclimatic measurements such as stomatal resistance, radiation, evaporation, relative humidity, and soil and air temperatures were made between the macrocontourlines. The yields and yield-determining factors of the crops nearest the contour strips were recorded to provide data in support of the above-mentioned measurements.

In the last phase ("on-farm trials") the best macrocontourlines were tested on 45 farms under different ecological conditions and simultaneously served the purpose of demonstration and

training. The trials were carried out by SECAP extension workers in cooperation with farmers who showed interest in the programme. Planting material was supplied and contour strips were planted by SECAP staff.

On all trial fields, soils were surveyed and meteorological data recorded. The on-station trials were laid out in randomized blocks or Latin squares to permit analysis of variance. Processing and analysis of data had not been completed by the time of publishing this paper. In view of the limited space available, only selected results are presented in the following. All calculations are based on a standardized arrangement of contour strips 2 m wide and 8 m apart.

5. Results

5.1 Erosion control

Average topsoil losses on arable land in the West Usambara Mountains are estimated to be 0.6-1.0 cm/year (BUCH 1983). Assuming a soil density of 1.25, this amounts to 100 t/ha/year. The effect of erosion control was studied on a demonstration plot situated on a lower part of a slope. The data compiled in Table 4 gives a rough impression of erosion control by the macrocontourlines.

Table 4: Effect of macrocontourlines on erosion control

	Soil losses in upper part of field		Soil accumulation in lower part of field	
	Average (mm/yr)	Range	Average (mm/yr)	Range
Without contour strips	20.7	12-29	38.0	
With macrocontourlines	15.8	12-20	15.7	7-21

Source: Own data; period of measurements Nov. 1986-Aug. 1987, precipitation during this period 930 mm, distance between contourlines 8 m, inclination of slope 7°.

In the treatments with macrocontourlines, soil losses of 15.8 mm/year were measured as compared to 20.7 mm/year without contour strips. This represents a 25% reduction but not a complete halt of soil erosion. In the fields without contour strips, more soil was accumulated at the lower position than was lost at the upper position, as some of the accumulated soil came from even higher up the slope. In the fields with macrocontourlines, by contrast, soil erosion and accumulation were balanced. The strips form barriers which catch the water and soil coming from further up the slope.

The lower the position on the slope, the better the fertilizing effect by accumulated soil and the water harvesting effect by surface runoff. This could be demonstrated in a trial with contour strips placed at different positions on the slope and studying the effect of additional compost and fertilizer applications higher up the slope (Table 5).

On average, the yield at the lowest position on the slope was over 3 times higher than at the highest position. On the lower slope, the soil layer was deeper and more fertile as a result of the

Table 5: Guatemala grass yields (t DM/ha/year) of macrocontourlines below differently fertilized fields*

Fertilization of field above contourlines	Position on slope				Mean
	Upper part	Upper middle part	Lower middle part	Lower part	
No fertilizer	9.25	10.04	12.94	24.20	14.11
5 t/ha compost	8.15	13.63	12.08	37.60	17.87
50/30 kg/ha N ₂ /P ₂ O ₅	10.80	11.96	15.14	39.77	19.42
5 t/ha compost + 50/30 kg/ha N ₂ /P ₂ O ₅	11.20	15.99	20.08	34.01	20.32
Mean	9.85	12.91	15.06	33.90	17.93

* Yields per hectare extrapolated from a grassline 0.66 m wide except in the case of slope position "lower part", where Guatemala grass grew in a 2 m wide macrocontourline associated with *Desmodium uncinatum* and *Leucaena leucocephala*; measuring period Nov. 1982–May 1984; age of contour strips 1.5 years as of Nov. 1982.



Multifunctional perennial contourlines are promoted in the West Usambara Mountains in order to control erosion.



Macrocontourline consisting of Guatemala grass (*Tripsacum laxum*) and the fodder bush *Leucaena diversifolia*.

accumulation of materials eroded from the area higher on the slope to which compost and fertilizer had been applied. However, it must also be noted that the Guatemala grass at the lowest position on the slope was growing in a mixture with the legumes *Desmodium uncinatum* and *Leucaena leucocephala*, which may have contributed to the extraordinarily high grass yields.

5.2 Plant ecological effects

The contour strips influence the adjacent field crops in many ways and it is extremely difficult to measure the effect of single factors such as soil moisture or relative humidity on crop yield. Figure 1 illustrates the complexity of these influences and their assumed beneficial or detrimental effects on crop yield.

Soil parameters. As data on soil moisture cannot yet be presented, it can only be assumed that soil accumulation on the lower slopes has a favourable influence on soil moisture status. Competitive effects of neighbouring perennials (*Grevillea robusta* and *Leucaena leucocephala*) are considered negligible as these are deep-rooting. To the contrary, the shading and the mulching layer of leaf litter may reduce evaporation considerably and thus improve water balance.

Soil nutrients as well as organic matter are influenced by the processes of erosion and accumulation. In the vicinity of the upper contour strips, a slight competition for nutrients but, on the other hand, a slight increase in organic matter can be expected. Close to the lower contour strips, soil accumulation results in a gain in nutrients as well as in organic matter.

Changes in infiltration rate follow the pattern of organic matter, and infiltration may be better next to the contour strips. With regard to N fixation, a slight increase might be expected at the lower field edge, where the bordering perennial (*Leucaena*) is a legume. However, data concerning this are not yet available. The effect of contour strips on erosion has already been discussed in the preceding section.

Microclimate. As can be seen from the data on microclimate presented in Table 6, average daily temperature near the contour

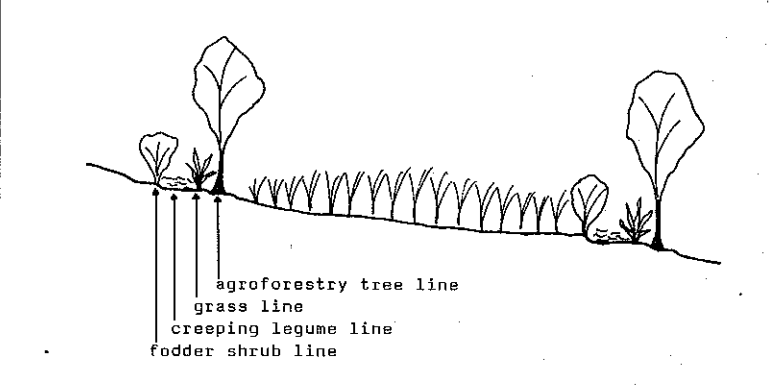
Parameter	Field between two macrocontourlines				
	Upper part	Upper middle part	Middle part	Lower middle part	Lower part
Soil:					
Soil moisture	+	+	o	+	+++
Soil nutrients	-	o	+	++	+++
Organic matter	+	o	o	+	++
N fixation	o	o	o	o	+
Infiltration rate	+	o	o	+	++
Erosion control	+	o	o	+	+++
Microclimate:					
Radiation	-	o	o	o	-
Lower temperature	+	o	o	o	++
Lower evaporation	++	+	o	+	++
Lower windspeed	++	+	(+)	+	++
Water use efficiency	++	+	o	+	++
Distance from contourline	1.5 m	2.1 m	4.5 m	2.1 m	1.5 m
					

Figure 1: Effect of macrocontourlines on soil and microclimate in the fields between them

Key: + = beneficial for field crops
 - = detrimental for field crops
 o = neutral for field crops

Table 6: Microclimatic changes between macrocontourlines with trees 4 m tall (*Grevillea robusta*)

Parameter	Distance from contour strip (m)				
	1.5	2.1	4.5	2.1	1.5
Average daily temperature (°C)	25.6	26.4	26.9	26.2	24.0
Relative radiation as % of total radiation*	79.0	100	100	100	81.7

* Daily average, measured 30 cm above ground over one day (8.00–18.00) every 30 minutes.

strips is reduced by more than 1 degree (6%) as a result of shading by the trees. Radiation is reduced by 18–21% next to the contour strips. A further important aspect which was not investigated but deserves consideration is the interrelation between wind speed and evaporation. Lowering of wind speed by the contour strips may reduce evaporation and thus improve water use efficiency.

Summarizing the ecological effects of the contour strips on the field crops between them, it can be stated that the most important effect lies in the accumulation of soil and soil moisture at lower parts of the field. Competitive effects between contour strips and field crops are considered to be rather small on account of the deep-rootedness of the perennials on the edges of the contour strips. Competitive effects were measured by assessing the yield of groundnuts and maize row by row at different distances from the contour strips. The results are presented in Figure 2.

A significant reduction in groundnut yield (28.5% and 22.3%) could be observed in the first row, i.e. at a distance of 30 cm; on each side of the contour strips. A significant reduction in maize yield could be recorded only in the case of stalks: 32.8% lower stalk production in the first row at the upper edge of the field. No differences were found in maize grain yield.

In comparison with the original grasslines, the macrocontourlines require more space but compete less with

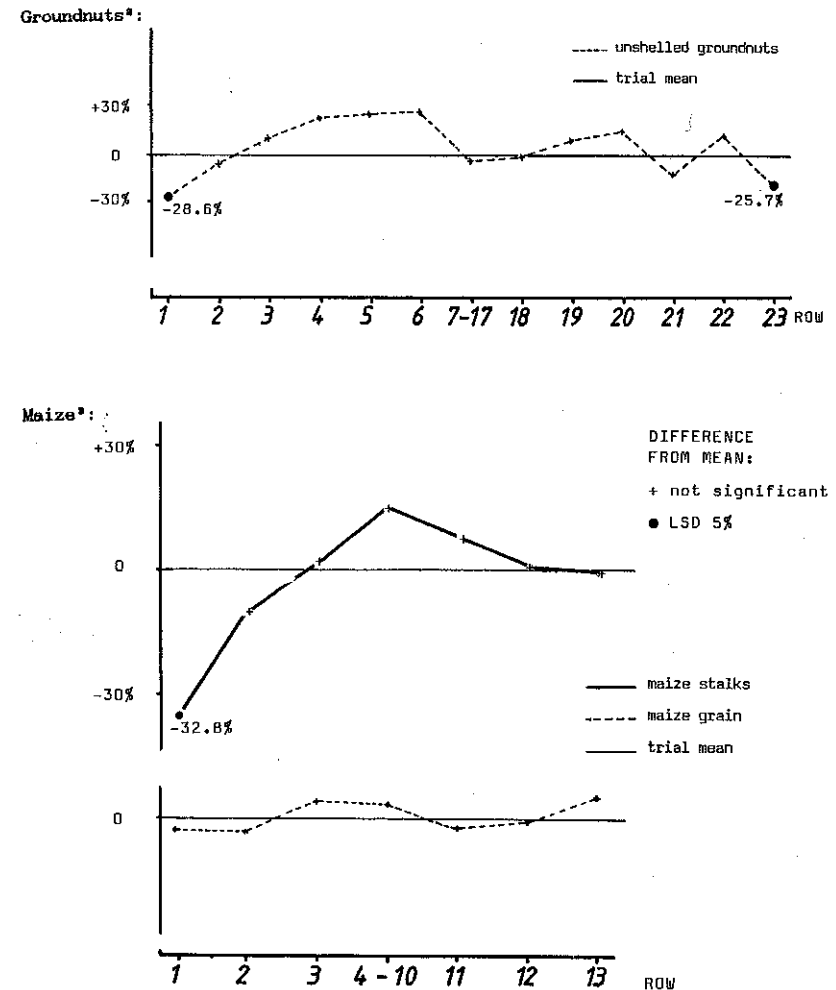


Figure 2: Effect of macrocontourlines on neighbouring crops¹: yield relative to trial mean (%)

¹ Fertilization: preceding green manure crop (*Crotalaria ochroleuca*) + 10 t/ha farmyard manure.

² Groundnuts planted 15 cm apart within rows and 30 cm between rows; average yield 3.97 t/ha fresh unshelled groundnuts; least significant difference (5%) = 25.2%, coefficient of variation = 25.3%.

³ Maize planted 30 cm apart within rows and 60 cm between rows; average grain yield 7.89 t/ha, moisture content 20%; least significant difference (5%) = 27.2%, coefficient of variation 31.4%.

neighbouring crops. This can be explained by the fact that the competitive Guatemala grass is enclosed by *Grevillea robusta* and *Leucaena leucocephala*, which root deeply rather than laterally and are thus less competitive.

The findings suggest that combining fodder shrubs, grasses and agroforestry trees in the pattern shrubs/grasses/shrubs/trees may be a solution to reduce the negative effects of contour strips. To be on the safe side, the border effect of macrocontourlines 2 m wide and 8 m apart is calculated to require another 0.5 m width. Thus, in effect, the contour strips occupy 25% of the arable land. The calculations in Section 5.4 take this reduction in area into account.

5.3 Productivity of macrocontourlines

In order to compare the physical and economic performance of fields with contour strips and those without, i.e. where field crops are planted in the area otherwise occupied by the strips, it was first necessary to determine the yield potential of species most suitable for the contour strips, to measure the biomass production of the species mixtures, and to design productive contour strips. In Table 7, yields of the most promising species are given. They can be attained in the second year after establishment in the case of grasses and creeping legumes, in the third year in the case of fodder shrubs, and after 8–9 years in the case of trees. The data for trees given in Table 7 represent the first yields only 5 years after establishment.

For detailed assessment of the macrocontourline production potentials, the fodder values of the perennials mentioned in Table 7 were analysed. Table 8 shows the assumptions which were made in order to calculate potential milk yields resulting from the consumption of different fodder plants as shown in Table 9. With the exception of *Canna edulis*, all fodder plants analysed were characterized by low energy content (average 6.9 MJ/kg) and high protein content (average 17.9% crude protein). As a result, achievable milk yields per TLU are low (average 0.7 kg/TLU), as the possible dry matter intake is insufficient. The energy content

Table 7: Average yields of different perennials constituting the macrocontourlines

Component	Potential fodder (tDM/ha/yr ¹)	Firewood (t/ha/yr ¹)
Grasses:		
Bana grass (<i>Pennisetum purpureum</i> × <i>P. typhoides</i>)	20.3	
Napier grass (<i>P. purpureum</i>)	14.4	
Guatemala grass (<i>Tripsacum laxum</i>)	14.4–38.9	
<i>Setaria plicatilis</i>	10.7–15.7	
Creeping legumes:		
<i>Desmodium intortum</i>	2.0– 9.3	
<i>D. uncinatum</i>	1.8– 3.2	
<i>Macroptilium atropurpureum</i>	1.1– 2.1	
<i>Stylosanthes guianensis</i>	1.2– 1.6	
<i>Glycine wightii</i>	1.1– 2.1	
<i>Calopogonium mucunoides</i> / <i>Centrosema pubescens</i>	1.6	
Fodder shrubs:		
<i>Calliandra calothyrsus</i>	3.9–22.4	2.14–23.46
<i>Leucaena diversifolia</i>	6.3–11.4	1.43–25.06
<i>L. leucocephala</i> K8	1.3– 9.5	
<i>L. leucocephala</i> K28	2.5– 3.9	8.10
<i>L. leucocephala</i> K743	4.6	8.60–10.10
<i>Sesbania aculeata</i>	2.2– 9.2	2.05
<i>Cajanus cajan</i>	14.1	
<i>Chamaecytisus palmensis</i> ²	16.7	14.39
<i>Canna edulis</i> (tubers)	5.3	
<i>C. edulis</i> (tops)	1.8	
Multipurpose trees: (stacked volume, m ³ /ha/yr) ³		
<i>Grevillea robusta</i>		0.95– 2.39
<i>Albizia falcataria</i>		3.35
<i>Acrocarpus fraxinifolius</i>		1.05
<i>Leucaena leucocephala</i>		0.47
<i>Casuarina montana</i>		0.42

¹ DM = dry matter; measuring period 3 years, 4 cuts/yr; from 2nd year onwards 12 m³/ha biogas slurry was applied to all macrocontourlines. Yield of contour strip component with width of ca. 0.6 m calculated on per hectare basis.

² Firewood and fodder yields from 1 cut one year after establishment.

³ Yields from 5-year-old trees; calculation based on following assumptions: 240 trees/ha, 5-year rotation, 48 trees harvested each year.

Table 8: Energy and protein requirements for the maintenance of a dairy cow production unit¹

	per day		per year	
	metabolizable energy (MJ)	crude protein (g)	metabolizable energy (MJ)	crude protein (g)
1 lactating cow 350 kg bodyweight 305 days lactation	44.9	341	13 649	104
1 nonlactating cow ² 350 kg bodyweight to be fed 125 days 305 days lactation	58.5	642	7 312	98
0.25 growing heifer ³ 200 kg bodyweight 0.2 kg daily gain	8.3	113	3 029	41
deduction for non-lactating crossbreds ³ – 10% energy – 15% protein	60.1	642	9 307	117
1 growing veal calf ⁴ 3 rd to 12 th month average weight 75 kg 0.3 kg daily gain	18.8	187	5 652	57
Total	123.8	1170	28 653	278
Daily requirement			78.5	0.76

¹ Calculations refer to NAS (1978)

² 125 days on account of 14-month intercalving period; results in 16.6% reduction in annual lactation yield

³ Refer to L. C. KEARL (1982).

⁴ Fed on roughage and 0.5 kg milk/day from 3rd month onwards; 210 kg milk must therefore be deducted from the lactation yield

– daily dry matter consumption amounts to 12.25 kg

– 1 dairy cow production unit consists of 1.9 TLU (1 TLU = 250 kg)

of some fodder plants did not even exceed maintenance requirements (energy content less than 6.4 MJ/kg). It is therefore of great importance to include energy-rich plants such as edible canna or sugarcane in the macrocontourlines.

More important, however, was the question as to which combination of species would be optimal to achieve the multiple

Table 9: Yield potential of fodder plants along contourlines in the West Usambara Mountains

Botanical name	n	ME/kg DM (MJ)	DM/ha Xa (t/ha)	ME/ha Xd (MJ/ha)	xP/ha Xd (kg/ha)	milk (kg)	TLU fed
Fodder shrubs:							
<i>Leucaena leucocephala</i>	3	6.2	4.3	73.0	3.2	nil	1.0 <0.2>
<i>Calliandra calothyrsus</i>	4	5.4	16.4	242.6	10.5	nil	6.9 (0.5) <1.4>
Creeping legumes:							
<i>Desmodium uncinatum</i>	4	7.0	3.9	74.7	1.9	258*	1.6 (0.1) <0.3>
<i>Desmodium intortum</i>	4	7.0	5.6	107.3	2.8	0.3	2.4 (0.2) <0.5>
<i>Macroptilium atropurpureum</i>	1	5.9	1.6	25.9	0.7	nil	nil
<i>Glycine wightii</i>	1	7.4	1.6	35.5	0.9	290*	0.7 <0.1>
Grasses:							
<i>Tripsacum laxum</i>	10	7.8	18.5	395.4	5.4	10.1 (0.8)	7.9 (0.6) <2.0> <1.6>
<i>Pennisetum purpureum</i>	3	8.1	14.4	321.1	4.9	8.0 (0.6)	6.1 (0.5) <1.6> <1.2>
<i>Pennisetum purpureum X P. americanum</i>	1	7.5	20.3	383.7	5.7	8.6 (0.7)	8.6 (0.7) <1.7> <1.7>
<i>Canna edulis</i> (tops and tubers)	2	9.4	7.1	185.3	1.7	8.4 (0.7)	2.4 (0.2) <1.7> <0.5>

¹ Refer to Table 8.

nil Energy content of fodder <6.4 MJ/kg DM means that all energy is needed to meet maintenance requirements.

* Milk yield just enough to feed a calf (kg/year).

() Yield/ha when planted along contourlines 8 m apart with contourline width of 0.6 m.

<> Yield/ha when planted along contourlines 8 m apart with contourline width of 2.0 m.

TLU Tropical Livestock Unit (250 kg).

n Number of samples analysed.

ME Metabolizable energy (MJ/ha and year; MJ/ha and day).

xP Crude protein (kg/ha and day).

functions described in Section 3.3. Suitable combinations for the 4 main agroclimatic sites are presented in Table 10.

Establishment of seedlings, biomass production and regeneration after cutting were the main selection criteria. *Calliandra* and Bana grass proved particularly successful at the warmer sites despite the lower rainfall (Ubiri and Mbwei), whereas *Leucaena* grew better with higher rainfall (Lushoto). Nevertheless, as not only the agroclimatic suitability but also the forage quality was an important selection criterion, *Leucaena leucocephala* was judged to be superior in macrocontourline mixtures: although it was outyielded by *Calliandra callothyrsus* with respect to dry matter productivity, its higher energy content results in higher milk yields (cf. the two mixtures at Mbwei in Table 10).

Table 10: Yields of fodder plant combinations in macrocontourlines

Site	Lushoto	Ubiri	Nywelo	Mbwei	Mbwei
Fodder plant combination	<i>Leucaena leucoc./ Glycine wightii/ T. laxum</i>	<i>Calliandra callothyr./ Desmodium uncinatum/ Napiergrass</i>	<i>Canna edulis/ Desmodium intortum T. laxum</i>	<i>Calliandra callothyr./ Desmodium uncinatum/ Banagrass</i>	<i>Leucaena leucoc./ Desmodium uncinatum/ Banagrass</i>
Dry matter yield (t/ha/year) ¹	10.1	8.9	14.5	15.3	9.0
Metabolizable energy (MJ/kg DM) ²	7.0	7.0	8.4	6.5	7.1
Protein/energy ratio ³	1.9	2.4	1.1	2.8	2.2
Expected milk yield (l/ha/day) ⁴	2.7	1.6	11.3	nil	2.5
Fuelwood (t/ha/yr)	13.2	12.8	-	12.8	12.8

¹ Yield per hectare extrapolated from width of contourline of 2 m.

² Metabolizable energy in megajoule/kg dry matter.

³ % crude protein/MJ metabolizable energy per kg dry matter.

⁴ Refer to Tables 8 and 9.

Napier grass could not be recommended for Nywelo; although it grew well, it led to multiplication of the stemborer in an area where maize is the most important crop. With regard to the creeping legumes, almost all of them had to be discarded because of difficulties in establishing them. Only *Desmodium uncinatum* grew well and brought high yields.

All fodder combinations have sufficient protein, as the minimum protein/energy ratio of 1 considered to be necessary for normal rumen activity (LANTSCH 1984) is exceeded in all combinations.

5.4 Comparison of different cropping systems

In comparing the yields of crops between contour strips and in fields without contour strips, two different types of cropping systems are involved in which several other factors besides the contour strips also differ. The contour strips not only reduce the cropping area by 18% (grasslines) or 25% (macrocontourlines). They also have beneficial and competitive effects on the field crops, and they provide animal feed which permits the production of milk, meat and manure. The manure can be used to fertilize the fields. The fodder yields of the grasslines and macrocontourlines are sufficient to feed 0.3 and 1.0 TLU, respectively, and thus to supply ca 5 t and 10 t farmyard manure per hectare and year.

A comparison of the physical outputs of traditional cropping without contour strips (System A) and cropping systems with grasslines (System B) and macrocontourlines (System C) is presented in Table 11. The comparison is not based on a field trial under controlled conditions but rather on many single yield measurements from various trial fields with contour strips and in adjacent farmers' fields without them.

Primarily as a result of the farmyard manure which could be applied to maize in the main cropping season, yields could be increased by 64% in System B and 87% in System C. The higher maize yields despite a 25% reduction in cropping area are quite impressive, and are due not only to the regular application of manure but also to better utilization of rainfall: surface runoff is

Table 11: Comparison of yields of different cropping systems

Cropping system	A	B	C
	Farmers' fields without contour strips	Fields with ¹ grasslines	Fields ² with macro-contourlines
Maize (dt/ha/yr) ³	10.0	16.4	18.7
Beans (dt/ha/yr) ³	6.7	5.9	5.0
Milk (l/ha/yr) ⁴		288.3	355.8
Bull calf (kg meat/yr)		15.0	15.0
10-yr-old cow (kg meat/yr)		35.0	35.0
Fuelwood (m ³ /ha/yr)			2.8

¹ Single row of Guatemala grass along contour lines, requiring 18% of arable land; 5 t/ha/yr farmyard manure applied to maize.

² Strips of grass, creeping legume, shrubs and trees along contour lines, requiring 25% of arable land; 10 t/ha/yr farmyard manure applied to maize.

³ Average yields measured on trial fields and nearby farmers' fields.

⁴ Average milk yields based on all macrocontourlines tested.

reduced by the contour strips to the benefit also of the field crops between them. However, the fertilizer effect does not appear to last through to the following short rains: bean yield reductions of 18% and 25%, corresponding to the reduction in cropping area due to the contour strips, had to be accepted.

With regard to milk production, an average farm in the West Usambara Mountains with 2.5 ha land can produce 2.4 l milk per day (range 0.8 – 5.6 l/day) with macrocontourlines covering ca 20% of the farm area.

With regard to fuelwood supply, the shrubs and trees in the macrocontourlines provide an average of 2.8 m³ firewood per hectare. Thus, an average farm in the West Usambara Mountains can produce 7 m³ firewood from the macrocontourlines. This corresponds to 95% of the annual fuel needs of the average farm family (GEISSEN 1984). The production of fuelwood and timber in macrocontourlines would provide a feasible alternative to

collecting wood from forest areas, which are presently diminishing, and would thus help considerably in reducing environmental deterioration.

In Tables 12 and 13, gross margins have been calculated for the different cropping systems. With respect to productivity of land (Table 12) it can be seen that gross margin per hectare in Systems B and C is 59% and 74% higher than in the system without contour strips. The greatest contribution to this increase is made by milk production, and the main input needed for this is additional labour. Labour inputs in Systems B and C are 35% and 34% higher than in System A and are required mainly for the

Table 12: Productivity of land for different cropping systems (gross margin in Tanzanian shillings/ha/yr)

Cropping system	A	B	C
	Farmers' fields without contour strips	Fields with ¹ grasslines	Fields ² with macro-contourlines
Monetary output:			
Maize	11 000	18 204	20 757
Beans	11 390	9 350	8 500
Milk		5 766	7 116
Meat of bull calf		1 750	1 750
Meat of 10-yr-old cow		825	825
Fuelwood			169
Subtotal	22 390	35 895	39 117
Variable costs:			
Seed for maize and beans, manure application, vet. drugs, minerals and sprays	2 000	3 460	3 649
Gross margin:			
Absolute (Tsh/ha/yr)	20 390	32 135	35 468
Relative (%)	100	159	174

Assumptions: average prices in Lushoto District 1981–87 (computed from HARDER 1986) maize 11.1 Tsh/kg, beans 17.0 Tsh/kg, milk 20.0 Tsh/kg, bull calf meat 5000 Tsh/animal, cow meat 8250 Tsh/animal, fuelwood 70 Tsh/m³; calving interval 17 months.

livestock sector. As the labour needed for the dairy component is distributed equally over the year, it does not increase work loads greatly during labour-intensive periods. Furthermore, it must be noted that the alternative to stallkeeping – free grazing of livestock – also requires labour. A labour study carried out by DUNKEL (1987) showed that only free-grazing herds of more than 6 TLU require less labour/TLU than stallfed animals under the overpopulated conditions of the West Usambara Mountains with only 15% grazing land. As rich farmers – for sociological and risk minimization reasons – distribute their cattle to poorer relatives or friends, herds are not usually so large.

In terms of labour productivity (Table 13), Systems B and C are superior to System A by 19% and 31%, despite the higher labour requirements. They bring a daily wage of Tsh 127 and Tsh 140 in comparison with only Tsh 107 in System A.

Table 13: Labour inputs (man-days/ha/yr) and productivity of labour (gross margin in Tsh/man-day)

Cropping system	A	B	C
	Farmers' fields without contour strips	Fields with ¹ grasslines	Fields ² with macrocontourlines
Labour inputs for:			
Field crops (maize + beans)	190	176	154
Contourlines (planting, maintenance, cutting)	–	9	15
Livestock	–	71	85
Total labour inputs:			
Absolute (man-days/ha)	190	256	254
Relative (%)	100	135	134
Gross margin:			
Absolute (Tsh/man-day)	107	127	140
Relative (%)	100	119	131

Sources: HARDER 1986, LUDWIG 1967, and own calculations.

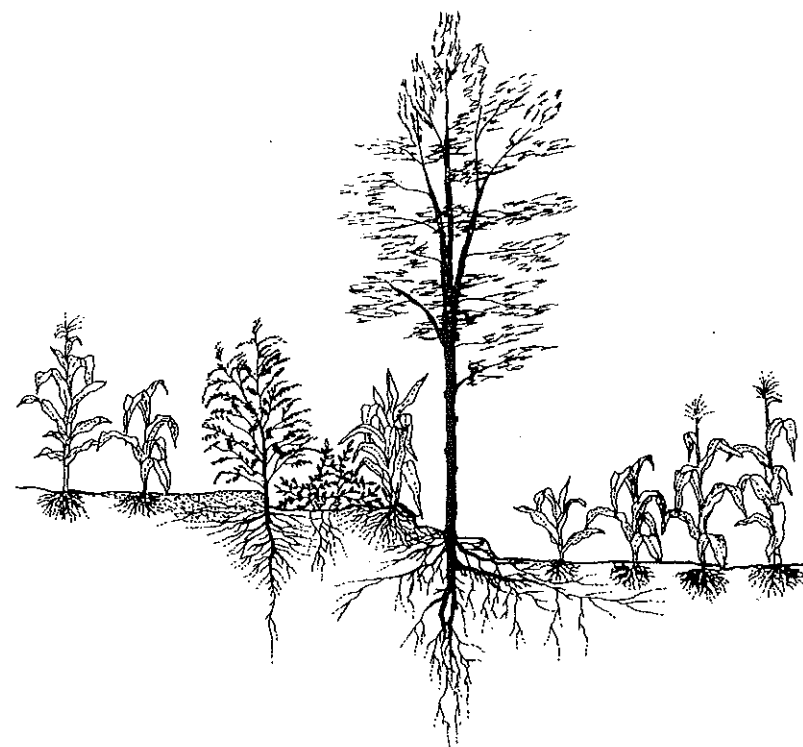


Figure 3: Cross section of a macrocontourline as surveyed in the present study: from left to right, maize plants in the upper field showing negative alley effect, fodder bush, creeping legume, fodder grass, tree, maize plants in the lower field.

Thus, the improved systems with macrocontourlines (C) offer a real alternative to cattle grazing for those farm families who own cattle and presently practise grazing. Not only would their income be higher, also environmental degradation would be reduced. The system with macrocontourlines proves to be the best in every respect.

6. Prospects

The macrocontourline as a central soil erosion measure delivers multifarious outputs. Because of its byproducts, it is an economi-

cally feasible way for the farmers in West Usambara Mountains to cope with soil erosion and accelerating land degradation. However, more detailed research is needed into its long-term effects, its management requirements and appropriate designs for different farm situations.

Particularly the multipurpose tree component requires more attention. A basis for further research in this respect has been laid during the past 3 years, as 24 potential agroforestry trees – mostly indigenous – have been established on trial fields all over the West Usambara Mountains. They are ready for further evaluation with regard to their production potential, management requirements and interface features.

The macrocontourline, although a central component, is only one measure to support agricultural intensification. Further attention must still be given to ways of increasing the productivity of land between the contour strips. Very promising research on simultaneous green manuring has already been commenced and needs to be continued within the framework of a detailed farming systems research programme.

7. References

- Backeus, I. 1982. A study tour to the indigenous forests of the West Usambara Mountains with special reference to regeneration. Växtbiologiska Institutionen, Uppsala.
- Baum, E., Kotschi, J., Lilley, J. & Ngware, S. 1983. Evaluation report SECAP. GTZ, Eschborn.
- Buch, M.W. 1983. Semiquantitative Beschreibung von Bodenerosion (rezente Abtragung und Akkumulation) an Hängen unterschiedlicher Landnutzung, Neigung und Länge in fünf Dorfgebieten der westlichen Usambara Mountains/Tanzania. Consultancy report for GTZ, University of Saarland, Saarbrücken.

- Burrow. 1946. The Mlalo Basin: Development of Mlalo Rehabilitation Scheme. National Archives of Tanzania, Documents from 1942–1951, Dar es Salaam.
- Dunkel, M. 1987. Aspekte des standortgerechten Landbaues in den West Usambara Bergen, Tanzania, unter besonderer Berücksichtigung des Faktors Arbeit in der Rinderhaltung. Diploma thesis, University of Göttingen.
- Ezaza, W. 1985. Untersuchung über die Problematik landwirtschaftlicher Nutzung in tropischen Gebirgen Ostafrikas unter besonderer Berücksichtigung geökologischer Faktoren. Dissertation, University of Giessen.
- Geissen, V. 1984. Firewood consumption and related aspects in five selected villages in Lushoto District. Institute for Animal Nutrition, University of Hohenheim, Stuttgart.
- Glaeser, B. 1981. Ökoentwicklung in Tanzania. Breitenbach, Saarbrücken.
- Harder, I. 1986. Economics of macrocontourlines. Technical Paper, SECAP, Lushoto.
- Kearl, L.C. 1982. Nutrient requirements of ruminants in developing countries. International Feedstuff Institute, Utah State University, Logan.
- Lantsch, H.J. 1984. Assessment of milk production capacity, mineral content and trace element content. Institute for Animal Nutrition, University of Hohenheim, Stuttgart.
- Locher, E. 1980. Prefeasibility study for the Integrated Livestock Development Project (LDP) in the West Usambara Mountains. GTZ, Eschborn.
- Ludwig, H.D. 1967. Ukara – ein Sonderfall tropischer Bodennutzung im Raum des Victoria-Sees. IFO Afrikastudien 22. Weltforum Verlag, München.
- Lundgren, B. 1978. Soil conditions and nutrient cycling under natural and plantation forests in Tanzania. Reports in Forest Ecology and Soil No. 31. Swedish University of Agricultural Sciences, Uppsala.

- NAS. 1978. Nutrient Requirements of Dairy Cattle. National Academy of Sciences, Washington, D.C.
- Niemeyer, J.J.W. 1979. National Soil Service. FAO Project File Tech/SS/4, Mlingano.
- Schaafhausen, S. 1981. Bodenerosion in den West Usambaras/Tanzania: qualitative Untersuchungen zur Bodenerosion in 5 Dorfgebieten unterschiedlicher Landnutzung. Diploma thesis, University of Hamburg.
- Schönmeier, H.W. 1977. Agriculture in Conflict: The Shambaa Case, Kübelstiftung, Bensheim.
- TIRDEP. 1977. Tanga Water Master Plan. Vol. VI. Land Use Atlas. Regional Development Director, Tanga.
- Woytek, R. et al. 1988. Soil Erosion Control and Agroforestry in the West Usambara Mountains: Evaluation of an Extension Approach. Volume 111. Postgraduate Training Centre for Agricultural Development, Technical University of Berlin.

VI. Multiple cropping with deciduous fruit trees in the cold tropical highland of Colombia

Karl M. Müller-Sämann

1. Initial situation

The research was conducted in Boyaca Department in the highland of Colombia. The capital of the Department is Tunja (5°31'N, 73°22'W), 150 km north of Bogota. Also outside of the urban centres, the region given the geographical designation of Altiplano (highland) Cundiboyacense is relatively densely populated: 60–120 persons/km² in the rural areas.

The people live primarily from agriculture, which is marked above all by high altitudes and low temperatures. The study area includes the municipalities of Tuta, Paipa, Sotaquira, Nuevo Colon and Boyaca/Boyaca, in which 92% of the agricultural land lies between the altitudes of 2000 and 3000 m. The mean annual temperature ranges correspondingly from 12 to 18°C. The mean annual precipitation of 700–1000 mm is distributed over two growing seasons (March–July, September–December), permitting year-round cropping. In the months of December, January and February (rarely in July/August), night frosts occur and can limit cropping.

On the whole, the soils are rich in humus but – except in the valleys and some newly cultivated higher areas (Paramos) – only moderately fertile. This is essentially on account of the low pH-values (often between 4.2 and 5), which lead to the binding of phosphate and reduced biological activity. In addition, after only a few years of cultivation, most soils tend to harden when dry. Especially in the plough-pan area, indurations often limit rooting penetration and water-holding capacity even in soils which are actually quite deep.

The dominant form of land use is extensive cattle-keeping by smallholders, greatly favoured by the spontaneous spread of Kikuyu grass (*Pennisetum clandestinum*) which now covers 50–70% of the agricultural area (ORSTOM 1984). Intensive forms of dairy husbandry (partly with irrigation) can be found in the valleys, where night frosts and seasonally high water tables render cropping difficult.

Most of the fields lie on more or less steeply inclined slopes, from which the cold air can flow off. Here, cropping has already resulted in considerable erosion over large areas, and the remaining shallow soils are now suitable only for grazing. Table 1 gives an overview of the extent and productivity of dairy farming. The remaining agricultural area is used for arable cropping and fruit and vegetable growing, as shown in Table 2.

Table 1: Area of grazing land, stocking rate and milk production (estimate)

Region	Sotaquira, Tuta Paipa	Nuevo Colon, Boyaca/Boyaca
Percentage of total agricultural area	73.4	48.5
No. of animals (TLU/ha)	0.8– 2.5	0.8–2.5
Milk production (l/ha/day)	1.8–11.8	1.0–4.3

Source: ORSTOM (1984), adapted.

Table 2: Percentage of agricultural area under important field, fruit and vegetable crops

Region	Sotaquira, Tuta Paipa	Nuevo Colon, Boyaca/Boyaca
Maize	8.8	11.2
Cereals	6.0	–
Potatoes	3.4	13.6
Fruits	7.4	14.0
Vegetables	1.0	5.0
Other	–	7.7
Total	26.6	51.5

Source: ORSTOM (1984), adapted.



Evening in the vicinity of Sotaquira. In the landscape characterized by smallholdings, fields with mixed crops alternate with extensively managed natural pastures and fruit gardens near the homesteads.



Smallholder in his field with maize, potatoes and grain legumes. The integration of fruit trees into the cropping systems helps stabilize the strongly fluctuating income from potato growing and gives some protection to the unstable slopes.

Apart from the facts that the frost-prone valleys are less suited for cropping, particularly potatoes and maize, and that cereals such as barley and wheat grow better on the uplands and slopes, the cultivation of different crops is determined not so much by ecological as by socioeconomic factors. In this regard, farm size plays an important role. Market-oriented dairy husbandry and cereal cropping are the domains of the large farmers, whereas potatoes and maize provide subsistence for the smallholders and, together with vegetables, are also sold. The yields of smallholder crops are shown in Table 3.

Table 3: Yields of the most important smallholder crops in Boyaca Department

Crop	Yields (kg/ha)
Field crops: ¹	
Maize	1 300– 2 200
Potatoes	11 000–15 000
Barley	1 200– 2 400
Wheat	1 300– 2 400
Fruit crops: ²	
Pears	12 000–18 000
Apples	10 000–12 000
Peaches	6 000– 8 000

Sources: ¹ MORENO (1985); ORSTOM (1984)

² FRANK (1985), estimates.

The growing of temperate fruits began ca 40 years ago and also provides cash income for the smallholders. On parcels of 0.1–0.6 ha, pears, peaches, plums, apples, mirabellas and some tropical fruits such as curuba are grown, mostly together with undersown field crops such as potatoes/peas, maize, beans and various vegetables.

The importance of smallholdings in Boyaca is clearly shown in the overview of farm size distribution (Table 4): 80% of all farms are not larger than 5 ha but cover only 22% of the total agricultural area.

Table 4: Farm size distribution relative to the total agricultural area in Boyaca Department (1984)

Farm size (ha)	Agricultural area		Number of farms	
	(ha)	(%)	(No.)	(%)
0–1	84 485	4.2	257 943	46.2
1–5	351 819	17.4	212 555	38.1
>5	1 581 821	78.4	87 463	15.7

Source: CEGA (n.d.), quoted in KEYLER (1987).

2. The problem and the aims

In the study area, particularly smallholders face serious ecological and economic problems. Their incomes are falling as a result of deteriorating soil fertility and increasing soil erosion, at the same time as costs of production inputs such as mineral fertilizers, plant protectants and machines are rising rapidly. This is illustrated well by developments over the past 10 years in potato-growing, a characteristic smallholder crop. Potato prices fluctuate seasonally and cyclically; on account of investment risks, neither the productivity nor the income from this crop has risen. To the contrary: corrected for inflation, potato prices have fallen by about 20% over the last 10 years, while production costs have risen. This led and is leading to rural impoverishment and continued outmigration of the rural population to the cities (MORENO & ACOSTA 1987).

Smallholder families constitute not only the largest part of the population but also the poorest. They are also usually farming in the poorer locations; their fields are mostly on slopes, i.e. are susceptible to erosion and often have only shallow soils. Nevertheless, many of these farms are intensively worked because land is scarce, and lack of rotations has led to soil exhaustion and serious erosion. If this successively degrading form of land use continues for lack of alternatives, the soil fertility decreases even

more (complete loss of topsoil, disappearance of humus) and entire slopes can be transformed over the years or decades into unfertile wasteland grazed by sheep.

From an agronomic viewpoint, biological methods of erosion control could offer effective remedies. The creation of contour strips with trees and shrubs, if complemented by improved crop rotations (undersown legumes in cereals with lupines as subsequent crop) and better use of stable manure⁹ and combined with improved tillage, could almost completely prevent soil losses. From a farm economic viewpoint, forestry measures are not very attractive, as the market for wood is satiated by cheap imports from the lowland. Moreover, the energy needs in the rural households are covered mainly by coal, which occurs in small outcrops of seams throughout the entire region.

In the search for suitable perennial crops, fruit trees offer the best possibilities. They can already be found in many smallholdings, where they are grown on small areas with undersown food crops. This cropping system is considered to be relatively erosion-safe, land-intensive and low-risk. Whereas the undersown crops (potatoes, beans, maize, etc.) secure subsistence, the fruits can be sold and provide cash income. Apples, pears, peaches and plums command high prices and the domestic market – until now supplied almost exclusively from abroad – is far from satiated.

It is therefore the aim of a Colombian-German development project (Caja Popular/GTZ, Tunja, Colombia) to promote smallholder fruit-growing through seedling production and agricultural extension and credit. The associated research programme has the task of investigating the efficiency of existing production techniques and developing them further. The first phase was devoted to identifying the important agronomic interactions between fruit trees and field crops, and measuring the effects of these interactions on yield, yield security and farm income. Particular attention was given to possible competition in the use

⁹ Stabling is practised on a significant scale only in the case of pigs.

of light, water and nutrients, as well as the positive effects between the individual components (e.g. through improved microclimate).

3. Methods

These questions were investigated mainly on small farms. Suitable experimental areas were selected in existing pear and peach plantations and directly adjacent open fields, and simply designed trials were laid out. For comparisons of efficiency, pear and peach plantations were selected in which the trees were 30 and 20 years old, respectively. As is often the case in trials with perennial crops, complete randomization was not feasible. A danger in non-randomized trials is that factor effects are confounded by soil differences. In order to avoid this systematic error, soil analyses and yield measurements were made over the

Table 5: Design of Trial I

		Design: block, two factors, split plot, 3 replications			
		Factor 1: a) without trees b) with 500 pear trees/ha			
		Factor 2: fertilizer application (3 levels: D ₀ –D ₂):			
		N	P ₂ O ₅	K ₂ O	MgO
Maize (1986) ¹	D ₀	no fertilizer			
	D ₁	85	60	90	10
	D ₂	160	120	170	20
Beans (1986) ¹	D ₀	no fertilizer			
	D ₁	24	60	36	4
	D ₂	48	120	72	8
Barley (1986/87) ²	D ₀	no fertilizer			
	D ₁	25	75	25	
	D ₂	50	150	50	

¹ Compound fertilizer 17-6-18-2 and triple superphosphate.

² Compound fertilizer 10-30-10.

Table 6: Design of Trial III

Design:	block, one factor, 3 replications
Variants:	a) without trees b) with 500 pear trees/ha
Field crop:	potatoes
Fertilizer ¹ :	130 N, 360 P ₂ O ₅ , 200 K ₂ O, 100 kg MgO, 100 kg Mn

¹ 1 t Thomas phosphate, 1 t compound fertilizer 13-26-6 supplemented with 140 kg K₂O as K₂SO₄ and 100 kg P₂O₅ as triple superphosphate, P fertilizer as customary in the area, N fertilizer reduced, K₂O improved.

entire trial plot and on its edges beyond the trees, and soil gradients were recorded. In this way, replication and factor effects could be separated. The data were subjected to analyses of variance and regression.

In the following, the results of Trials I (1986 and 1986/87) and III (1986/87) are discussed. It must be noted that the data are derived from only the first 18 months of investigations. The present results can therefore be regarded as only preliminary and must still be supplemented by data from at least one more growing period. The design of the trials is described in Tables 5 and 6.

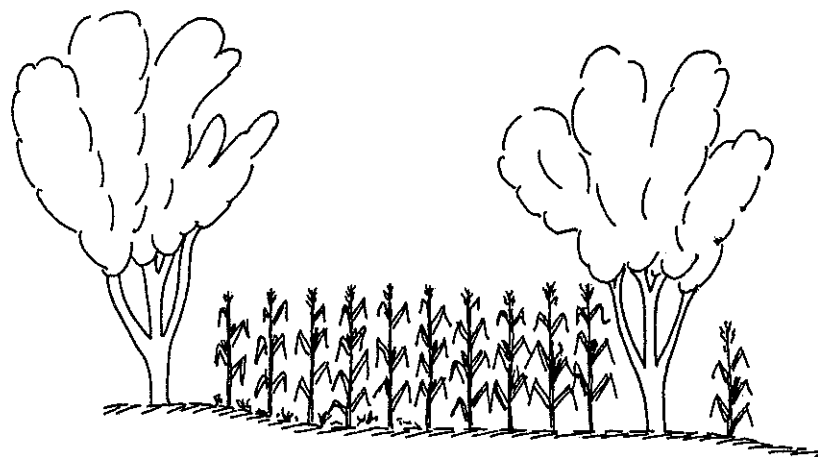


Figure 1: Cross-section of a tree alley planted to maize at time of ripening (November/December)

Both trials were located on the farm "Nueva Debrezin" in Sotaquirá Municipality. The plots are on a hillside with 5–10% slope. Pear trees are planted with 3 m spacing in rows along contour lines 6.7 m apart. The trees are about 30–40 years old (trunk circumference 50–60 cm, crown 4–5 m, height 5–6 m, 3–4 main branches, half standard), so that a fully developed cropping system can be assumed in the comparison of variants (see also Tables 10–12). Depending on the interrow spacing of the under-sown crop, strips of ca 14 m are left open for the tree rows. The area under trees which is not used for cropping thus amounts to 22% of the total field area. Therefore, in the case of all crops under trees, 22% of the calculated yield/ha is subtracted, as the sown area is actually only 78% of the total field.

4. Results

4.1 Plant ecological aspects

Erosion control. As the trial plots were on slopes and the trees planted along contours, an attempt could be made to investigate the question of erosion control. On all fields with rows of pear trees, a distinct soil gradient was evident: removal of sediment from the upper part and accumulation of sediment in the lower part of the cropping strip. This is clearly reflected in the yield data (see Table 7). The differences are considerable, above all in

Table 7: Influence of position on terrace and soil quality on undersown crops

	Upper part of terrace	Lower part of terrace	LSD 5%
Maize (I/1986):			
Height at harvest (cm)	171.0	185.6	n.d. ¹
Yield (kg/ha)	3354	3435	126.5
Green oats (I/1986/87):			
Above-ground biomass (kg DM/ha)	1365	2424	n.d. ¹

¹ Not determined.

the case of the dry-season crop barley: its yields were 78% higher in the lower than the upper part of the terraces. In contrast, the differences in maize were smaller, presumably on account of its greater root penetration and the better water supply during the growing period.

The east/northeast to west/southwest arrangement of the trees rows also resulted in somewhat greater partial shading in the lower than the upper part of the terraces.

Yields. With respect to the efficiency of intercropping, three questions were of primary importance:

- To what extent do the trees influence the yields of the under-sown crops?
- Is the yield reduction on account of loss of land (22% for the rows of trees) aggravated by competitive effects (nutrients, water, light), or can it be offset by more favourable growth conditions in the mixed stand?
- How do the pear trees react to the presence of an under-sown crop?

The influence of the trees on crop yields is shown in Table 8. With the exception of maize, yields were reduced by 7–38% un-

Table 8: Influence of pear trees on the yield of undersown food crops

Factor	Without trees	With trees ¹		
	Absolute (kg/ha)	Absolute (kg/ha)	Relative (without trees = 100)	
Potatoes ²	19 625	12 231	62 %	
Beans ³	519	439	85 %	
Oats ²	1 603	1 497	93 %	
Maize ³	D ₀	3 209	3 210	100 %
	D ₁	3 594	3 297	92 %
	D ₂	2 169	3 785	175 %

¹ Yields per hectare relative to total area, i.e. yield per hectare harvested minus 22% loss of land for the rows of trees.

² Trees fully foliated.

³ Trees predominantly leafless during the growing season.



Growing maize and field beans in a fruit tree stand: once the plants have emerged, the pear trees have dropped most of their leaves and thus permit good development of the understorey crops (experimental field, 20 May 1987).



Growing barley in an only slightly shaded pear tree stand near Sotaquirá in late May. As the cereal competes relatively strongly with the trees, this form of cropping is not very common and is also not recommended.

der trees. If 22% is subtracted from this to account for the reduction in planted area, the resulting yield differences relative to the actual area planted with field crops are +15% in the case of oats and -16% in the case of potatoes²⁾, i.e. the growth conditions and, thus, the yields under the pear trees were partly better, partly worse than in the open field.

Numerous factors influence the yield. The trees alter the microclimate: the reduction in air circulation and light intensity affects temperatures, temperature fluctuations and relative air humidity in the stand (e.g. light freezing of maize and beans occurred only in the open field). This, in turn, directly affects the yield physiology of the undersown crops and, in the long run (both directly and indirectly), also soil characteristics, particularly humus balance (cf. JAGNOW 1967).

A further complex of factors comprises the reciprocal effects of the root systems of the perennial crop (trees) and the annual crops. The multitude of possible additive, complementary and opposing effects in this connection have been investigated in only relatively few analytical trials. This makes the comparison "Arable farming with and without trees" more difficult. The measurements of light intensity, evapotranspiration, soil moisture and fertilizer levels provide only an initial basis for such a discussion and can be satisfactorily interpreted only after completion of the trials.

Water balance. The fertilizer effects suggest that the yield differences in the first growing season are due largely to water balance. As shown in Table 9, fertilizer application increased yields under trees but led to some distinct yield depressions in the open field. It appears that insufficient water was available to transform the luxuriant vegetative growth of the plants into grain yield. The factors which led to a much better water supply to crops under trees could not yet be adequately investigated. However, initial microclimatic measurements gave some indications: the values of potential evaporation (measured with Piche evaporimeters under

²⁾ Potatoes and oats were sown when the trees were fully foliated. Maize and beans were shaded only slightly during the main growing season, as the pear trees were dormant from late May to late September and had shed their leaves.

Table 9: Effect of different fertilizer rates on the yield of food crops grown in the open field and under trees (values relative to $D_0 = 100$)

Crop	Variant	D_0	D_1	D_2
Beans	Without trees	100	92	88
	With trees	100	99	102
Oats	Without trees	100	99	89
	With trees	100	120	110
Maize	Without trees	100	112	68
	With trees	100	103	118

the trees) in the mixed stand were 22% lower than in the open field. This suggests a lower water consumption per unit of biomass produced. In addition, in the 30-year-old pear tree plantations, the soil humus content and, thus, the infiltration rate and field capacity may be higher, creating the prerequisites for a better water supply. However, these are only assumptions at this point, as the relevant soil analyses have not yet been completed.

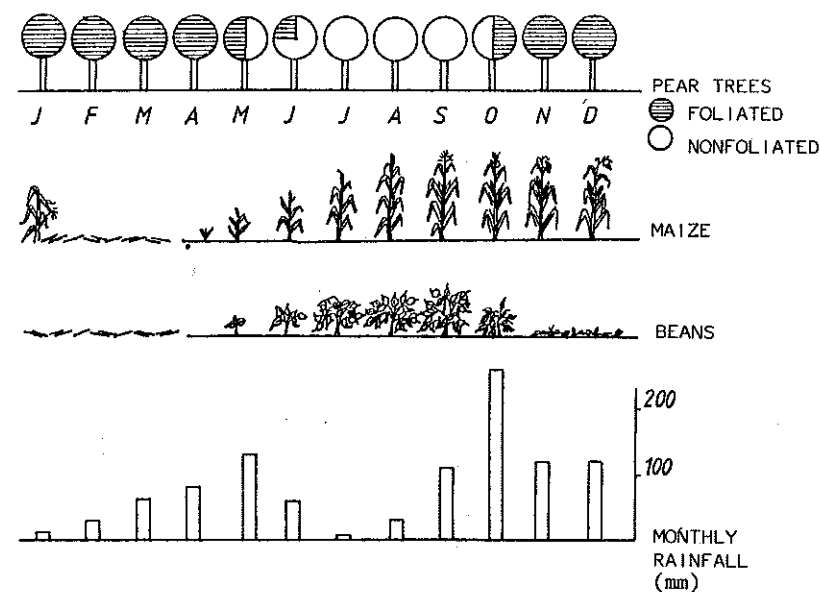


Figure 2: Monthly rainfall (1986/87) and development stages of the pear trees and the maize and bean plants (2700 m elevation)

Light balance. In the field trials described here and in a trial with field beans under controlled conditions, the question of possible shading effects was examined in detail. Effects on yield-determining factors such as pod formation and grains per pod could be recorded only when the tree crowns intercepted more than 30–35% of the light (as a mean over the day). The deciduous trees surpassed this value only rarely; the amount of light reaching the ground was usually higher. In the long rainy season (March–July) the amount of light was more than sufficient; on account of leaf shedding in May, a maximum of ca 20% of the available light was intercepted. Only the branches of the trees and a few remaining leaves threw a light shadow. In October when new leaves began to sprout, shading became greater again. The results achieved with field beans under local conditions (high radiation intensity in the tropical highland) suggest that the crops grown in the alleys between the trees at this time of year suffer no or only very little negative shading effects.

The situation differs in the short rainy season. In October–January only about 60% of the light penetrates into the alleys and negative effects on the yields of the undersown potatoes can be assumed. In the alleys between the pear trees, not only are the potato yields particularly low (–32%); maturation is also delayed. The number of still green shoots 6 weeks before harvest was 62% higher under trees than in the open field. Grading was altered under the trees in favour of large tubers (> 4.5 cm diameter).

Nutrient balance. The application of different levels of fertilizer was intended primarily to explain the influence of the tree storey on nutrient supply to the understorey crops. The above-mentioned strong interaction between water balance and fertilizer recorded in the total plot evaluation may conceal other relations. As the yields of oats were recorded row for row, statements can be made about the border areas between tree rows and undersown crops. Statistically confirmed reductions in yield could be found only in the outermost rows of the upper terrace edge and only with the fertilizer levels D₀ and D₁, whereas no differences were evident on the edge of variant D₂. This suggests

primarily a competition for nutrients in the fertilizer levels D₀ and D₁, but the question cannot yet be definitively answered. Relative to the total area and its yield, however, the border effects were insignificant.

Summary. In most cases, the yields of field crops under trees were reduced (7–32%) in comparison with yields in the open field. This is due primarily to the reduction in crop area. Insufficient light led to lower yields only in the case of potatoes, which were grown while the trees were in full foliage. Competition for nutrients between trees and field crops was evident only at the upper edges of the terraces and was negligible relative to total yield. Large differences were evident in water supply but other than expected. Both water utilization and water supply appeared to be better under the pear trees and enhanced yields. The arable crops scarcely competed with the trees for water, as they were no longer in the field at the time when the water requirements of the trees were greatest.

4.2. Economic comparison of cropping systems

On the basis of the agronomic results, different cropping systems were defined and evaluated in monetary terms:

Table 10: Crop yields (kg/year) of three different cropping systems

System	I	II	III
Crop	Arable cropping ¹	Pears mulched with grass-clover	Pears combined with arable cropping ¹
Beans (0.5 or 0.39 ha) ²	294.5	–	236.5
Potatoes (0.5 or 0.39 ha)	9813.0	–	6115.5
Maize (0.5 or 0.39 ha) ²	1797.0	–	1648.5
Pears (1 ha)	–	2973.0	2579.0

¹ Crop rotation over 2 years: beans (April–August), potatoes (September–February), maize (April–January).

² Fertilizer level D₁.

- I Arable cropping (rotation over 2 years: beans, potatoes, maize)
- II Pear trees with grass-clover as ground cover, regularly mulched
- III Pear trees with undersown arable crops as in System I.

Table 10 shows the crop yields of the three systems based on the proportion of area planted and the yields recorded in the trials. The pear yields derived from these trials lie far below the average values shown in Table 4. This can be explained by the fact that the trees had not been pruned, as pruning is not commonly practised by smallholders. Considerable additional potential lies in raising the fruit yields.

In the monetary assessment, 1987 prices and costs according to ICA (1987) are applied to the three cropping systems defined

Table 11: Land productivity (gross margin in pesos/ha/year) of three different cropping systems

System	I	II	III
Crop	Arable cropping ¹	Pears mulched with grass-clover	Pears combined with arable cropping ¹
Beans (0.5 or 0.39 ha)	21 548	—	20 246
Potatoes (0.5 or 0.39 ha)	91 395	—	7 215
Maize (0.5 or 0.39 ha)	58 140	—	40 779
Pears (1 ha)	—	229 597	228 689
Total	171 353 (100%)	229 597 (134%)	296 929 (173%)
LER ²	1.0	1.0	1.39

Source: ICA (1987) and own calculations.

¹ Crop rotation over 2 years: beans (April–August), potatoes (September–February), maize (April–January).

² Land equivalent ratio.

above and the measured values. As the smallholder is concerned less with maximizing profits than with the question of how to raise output per unit of limited land area and this as far as possible with the same or even higher productivity of labour, gross margins were calculated per units of land and labour. The results are summarized in Tables 11 and 12, in which the land productivity (output per unit of area) of the three systems is compared.

As the figures reveal, the seemingly extensive fruit-growing system (II) is 34% more productive and intercropping (III) is 73% more productive than the arable farming system (I). The LER of the intercropping system is 1.39, which represents a considerable increase in land productivity.

Table 12: Labour inputs and productivity of labour of three different cropping systems

System	I	II	III
Crop	Arable cropping ¹	Pears mulched with grass-clover	Pears combined with arable cropping ¹
Labour inputs (working days/ha/year):			
Beans (0.5 or 0.39 ha)	22.5	—	17.6
Potatoes (0.5 or 0.39 ha)	54.0	—	42.1
Maize (0.5 or 0.39 ha)	36.5	—	28.5
Pears (1 ha)	—	118.0	62.0
Total	113.0 (100%)	118.0 (104%)	150.0 (133%)
Productivity of labour (gross margin in pesos/working day):			
Total	1516 (100%)	1946 (128%)	1980 (131%)

Source: ICA (1987) and own calculations.

¹ Crop rotation over 2 years: beans (April–August), potatoes (September–February), maize (April–January).

Consideration of the individual yield components reveals that the pear yields in sole and mixed stands were almost identical³⁾, whereas the yields of the field crops were reduced in mixed stands, primarily because less area was available for cropping under the trees. The high contribution of the pears to the total gross margin means that, with increasing intensification of the fruit-growing component, the LER value falls, i.e. arable cropping under pear trees becomes less profitable. Under these conditions, the value of the intercropping system can be seen above all in the possibility of securing subsistence via arable cropping and simultaneously gaining cash income via pear production. This combination of subsistence and cash cropping with high land productivity on very small areas is attractive for the smallholder, particularly because production risks are kept low. From the viewpoint of profitability, intercropping is especially interesting for farms which, because of scarce capital, must do without external production inputs such as mineral fertilizers and plant protectants.

Another positive aspect of the intercropping system is that the undersown crops guarantee that maintenance work is carried out in the tree stands. If arable cropping is not done, cultivating the soil between the trees is often neglected – also against better judgement – and the result is commonly the invasion of weeds and Kikuyu grass.

The results with respect to labour economics follow the same lines as the income comparison. The labour inputs in systems I and II are almost the same (113 and 118 working days/ha, respectively), whereas system III requires 150 working days/ha, or 32% more than the arable cropping system. In terms of labour productivity, systems II and III are superior to system I by 28% and 31%, respectively, and bring a daily wage of 1946 instead of 1516 pesos/working day.

³⁾ This was the case during the period of observation but could change with time, as the trees' reaction to certain cultivation measures may be delayed. When the trial began, both the plot with only trees and the intercropped plot had been cropped extensively with maize and beans.

5. Future tasks

Now that the greater efficiency of the intercropping system with deciduous trees could be proved in the first phase of research, the next phase should be devoted to improving and intensifying this system with the aim of further developing the content of agricultural extension. This research would comprise:

- further investigations of labour economics (particularly labour peaks, labour divisibility),
- further measurements of the erosion control effects of different crops and cultivation techniques within the intercropping system,
- improvement of management with respect to partial mechanization and plant protection,
- determining optimal plant population densities and optimal arrangement of crop components, and
- development of improved fruit/forage combinations.

These investigations require more applied methods than the first phase of research, and should involve the active participation of fruit growers. As complementary research, some of the current on-farm trials should be continued, particularly those involving fruit tree pruning and establishment of new fruit tree gardens with different companion crops.

6. References

- Frank, H. 1985. Analisis de las posibilidades de produccion y promocion de cultivos des frutas para climas templados. PN 79.2196.8 Proyecto Colombo-Amalan. Tunja: Caja Popular/GTZ.
- ICA. 1987. Costos de produccion agropecuarios 1987. Tunja: Oficina Distrital Tunja, Instituto Colombiano Agropecuario.

- Jagnow, G. 1967. Der Humusgehalt tropischer Böden und seine Beeinflussung durch Klima, Bodennutzung, Trocknung und Erhitzung. Professorial thesis, University of Giessen.
- Keyler, S. 1987. Möglichkeiten und Grenzen des institutionalisierten Kredites in Entwicklungsländern am Beispiel der Caja Popular Cooperativa, Kolumbien. Masters thesis (unpublished), Technical University of Munich.
- Moreno Diaz, A. 1985. La extension rural y los principales cultivos der area central de Boyaca. Estudio No. 1. Publicaciones des Proyecto Colombo-Aleman. Tunja: Caja Popular/ GTZ.
- Moreno Dias, A. & Acosta, Gloria N. 1987. Mercadeo de tuberculos y raices. Tunja: Instituto de Educacion Abierta y a Distancia, Universidad Pedagogica y Tecnica de Colombia.
- ORSTOM. 1984. Estudio regional integrado del Altiplano Cundiboyacense. Anexo de uso de suelo. Bogota: ORSTOM/Instituto Geographico "Agustin Codazzi".

VII. Low-cost soil and water conservation measures for smallholders in the Sudano-Saharan zone of Burkina Faso

Helmut Eger¹⁾

1. Introduction

Since the 1950s, significant changes have occurred in the Sudano-Saharan environment of West Africa. Especially the long drought caused degradation of vegetation and soils and an increase of runoff and soil erosion, which led to a lowering of the groundwater table and to microclimatic changes (REIJ 1983, MARCHAL 1983, ALBERGEL et al 1984, BROEKHUYSE 1985, ROOSE 1986).

The drought, together with a high population pressure and profound socioeconomic changes, also caused severe environmental problems in the major part of the study region, the Central Plateau of Burkina Faso (MARCHAL 1983, ROOSE & PIOT 1984). Consequently, sheet and gully erosion on the glacia and silting up of the lower-lying areas occurred.

Already between 1962 and 1965, the Water and Forestry Branch of Yatenga Province in cooperation with the European Group of Soil Restoration (GERES) attempted to overcome this land degradation process with a rather technocratic top-down approach which turned out to be a complete failure (KOTSCHI et al. 1986).

Other organisations and approaches followed in the endeavour to combat the degradation of this fragile environment (PAE 1985, MINOZA et al 1986). Within this framework, an on-farm research

¹⁾ in cooperation with M. Graf, S. Groten, T. Kost, K.H. Schmitt and G. Winckler