SOIL DYNAMICS UNDER TRADITIONAL AND ALTERNATIVE CROPPING SYSTEMS IN THE HIGHLANDS OF NORTHERN THAILAND

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Abstract

The highland agriculture of northern Thailand is in full transition. As the land pressure is rapidly increasing, farmers are forced to reduce the fallow area. (Semi)permanent landuse, combined with the traditional slash and burn techniques, results in a productivity decline. Depletion of nutrients, erosion and increased weed pressure are the main causes.

Five long term experimental fields, where different alternative systems are tested, were studied on their effect on soil quality. Continued traditional monocropping clearly results in a yield decline and soil deterioration. Benched terraces can greatly reduce erosion, but not the fertility decline. Vegetative conservation measures, combined with cereal-legume crop rotation, seems to result in an appropriate soil environment and sustainable yields. Two different types of buffer strips are used: strips with grasses and strips with nitrogen fixing trees. Both systems can be suitable, depending on the physical and socioeconomic conditions.

1. AGRICULTURAL TRANSITION IN THE HIGHLANDS OF NORTHERN THAILAND

1.1 An agricultural bottleneck

About seventy percent of the surface of Nothern Thailand is covered by highlands, which are inhabited by half a million of hilltribe people. The traditional farming system depends mainly on the subsistence oriented cultivation of upland rice and maize, by using slash-and-burn technique. The shifting cultivation system is probably the most optimal way to make use of this marginal sloping land without external inputs.

It is a stable agricultural practice, but needs a fallow area which exceeds several times the actual cultivated area.

During the last decade, the agriculture in the highlands of Northern Thailand is in full transition.

Increased land pressure reduced the fallow area. The ratio between cultivated and fallow land has fallen from 1:10 to less than 1:1 and marginal land has been taken in cultivation in many areas (TG-HDP,1989). Farmers were enforced to adapt a semi-permanent land use system; whereas the cultivation method is basically still the same slash-and-burn technique.

Land pressure is increasing due to different reasons:

- The population in the highlands has significantly increased, because of high population growth rates, and immigration from lowland and neighbouring countries.
- Poppy cultivation used to be a traditional source of cash for many highlanders, either as producers or as hired labour. But this cash inflow is drying up due to increased opium suppression activities conducted by government agencies and the army. These farmers have to look for new cash crops, which are in general more surface consuming. And, if they do not have access to the urban markets, they have to enlarge the area for subsistence farming.
- In the lowlands, floods (followed by periods of drought) and siltation of irrigation constructions, attracted the attention of the policy makers to the protective function of the hill forests for soil and water resources. Consequently, the government has imposed a logging ban throughout the country (February 1989). Meanwhile, reforestation by mainly pine trees is further diminishing the fallow area.

The steep slopes (average range of slopes: 20-50%), which are coming under permanent cultivation, cause considerable soil losses and the short fallow periods are not capable to rebuild the original fertility level. As the natural soil fertility status is quite low and mainly concentrated in the topsoil (0-2-cm), reduced fallow and soil erosion are resulting in yield decline. Long-term sustainability of agriculture on sloping lands becomes impossible in this way.

1.2 Alternative cropping systems for sloping land

Several government agencies, bilateral projects, non-governmental organizations and farmer groups are trying to establish sustainable agriculture, by developing and extending an integrated package of different measures which cope with the (semi) permanent landuse.

The most common soil conservation tools are:

- grass-strips,
- nitrogen-fixing (Nf) tree strips,
- benched terraces,

Which are combined with one or more of the following measures:

- legume-cereal rotation
- integration of legume cover crops
- contour planting
- organic and mineral fertilizers
- zero burning
- minimum tillage
- mulching

2. FIELD TRIALS TO EVALUATE CROPPING SYSTEMS ON STEEP SLOPES

2.1 Sites and treatments

During the 1990 rainy season, the Soil Fertility Conservation Project conducted research at 5 long-term experimental fields, where different soil & crop management packages are evaluated.

- Continuous cropping (CC) of upland rice is the reference treatment (this includes yearly burning, tillage and no fallow). Planting upland rice for 4 or more successive years, is a case of cropping where land is very scarce and permanent agriculture has to be practiced.
- The alternative systems are terraces (Te), strip cropping with grass-strips (GS) and strip cropping with nitrogen-fixing tree strips, also called alley cropping (AC).

Most measures, mentioned in 1.2, are included in the alternative systems. Consequently, only the complete impact of each of the 4 packages could be studied, without identifying the relative importance of each measure separately.

2.2 Features of the experimental fields

The fields are located at:

- Jabo, Tambon Subpong, Mae Hong Son Province
- San Charoen, Amphoe Mae Suay, Chiang Rai Province
  [Conducted by DLD (Department of Land Development, region 6&7) and TG-HDP (Thai-German Highland Development Programme), set up in '87 and '88]
- Lao Che Guay, Amphoe Mae Chan, Chiang Rai Province
- Doi Yao, Amphoe Muang, Chiang Rai Province
- Mae Sawan Noi, Amphoe Mae Sariang, Mae Hong Son Province
  [Conducted by TA_HASDP (Thai-Australian Highland Agricultural and Social Development Project) and Public Welfare (PW), set up in '85 and '86]

The fields have a slope between 30 and 55%, and are situated at altitudes varying from 480 to 1000 meter.

The soils are acid (pH of topsoil: 4.8-5.8) and 4 of the 5 sites are poor in phosphorus (3-10 ppm P with Bray 11 method). They are classified as Acrisol & Alisolin the FAO system, and as Ultisol in Soil Taxonomy (USDA). The Jabo site is particular; as it is situated in a limestone area, the pH is neutral and the soil is classified as an Alfisol (USDA).

2.3 Research approach

In order to assess the sustainability of various management packages on steep slopes, the changes of soil properties were monitored. Different aspects were studied, such as soil fertility, soil biology, soil physics and nutrient losses by erosion. Topsoil samples (0-20cm) for fertility and biomass measurements were taken before the rainy season, before planting (March-April'90). The conclusions will only reflect this stage, although some soil properties will change during the growing season. In this article, an overview of the research results of 1990 is given, combined with some findings of DLD/TG-HDP and TA-HASD/PW. Sampling technic and analyse methods are described in the scientific report of the SFC-Project (SFC, 1991).

3. SOIL DYNAMICS UNDER DIFFERENT SOIL & CROP MANAGEMENTS

3.1 Forest soil

Soils under evergreen forest are in general well stabilized: the nutrient balance is in equilibrium, and soil erosion is limited (Chunkao,1987). This is caused by the permanent soil cover and the typical soil properties.

Compared to the cultivated soils, forest soil shows: (forest only present at Jabo)

- the least compaction in the toplayer (measured by bulk density, fig. 1),

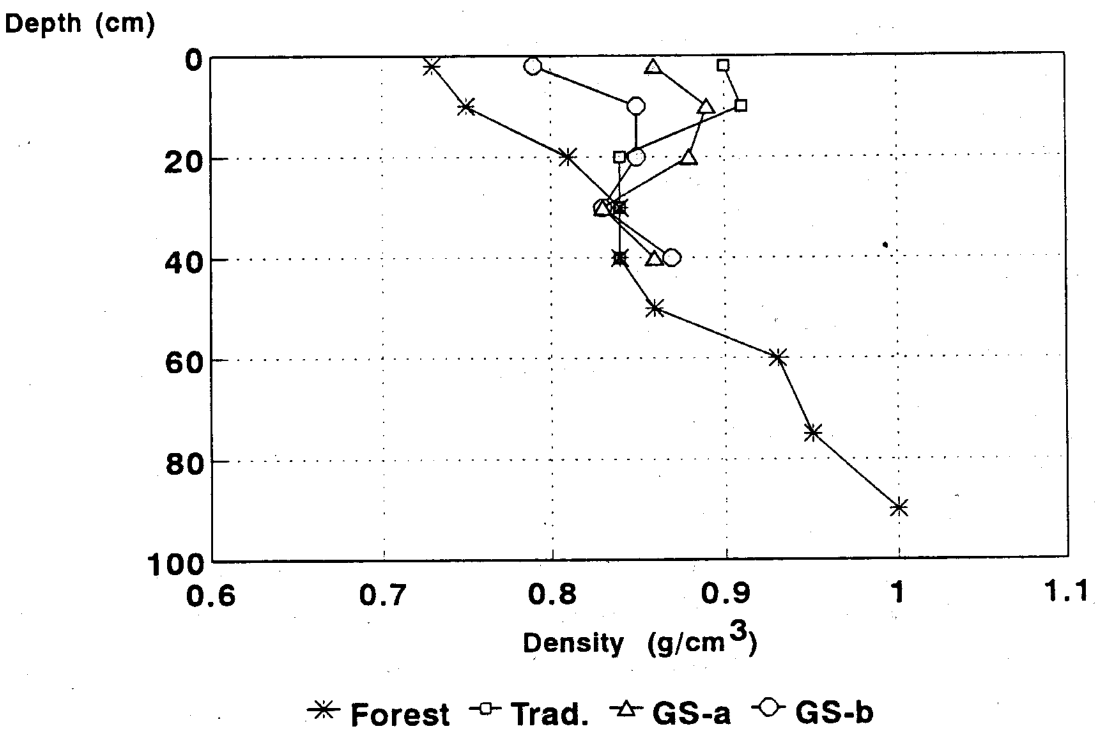

Fig. 1. Bulk density profiles at the experiment station of Jabo.

• a drier subsoil (20-100cm) during the dry season and the first half of the rainy season due to root activity of the trees (fig. 3),

• a higher moisture retention at low tensions (pF curve, fig. 2).

It can be stated, that the forest soil at Jabo is more stable than the cultivated soil, in the sense that it can easier absorb the rain water, that it has more room to store the infiltrating water and that it can retain more water in the macropores. This makes this soil less susceptible for runoff and leaching.

3.2 Soil under continued traditional cultivation of upland rice

Crop yields are satisfying the first years after clearing and burning a forest or old fallow. In a separate study at farmer's fields, Soil properties of forests were compared with 1 to 2 year old upland rice fields at 7 sites in Northern Thailand. An increase of pH, ECEC (Effective Cation Exchange Capacity), available phosphorus, extractable calcium and magnesium was measured at the rice fields, and was attributed to the presence of ash. Soil organic-matter and total nitrogen content decreased. As data have consistently shown that forest burning has little or no immediate effect on the level of humidified soil organic-matter (Kang and Juo,1986), exposure of the topsoil, which induces increased mineralization, and erosion are assumed to be responsible.

Continued traditional cropping however, as shown at the field trials, leads to yield reduction. After a few years, the yield of upland rice was about half of that in the alternative systems (TG-HDP, 1989; Anecksamphant, 1987; Hoey, 1990). A crop unfriendly condition is created by increasing weed pressure and a deterioration of the soil properties:

• In the older field trials (3 to 5 years), the clearest difference between the traditional fields and the buffer strip treatments (GS and AC) was observed in the soil organic-matter (SOM), and the soil microbial biomass (SMB) content (fig. 4). They score 15 to 30% lower in the traditional plots.

Extractable bases and available phosphorus content were not clearly affected, and surprisingly, there was no significant impact of the treatments on the acidity status (pH).

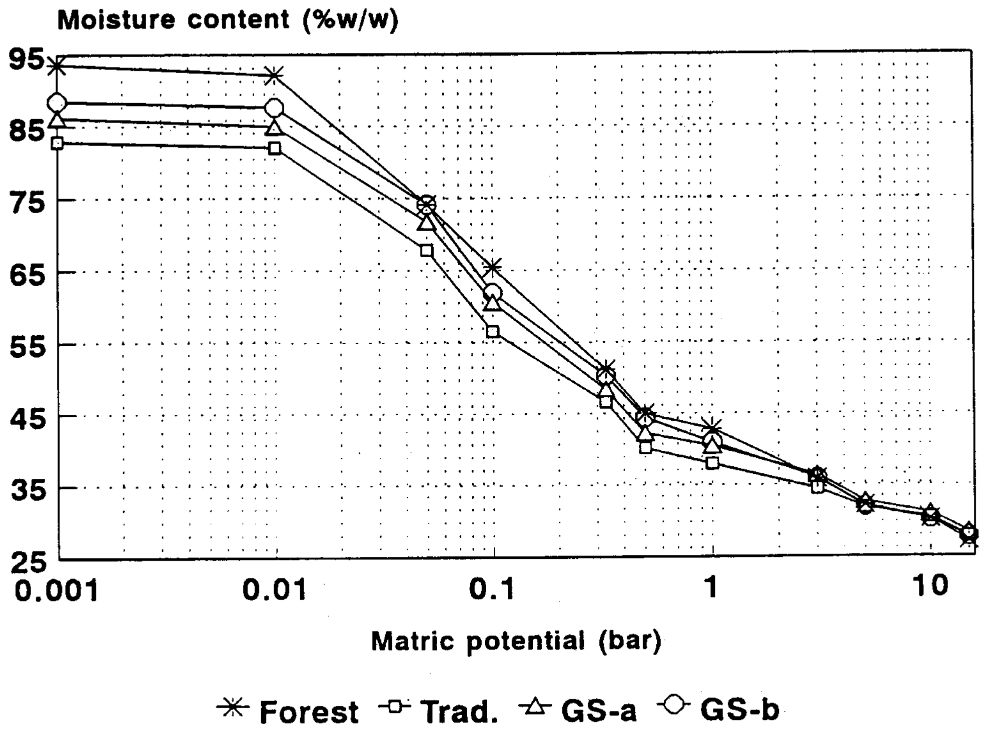

Fig. 2. pF curves of topsoil (0-4 cm) at the experiment station of Jabo, 1990.

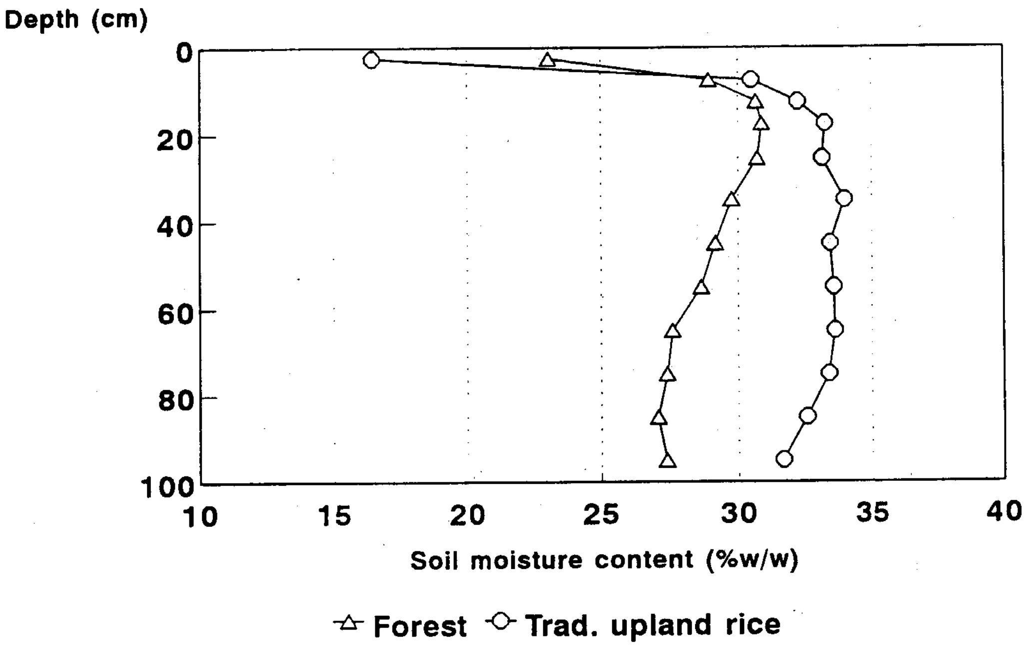

Fig. 3. Soil moisture profile at the experiment station of Jabo, 1990.

• Cultivation results in soil compaction (fig. 1), collapse of the macropores (bigger than 30 pm-fig. 2) and a wetter subsoil (20-100 cm) at the beginning of the rainy season (fig. 3).

Soil loss is high, and varies from 25 to 125 ton/ha/year (2 to 12 mm topsoil, table 1), which far exceeds tolerable rates. Extremes are ranging from 15 kg up to several hundreds ton/ha/year (Inthapan, 1991; Hoey, 1990; IBSRAM, 1990). The reason for this wide variation is probably due to the differences of soil erodibility and rainfall erosivity, as other erosion affecting factors are similar.

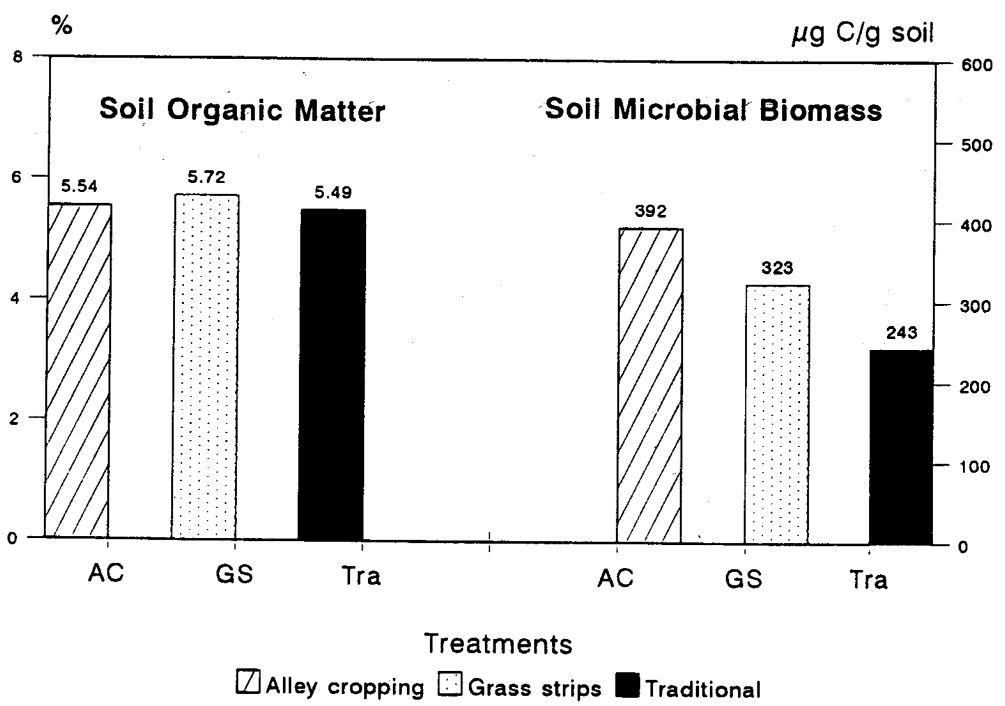

Fig. 4. Soil Organic Matter (SOM) and Soil Microbial Biomass (SMB) under different management systems.

Table 1. Soil loss rates, as measured on field trials in northern Thailand.

Treatment	Soil loss (ton/ha/y)	
	median	lower - upper quartiles
Continued traditional (TRA)	60.00	25 - 125.0
Terraces (Te)	0.12	0.05 - 1.0
Grass-strips (GS)		
* all observations	0.20	0.04 - 5.0
* well established	0.13	0.03 - 1.5
Nf tree strips (AC)		
* all observations	1.50	0.09 - 30.0
* well established	0.20	0.06 - 2.5

Sources : DLD, TG-HDP, TA-HASDP, PW and IBSRAM. (the data are collected from 7 expimental sites, period 1985-1990)

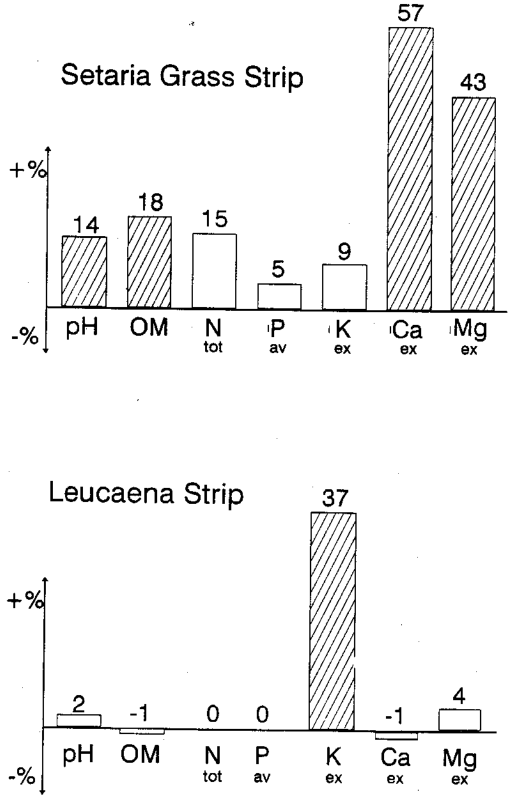

Fig. 5. Accumulation of soil organic matter and nutrients under different buffer strips.

When eroded soil and runoff water are analysed separately, the erosion fraction showed to carry 90 to 95% of the transported nutrients (table 2). Runoff seems to have a substantial contribution for the transport of mineral-nitrogen (NH_4^+, NO_3^-) and potassium only.

The amount of lost nutrients on an average highland soil with a rate of soil loss of 60 ton/ha/year is calculated in table 3. Considerable amounts of nitrogen and phosphorus are lost, although about 1.5% of this amount is available for the plants. If compared with the nutrient removal by rice harvest, phosphours shows to be the most precarious nutrient. The removal of soil organic matter and bases is also significant, but they will affect soil productivity only in the long run.

Also, it should be considered that a part of the "losses" which are gathered in the collection tanks, are accumulating as colluvium at the farmer' fields.

Table 2. Nutrient transport by erosion and runoff at 2 traditional plots with upland rice, 1990.

	Lao Che Guay			Jabo, replicate 3		
Nutrients in erosion fraction (kg/ha)	Erosion	Runoff	% of nutrients	Erosion	Runoff	% of nutrients in erosion fraction
OM	5,435.0	-	-	2,316.0	-	-
Ntot	254.0	-	-	93.0	-	-
Nmin	3.8*	1.00	79%	1.4*	0.08	95%
P (avail)	1.6	0.05	97%	1.7	0.02	99%
K (ex)	49.0	10.59	82%	12.9	3.03	81%
Ca (ex)	202.0	8.48	96%	140.1	7.08	95%
Mg (ex)	53.8	2.63	95%	9.7	0.64	94%
Total Soil Loss (kg/ha)	216,890			32,173		
Total Runoff (m^3/ha)	2,252			524		

- = not measured

* = estimated value, with the assumption that 1.5% of the N(total) fraction is N (mineral)

The total erosion and runoff rates are measured by TA-HASDP and DLD, region 6.

Table 3. Nutrient removals by erosion and harvest in an average highland situaton.

	Average soil properties		Removed by an averge erosion rate (60 ton/ha+runoff)	Removed by an average rice yield (1.5 ton/ha)	Recom-mended fertilizer/ha
	concentration	quantities in top 20cm/ha#			
Organic Matter	4.00 %	96000 kg	2952.0 kg	-	-
N(total)	0.17 %	4080 kg	112.0 kg	-	50 kg
N(available)	*	326 kg	7.5 kg	19.3 kg	-
P(total)	400 ppm	960 kg	28.3 kg	-	20 kg
P(available)	6 ppm	14.4 kg	1.1 kg	3.1 kg	-
K(ex)	190 ppm	456 kg	17.0 kg	6.5 kg	-
Ca(ex)	420 ppm	1008 kg	38.0 kg	0.3 kg	12 kg
Mg(ex)	120 ppm	288 kg	9.0 kg	3.7 kg	-

= a bulk density of 1.2 g/cm^3 is used

* = an accumulated mineralisation rate of 5% per year is assumed

Calculations are based on field research in northern Thailand.

3.3 Soil at Benched Terraces (Te)

Only the not submerged terraces for rainfed cultivation are considered here. They prove to be an effective erosion control measure (reduction over 90% compared to the traditional plot, table 1) (Suebsan,1991; Hoey,1990). Crop yields are however very poor in the initial years, but seem to recover partly. The yield after 4 years is approximately 20 percent less than for the other treatments (GS & AC) at TA-HASD /PW sites(Hoey,1990).

As the top layer has to be removed for the construction of the terraces, soil acidity increases, and soil organic matter (fig. 4), total nitrogen and extractable calcium and magnesium are scoring lower in the new topsoil. The fertility status becomes comparable with a degraded traditional plot.

3.4 Soils under strip cropping with grass strips (GS)

Satisfying yields of upland rice and corn can be achieved continuously in this system (Hoey, 1990; Inthapan, 1991; Suebsan, 1991). This corresponds with the screened soil parameters :

- The most visible measure in this system is the grass buffer strip. Well-established strips can reduce erosion with more than 90%, which corresponds with acceptable erosion rates (Hoey, 1990; Inthapan, 1991). The nutirent losses by erosion and runoff become negligible in this way.
- The soil organic matter & soil microbial biomass (fig. 4), total nitrogen, and the extractable calcium and magnesium content are improved, compared to an equally old traditional plot.
- Minimum tillage and increased organic matter content have helped to reduce the compaction of the toplayer, which is reflected by a lower bulk density.

The used grass varieties are *Setaria anceps* at TA-HASD/PW sites and *Brachiaria ruziziensis* (Congo grass) at DLD/TG-HDP sites.

The grass-strips show gradual terrace formation, cause by sedimentation of soil erosion. Downslope hoeing at farmers' fields mostly increases this effect.

A side effect is an accumulation of soil organic matter, exchangable bases (K,Ca, Mg) in the topsoil under the buffer strips (fig 5.). The effect on long term sustainability might be considered, as crops do not directly benefit from these nutrient.

As grass-strips produce a lot of dry matter (8.4 ton/ha system/year at Jabo, '91), they should be cut regularly (every 1 to 2 months). If the grass used as mulch, its high C/N ratio (31:1) will result in a slow decomposition. A C/N ratio of approximately 20:1 is the dividing line between immobilization and release of nitrogen (Tisdale, 1985). The advantage is that the soil will be covered for a long period.

A valid alternative is to concentrate the grass cuttings at the upper side of the buffer strip as an extra erosion barrier, or use it as animal feed if the transportation distance is limited.

3.5 Soil under strip cropping with nitrogen-fixing (NF) tree strips, or Alley-cropping (AC)

Crop yields (Hoey, 1990: Inthapan, 1991) and soil conditions are similar to the grass system (GS).
However, the soil organic matter & microbial biomass (fig. 4) and total nitrogen content at the topsoil however, score even higher, which improves the expectation of sustainability. The nitrogen-fixing capacity anf the root system, which is able to recycle nutrients at deeper layers, seem to be the only reason to expain the difference.

Leucaena leucocephala, Cajanus cajan (Pigeon Pea) and *Glyricidia sepium* are used in the buffer strips at the experiments. low pH, high altitude and the presence of specific pests limit the area where those Nf trees can be grown successfully.

If NF-strips are well-established, they can be almost as effective for erosion control as the grass-strips (Inthapan, 1991; Hoey, 1990). However, no nutrient accumulation (except K) under the strips was noticed (fig. 5)

The dry matterproduction of the cutting (about 3.8 ton/ha/year at Jabo) is lower than for the grass strips, but the effect of the psyllid leaf hopper attacks is difficult to estimate. The turnover of N however is similar, due to the high nitrogen content of the Leucaena pruning.

The low C/N ratio of the cutting (12:1) causes a quick mineralization, which can be an advantage in soils where the mineral nitrogen content in the soil is critical. At the other hand, as resilt of the quick decompositon, a sharp rise of soil mineral N increases tne risk of leaching losses, and the branches have a limited value as soil cover.

The branches can also be put at the buffer strip as an extra erosion barrier, can serve as fire wood, or can be used as animal feed in limited quantities (e.g. cows diet may be composed of leucaena branches for a maximum of 50 %).

CONCLUSION

Several alternative cropping patterns can be appropriate to attain sustainable agriculture on sloping land, depending on the physical environment and the socio-economical situation.

Shifting cultivation is an ideal method, which makes optimal use of the opportunities of these marginal soils, without external inputs. Increasing land pressure however, is restricting this way of agriculture.

Soils under **permanent traditional cropping** (slash-and-burn) are losing their initial favourable condition by continuous erosion, deterioation of the soil physical structure, and declining soil organic matter lavels.

Benched terraces are an effective erosion control measure, but results in a low topsoil fertility status. They are promising in area of intensive cash crop cultivation, where water is available all year round.

The test alternative systems with buffer strips in experimental conditions seem to be sustainable for (semi)permanent landuse in the highlands of Northern Thailand.

Grass-strips are a reliable way to reduce erosion to acceptable quantities, If they are not burnt. Combined with the other measures, the soil porosity and fertility status of the topsoil improved, compared to an equally old traditional field. The strips produce a lot of dry matter, which integration with livestock is positive. Also situations with high erosion risks, like some cash crops and very steep slopes, should be considered for grass-strip reccommendation.

The advantages of **alley cropping** are similar as for the grass based system, but the system differs by its higher organic matter and biomass content in the topsoil, and its nitrogen rich cuttings. However, when the nitrogen fixing trees establishment is poor, dry matter production is minimal, and erosion control is not effective. Alley cropping is probably more appropriate for areas with subsistence farming with soils poor in nitrogen, on the condition the trees can well establish. Experimenting with new tree species in Northern Thailand is therefore recommended.

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