NATURAL RESOURCES MANAGEMENT ON SLOPING LANDS
A LITERATURE REVIEW

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1. Introduction

1.1. Importance and issues related to mountains

The world's mountainous areas are important for many reasons, including agricultural production, supplying water through streams and rivers and raw materials for industry, and as attractive destinations for ecological tourism. However, if improperly managed, mountainous areas can also cause significant losses through floods, landslides and global climate change.

A large number of the world's poor, around 770million people, live in mountainous areas. Many of these people are currently unable to achieve food and nutrition security. Agricultural development alone cannot solve this problem. The development of water and forest resources, off-farm income, ecotourism, and other income-generating activities are needed.

There are two approaches to improving the sustainability of mountains:

- The first approach is concerning traditional cultures, emphasising *local* sustainability. This approach supports the diversified utilization of resources for subsistence only.
- The second approach is concerning the sustainable systems that connect mountain and lowland areas. This approach works to guarantee the sustainability of environmental services for lowland people, while the rights of mountainous people are still guaranteed (Dao The Tuan, 2003).

1.2. Current use of sloping land in Vietnam

Mountainous and hilly lands (sloping lands) constitute 3/4 of the natural inland territory of Vietnam. In general, sloping lands are not favourable for agricultural production, especially those stripped of vegetation. Available data show that in the 1940s the forest cover in Vietnam was 43%, and reduced to 25% in the 1980s. Nowadays, through concerted efforts by the Vietnamese people, plus significant reforestation support from international communities, the forest cover reached 38% in 2008.

Sloping lands are present in all 9 ecological regions of Vietnam, but mostly in the Northern Mountainous, Central and Tay Nguyen regions. Most of the gentle slopes (less than 15°), accounting for 21.9%, have already been used for agricultural and forestry production. The lands with 16° to 25° slopes occupy 16.4%. The remaining 61.7% are very steep (Table 1). Due to the lack of alternative land, mountainous farmers have to cultivate food crops on these very steep slopes of more than 25°. On such slopes, soil erosion occurs rapidly, so the period of productivity is brief, commonly only 2 or 3 seasons of short cycle crops, followed by cassava, which is planted as the last crop of a cultivation cycle.

Slopes (Degree)	Area (1000 ha)	%
<15	5,533.03	21.9
16-25	4,143.46	16.4
> 25	15,588.51	61.7
Total	25,265.00	100.0

Table 1 Sloping land patterns based on degree of slopes

According to Thai Phien and Nguyen Tu Siem (2002), Vietnam is using about 14 million ha of sloping lands for agriculture and forestry production.

Of this sloping land, about 43% of land used for agriculture is on steep slopes (Table 2), where soil erosion is intensive.

Slope category (degrees)	Area (mil. ha)	Proportion of total used land (%)
3 - 10	2.7	18.8
11 - 15	5.5	38.2
16-25	3.7	25.7
> 25	2.5	17.4
Total	14.4	100.0

Table 2 Used sloping land patterns based on degree of slopes

Due to population pressure, fallow periods are commonly reduced from more than 25 years to 5, and sometimes 3 years, which are not long enough for rejuvenation of soil fertility. The overall outcome is very low crop yields. Most of the gentle slopes have gone through many crop-fallow cycles, so the soil fertility has been chronically reduced. On these gentle slopes, in addition to poor nutrition, the constraints to crops include soil toxicity and soil compaction. 'Spent' slopes are left as bare hills or with very low levels of vegetation. In 2000, unused mountainous land made up 95% of the country's unused land. The total area of unused land in Vietnam, mostly bare hills reached 10.03 million hectares in 2003 and reduced to 4.73 million hectares in 2008 (Table 3). This was, mainly as a result of extensive investment of the Government in reforestation. Agricultural activities on bare hills and other lands have been ineffective for regeneration so not encouraged.

Land use type	Whole country (1000ha)		Mountainous Regions (1000ha)	Mountainous Regions (% of country)
	2000	2008	2000	2000
Total land area	**32,956.0**	**33,115.0**	**27,474.0**	**83.37**
1. Agricultural land	9,345.40	9,420.3	5,517.6	59.04
1.1. Annual crop land	6,129.5	6,309.6		
- *Rice area*	4,267.9	4,105.8		
- *Sloping land rice field area*	644.4	80.0		
- *Other short cycle crops*	1,217.2	2,123.8		
1.2. Perennial crops/trees	2,181.9	3,110.7		
1.3. Grassland for livestock	37.6	56.1		
1.4. Water surface for aqua-culture	367.9	7,28.6		
2. Forest land	11,575.4	14,816.6	11,118.6	96.05
Productive forest		6,259.6		
Protective forest		6,565.3		
Specially used forest		1,991.7		
3. Special use land	1,532.8	1,553.7	1,076.3	70.22
4. Living land	443.2	620.4	250.7	56.57
5. Unused land	10,027.0	**4,732.1**	9,510.8	94.85

Table 3 Available data on Land use in Vietnam in 2000 and 2008 Land in mountainous regions has a much lower utilization rate than the rest of the country.

Source: General Department of Statistics 2000-2008 and Decision No. 1682/QD-BTNMT dated August 26th 2008 of Minister of Natural Resources and Environment.

1.3. Classifying mountainous lands

Mountainous lands, with their great variability, can and should be categorized in many ways beyond 'degree of slope.' Below are some data supporting categorization into ecological zones, soil groups, tendency for erosion, thickness of soil layer, soil fertility,

Ecological zones

Sloping lands encompass those on the hill sides, in the highland plateau, or on the sides of low and high mountains in the 9 agro-ecological regions all over our country. However, in the Red and Mekong Rivers' deltas, the area of sloping land is negligible, so research should be focused on the other 7 regions. These regions have a total area of 27.7968 million ha, of which 366 thousand hectares are rocky mountains. Rivers, streams, ponds and lakes occupy 93.7 thousand hectares and the real, 'useable' land areas occupy 27.3371 million hectares (Table 4).

Land type	Area (1000 ha)	%
Rocky mountain	366.0	1.3
Water surface	93.7	0.3
Useable lands	27,337.1	98.4
Total area	27,796.8	100.0

Table 4 Land area in 7 ecological regions (Except the Red and Mekong Rivers' Deltas)

Soil groups

There are 13 soil groups (see Table 5):

i. Sandy soil
ii. Saline soil
iii. Acid sulphate soil
iv. Alluvial soil
v. Gley and peat soils
vi. Grey eroded soil
vii. Brown-grey semi-arid soil
viii. Black soil
ix. Yellow-red soil
x. Humus yellow-red soil (in mountains)
xi. Alit humus soil (in high mountains)
xii. Sediment sloping soil
xiii. Eroded soil exposing gravels and stones

Among the 13 soil groups, the yellow-red soils, found lower than 900m elevation, occupy the largest area (17.346 million hectares or 63.5% of sloping lands in Vietnam). This is followed by the humus yellow-red soil at 900-1800m elevation, occupying 3.484 million hectares or 12.7%. The rest of the yellow-red soil is found at 1800-2000m, occupying 187.5 thousand hectares or 0.6%.

Grey degraded (eroded) soil occupies 1.887 million hectares or 6.9% of sloping lands. The sediment soils cover 339.1 thousand hectares or 1.2%. The group of severely eroded soils, with exposed stones and gravel occupies 285.1 thousand hectares or 1.0%.

Table 5 Area of main soil groups in Vietnam (1000 ha)

Soil groups	Total	Ratio (%)	Northern mountainous regions			Red River Delta	North central coast	South central coast	Tay Nguyen	East of the South	Cuu Long River Delta
			Northwest	Hoang Lien Son	Northeast						
1. Sandy soil	547.1	1.7		0.5	5.9	15.7	187.8	264.2		28.2	44.8
2. Saline soil	959.7	2.9			50.3	101.3	46.2	50.0		2.5	709.4
3. Acid sulphate soil	1,826.4	5.5			5.0	52.9	42.1	7.6		176.4	1,542.4
4. Alluvial soil	3,522.3	10.7	23.5	149.6	158.9	790.7	555.6	375.5	174.8	98.5	1,195.2
5. Gley and peat soils	52.1	0.2	0.6	1.7	17.1	2.5	1.4		4.8		24.0
6. Grey color eroded soil	2,066.2	6.3		39.2	59.0	44.8	45.5	430.3	527.6	785.1	134.7
7. Brown gray semi-arid soil	39.7	0.1						39.7			
8. Black soil	344.1	1.0	5.9	1.4	5.5	2.9	11.8	22.1	136.5	158.0	
9. Yellow-red soil	17,534.0	53.1	2,118.1	2,139.6	2,486.7	105.2	3,319.1	2,717.8	3,623.2	941.1	83.2
10. Humus yellow red soil in mountains	3,483.8	10.5	1,167.8	659.7	140.4	0.3	352.6	276.0	887.0		
11. Alit hummus soil in high mountains	187.5	0.6	78.7	89.4			4.7	45.7	14.7		
12. Sediment sloping soil	351.2	1.1	7.1	23.2	43.2	12.1	98.1	46.9	74.3	47.5	
13. Eroded soil exposing gravels and stones	302.5	0.9		1.9	48.0	8.6	137.5		38.2	12.6	8.8
Total land area	**32,216.6**	**94.5**	**3,401.7**	**3,401.2**	**3,020.0**	**1,137.0**	**4,802.4**	**4,275.8**	**5,481.1**	**2,249.9**	**3,742.5**
Rocky mountains	1,029.2	3.1	147.0	158.7	302.1	62.2	232.3	67.2	41.4	17.3	1.0
Rivers, streams, ponds, lakes	782.6	2.4	25.9	78.0	15.3	67.1	95.7	78.8	55.8	84.2	221.8
Total natural land area	**33,028.4**	**100**	**3,574.6**	**3,342.9**	**3,397.4**						
			10,314.9			**1,266.3**	**5,130.4**	**4,421.8**	**5,578.3**	**2,351.4**	**3,965.3**

Source: National Institute of Agricultural Planning and Projection

Tendency for erosion

Sloped lands can be classified in five erosion categories, with soil loss varying from 50 to more than 500 T/ha/year (Table 6).

N°	Region	Characteristics	Possible soil loss (T/ha/year)
1	Midlands, low mountains	Rainfall: 2000-2400 mm/year; Slopes: 3-15 degrees; Main crops: food, fruits, industrial; Soil cover: 20-40%.	50-100
2	Northern mountains and the like	Rainfall: 1500-2000 mm/year; Slopes: 15-25 degrees; Main crops: food, fruits, perennial; natural forests; Soil cover: 20-40%.	100-200
3	Northwest and the like	Rainfall: 2400-2800 mm/year; Slopes: 20-40 degrees; Main crops: food, fruits, perennial; natural forests; Soil cover: 20-40%.	200-300
4	A part of the North, Truong Son, Mong Cai, East of Tay Nguyen	Rainfall: 2400-2800 mm/year; Slopes: 40-45 degrees; Main crops: almost no forest; Soil cover: 1-20%.	300-500
5	Locations with high rainfall (Bac Quang, West Hue, Ba To and Tra Mi)	Rainfall: 3200-4500 mm/year; Slopes: > 25 degrees;	>500

Table 6 Erosion sensitive regions in Northern mountainous regions of Vietnam

Thickness of soil layer

The mountainous and hilly lands generally don't have a thick soil layer, except those developed from basal stone. The sloping lands can be divided into three soil thickness groups, as shown on Table 7.

Soil thickness (cm)	Area (1000 ha)	%
> 100	7,680.56	30.4
50-100	8,059.54	31.9
<50	9,524.91	37.7
Total	25,265.00	100.0

Table 7 Sloping land patterns based on thickness of soil layer

Soil fertility

The soil of Vietnam's 7 agro-ecological regions may be divided into five fertility grades (Table 8).

Grade	Number of land units	Area (1000 ha)	%
Grade 2 - High fertility (from yellow-red soils on clay stone, degraded stone and red brown soils on basal and lime stones).	195	3,336.00	13.4

Grade 3 - Medium soil fertility	98	1,608.00	6.5
Grade 4 - Low soil fertility	47	909.90	3.7
Grade 5 - very low soil fertility (high slopes and high erosion rates)	112	2,070.00	8.3
Grade 6 very low soil fertility (very high slopes and very high erosion rates)	252	16,940.00	68.1
Total		25,265.00	100.0

Table 8 Sloping land patterns based on soil fertility Values are based on total sloping land area of 25.265 million hectares, with 614 land units across Vietnam

Land use

In 2003, the whole country used 9.35 million hectares for agriculture, accounting for 28.4% of total natural land area. There was a slight increase to 9.42 million ha in 2008. Meanwhile, the forested lands increased from 11.58 million hectares in 2003 to 14.82 million ha in 2008. Lands used for living occupied 0.44 million to 0.62 million hectares in 2003 and 2008, respectively.

The mountainous land use patterns in 2003 were:

- 5.518 million hectares for agriculture (59.04% of the country's agricultural lands)
- 11.119 million hectares for forests (96.05% of total mountainous lands)
- 250.7 thousand hectares for living (56.98% of total land occupied for living)

It is notable that up to 94.85% of unused lands or 9.511 million hectares are located in mountainous regions.

Since 1990 when unused lands constituted 14.925 million hectares, the number has reduced by an average of 4.898 million hectares each year. This dramatic decrease was due to reforestation and development of agriculture. Regarding agricultural lands, there is a tremendous change from low yielding annual crops to perennial crops/trees like coffee, rubber, tea and fruit trees. According to the Department of Cadastral Management, perennial crops occupied 1.05 million hectares in 1990. In 2000, this number increased by 2.1 times (2.18 million ha), and almost 3 times by 2008 (3.11 million ha). This is a positive trend as most perennial crops/trees are planted for commercial purpose and it occurs mainly in mountainous regions.

A land use evaluation determined that Vietnam has 15 main land uses, distributed in 388 land use units. To ensure agricultural development oriented on intensive farming, crop diversification and income increase for farmers, 6 major land use types were selected for further development (see 'Land use adaptation' below). Constituting 169 land use units, the land-use types selected for further development were: rice land, secondary crops and short cycle industrial crops/trees, perennial crops/trees, grass land, agro-forestry and aqua-culture.

Land use adaptation

Some lower lands have been marked for adaptation:

- 4.35 million hectares adapted to rice cultivation mainly in alluvial flat lands, including saline, acid sulphate, sandy and grey ones,
- 1.656 million hectares for dry land crops like sugar cane, legumes, maize, etc, mainly planted in sandy, acid sulphate, saline and gray lands in higher elevation and
- 448.4 thousand hectares for aquatic culture distributed in saline, acid sulphate, alluvial lands in the deltas from 10 million hectares

The rest of the area marked for land use adaptation, including highlands is:

- 2.457 million hectares for perennial crops/trees distributed in gray and red yellow lands in higher elevation
- 783.3 thousand hectares mainly of red yellow lands in sloping areas are projected for forest trees or agro-forestry.

An assessment of land adaptation in 7 agro-ecological regions showed that:

(a) Perennial industrial crops/trees have largest area of adaptation on sloping lands but at three levels (i) high adaptation, (ii) medium adaptation and (iii) low adaptation covering 14.568 million hectares, concentrated mainly in Tay Nguyen and East of the South with the areas of 5.6 and 4.24 million hectares, respectively, followed by South and North Central coastal regions, then Northernmost (Hoang Lien Son), Northeast and Northwest with the respective areas of 1.87; 1.48; 0.72; 0.44 and 0.22 million hectares.

(b) Coffee and black pepper have the largest adapted areas in Tay Nguyen and East of the Southern part with respective areas of 0.978 and 0.827 million hectares, followed by North and South Central coastal regions with 0.32 and 0.17 million hectares, respectively. Three Northern agro-ecological regions (Northwest, Northernmost - Hoang Lien Son and Northeast) have adapted lands for coffee and pepper of about 30 to 40 thousands hectares. For rubber trees, the most adapted lands are also located in Tay Nguyen and East of the South with the respective areas of 1.29 and 1.39 million hectares, followed by North and South Central coastal regions with 0.58 and 0.69 million hectares, respectively. Cashew nut is also an important market crop adapted to Tay Nguyen and East of the South with the areas of 1.91 and 2.02 million hectares, respectively, followed by South Central coastal regions with the areas 1.01 million hectares. Tea has the adapted areas of 3.04 million hectares mostly concentrated in Tay Nguyen, Northernmost - Hoang Lien Son, North-central coast, Northwest and Northeast with 1.42; 0.585; 0.578 and 0.174 million ha, respectively.

(c) Cultivation of dry land crops and short cycle industrial crops, 7.08 million hectares. Land adapted for dry land crops and short cycle industrial crops are concentrated in 3 regions: South Central coastal regions, Tay Nguyen and East of the South with the respective areas of 2.88; 1.58 and 2.00 million hectares.

(d) Fruit trees cover 7.04 million hectares of land. Land adapted for fruit trees is concentrated in 4 regions: Northernmost - Hoang Lien Son, Northeast, Tay Nguyen and East of the South with the respective areas of 1.41; 1.34; 1.45 and 1.40 million hectares.

Based on soil adaptation assessment combined with socio-economic factors like food security demands, physiological and ecological requirement of crops, capacity in running and managing production, demands for environment protection, market access, economic efficiency and investment capacities, it is possible to suggest some principles for arrangement of land use in 7 regions as follows:

- **Irrigated rice:** The main requirement is to have available water for irrigation or an average of 200 mm rainfall per month. So, in the areas where there is no water for irrigation, the rainfall must be high enough for cultivation of two rice crops per year. It is necessary to exploit mostly black and gray soils which are irrigation capable, to produce two rice crops per year, ensuring food security.

- **Dry land crops:** Have a lower water requirement and can be cultivated even if half of the high rainfall is evaporated. Cultivation of short cycle dry land crops should be conducted only on land of less than 8° slopes, concentrating on dark brown, grey and partly red basal or red yellow soils.
- **High value crops:** Priority should be given to high economic value crops/trees like coffee, rubber, fruit trees or species for processing like sugar cane, tobacco in localities where processing factories already exists.
- **Forestry:** Sloping with thin soil layer lands should be used for forestry combined with animal husbandry under the forest canopy. Rigorous protection of existing forests, especially the rich, fully shaded and evergreen ones. If necessary, only degraded forests can be exploited for agricultural production.
- **Long cycle industrial crops:** Recommended for considerably large areas (1.679 million hectares) in 7 regions, in which Tay Nguyen and East of the South are the main producers. Rubber is suggested to grow largest in the East of the South, followed by South and North Central coastal regions. Cashew nut is proposed to be developed in 0.45 million hectares, largest in East of the South (0.26) and South Central coastal regions (0.15 million hectares). The area for coffee is largest in Tay Nguyen (0.3 million hectares). It is also recommended to grow in the North with Catimor type.
- **Fruit trees**: Proposed for all 7 regions with a total area of 0.483 million hectares, the largest is East of the South (0.26), followed by South Central coastal regions (0.15 million hectares). The other areas belong to North Central coastal regions and Northwest.

2. General assessment of land use and land use change in Vietnam in recent years

Examining the period from 2000 to 2008 only, the following trends are seen:

- Total area for annual crops remains almost the same between 2000 and 2008; the increase was only 0.7% for 8 years.
- Irrigated rice area was reduced from 2000 to 2008 (by 4% in 8 years or 0.5%/year).
- Upland rice area was reduced also sharply (by 8.8%/year).
- Other annual crops' area was increased (by 9.4%/year).
- Perennial crops/trees area increased sharply (by 5.3%/year).
- Afforestation occurred at a considerable rate (3.5%/year).
- Lands for aquaculture were also extended sharply (by 12%/year).
- Unused lands were consequently reduced (by 26%/year).

The above summary shows positive trends in changing land use patterns towards greater sustainability, especially the fast increase in perennial crops/trees and forested lands.
The increased area of 'other annual crops' may be due to the increase in the area of sloping land maize cultivation (Table 9).

Year	1994	2000	2005	2007	2007/1994 (%)	Annual increase rate (%)
Area (1000 ha)	534,6	730,2	1052,6	1072,8	201	7.8
Yield (T/ha)	21,4	25,1	36,0	39,6	185	6.5
Production (1000 T	1143,9	2005,9	3787,1	4250,9	376	21.2

Table 9 Maize production in Vietnam in 1994 – 2007
Source: General Department of Statistics, MARD, 2007.

It is clear that the area of sloping land maize cultivation increased very sharply (by 7.8% annually). This is, on one hand, a good sign of commercial production of maize. In fact, a large number of upland farmers have become rich from maize cultivation. On the other hand, however, this causes a lot of problems threatening the sustainability of maize based cropping systems, mainly due to severe soil erosion on maize fields.

Poverty, food insecurity and environmental degradation are common problems in mountainous regions. In the past, the traditional cultivation methods were comparatively simple but suitable to the contemporary natural and social conditions in the regions. Recently, due to population pressure, farmers started to apply new cultivation techniques exploiting more natural resources, hoping to produce more products. However, little has been done to conserve and improved the soil fertility. This has lead to exhaustion of natural resources, especially to severe land degradation, water scarcity and biodiversity. As a result, the farmers' living standards remain low.

3. Soil erosion and land degradation in mountainous regions

3.1. Main cause of soil erosion and land degradation:

There is still a common belief that surface runoff is the most important reason for soil degradation because it takes away soil particles with their nutrition, which could otherwise supply crops. However, it is the kinetic energy of raindrops that plays the most important role in accelerating soil erosion. The raindrops, striking bare soil, cause detachment of soil particles (Greenland 1989; Lal 1989), and then these particles are washed off by the rain water. Therefore, the more the sloping lands are well prepared (made bare), the less protected they are from this kinetic energy and the more severe and rapid the soil degradation. Additionally, surface runoff is accelerated due to forest destruction, over grazing and over cultivation, which eliminate the soil vegetal cover. All these eventually lead to low productivity of lands because of the loss of organic matter, mineral nutrition, water-holding capacity, soil porosity and biological activities. Severe soil erosion leads to low productivity or harvest failure. Ultimately, plants cannot grow on degraded soils, and they become bare lands.

So the root causes of soil erosion and land degradation are the denudation of the soil (removal of vegetation) and excessive soil disturbance before sowing.

3.2. Main factors influencing soil erosion:

- Nature of rains: intensity, size of rain drops and raining time;
- Soil types and properties;
- Cultivation techniques;
- Structures of topography and landscapes.

3.3. Mechanisms governing soil erosion:

- Ability to detach the soil particles: kinetic energy of rain drops and degree of soil protection are important factors affecting soil erosion;
- When detached, the soil particles move with rain water and fill up all air spaces in the soil, sealing the soil surface, hence preventing water penetration into the soil. This, in turn, increases the surface run-off, thus contributing to more soil erosion and less ability to capture and store the rain water in the soil.
- Once in the erosion spiral, the adjustment of cultivation technologies and cropping patterns are necessary to manage and control the soil erosion.

3.4. Equation to estimate soil erosion:

$$A = R \times K \times L \times S \times C \times P$$

where:

- A - The soil loss due to erosion,
- R - Rain properties,
- K - The erosion sensitivity of the soil,
- L - Slope length,
- S - Slope degree,
- C - Crop management factors,
- P - Other erosion management factors.

Interventions can be applied to five of the six factors, to reduce the soil erosion. Of course, rain properties cannot be changed, but one can take measures to mitigate or even eliminate the effects of rainfall on soil erosion.

3.5. Most important constraints to sloping land agriculture:

Soil erosion: The danger of soil erosion is equally very high in all seven regions of Vietnam. In the Northeast, quite a large proportion (17.7%) of sloping lands are less than 15° (grade 1). In the Northernmost regions - Hoang Lien Son and Northwest, only 4 - 8% are low in slope. Therefore, the northernmost region has a high rate of erosion. About 2/3 of the natural areas in the Northeast have been cleared of forests and savannas and bare lands/hills remain. In Hoang Lien Son, more than 40% of the red-yellow soils on clay and degraded rocky soils are bare, with no vegetal cover, so they are severely eroded. In the North Central coastal regions, 13% of lands are severely eroded and 79% are over-eroded. The respective proportions in South Central coastal regions are 14 and 70%. The most endangered areas are those located in the low mountains, the transition between higher mountains to the coastal plains, because they are under very intensive exploitation for cultivation of short cycle dry land crops. Tay Nguyen (Central Highlands Region) has only 7.8% of sloping lands of less than 3°, the rest are at risk of extensive erosion. However, thanks to high vegetal coverage, the erosion rate there is lower than in other Regions. Only 25% of land in the East of the South has forest cover, and the situation is worsening; Young forest regeneration is weak and the bamboo reserves are poor. As forest resources are rapidly reduced, the consequent danger of erosion is increasing.

Steep slopes: The constraints caused by steep slopes in the Northeast Region of Vietnam can be divided as into three groups, according to degree of limitation (Table 10).

Region	**Slight** Grade 1 (< 15° slope)	**Medium** Grade 2 (15-25° slope)	**Strong** Grade 3 (>25° slope)
Northeast	17.68	13.55	68.67
Hoang Lien Son	8.59	10.71	80.7
Northwest	4.46	8.09	87.45
North Central Coast	13.48	8.81	72.9
South-Central Coast	12.29	18.23	69.48
Tay Nguyen	10.94	42.67	46.39
Southeast	76.02	13.71	10.27

Table 10 Proportion (%) of total land subjected to degrees of constraint due to land slope Land areas with lower grades of slope experience lower levels of slope-associated limitation. The northwest Region has the greatest percentage of land under strong slope-associated limitation, and the Southeast has the least.

Shallow soil depth: The Northeast has the largest proportion of land with shallowest soil depth; The Southeast has the greatest proportion of land with the deepest category of soil (Table 11).

Soil depth	North west	Hoang Lien Son	North east	North central coast	South central coast	Tay Nguyen	Southeast	Average
>100 cm	25.25	57.32	23.28	54.78	28.76	23.92	73.09	40.96
50-100 cm	48.21	32.29	28.67	25.93	45.55	70.36	8.47	37.17
<50 cm	26.25	9.39	48.05	19.29	25.69	5.71	18.45	21.87

Table 11 Distribution (% / local area) soil depth in agro-ecological regions

Rainfall: As previously discussed, kinetic energy from rainfall is a major cause of erosion, thus in the context of land quality, low rainfall presents low limitation, medium rainfall, medium and high, high.

Among the three Northern regions, the Northernmost, Hoang Lien Son has the highest proportion of sloping land with the highest category (more than 2000 mm) of annual rainfall, accounting for 78.39%; 19.55% of sloping land in this region has the medium (1500-2000mm) rain and 2.02% of Hoang Lien Son's land falls in the lowest category (less than 1500 mm) of rainfall.
The Northwest and Northeast Regions are similar, with respective proportions of sloping land in each rainfall category (high, medium, low) of 15.82, 51.18 and 33.00%, and 15.63, 50.27 and 34.10%.
In the Northcentral coast, 76.18% of sloping land receives the lowest category of rainfall, 9.43% has medium rainfall.
In valleys with limited wind, the rainfall is generally low and the rain periods are also characterised by the West dry and hot wind causing strong evaporation that severely influence the crop growth and development. In the valley of Muong Xen, the rainfall is very low (700-1000 mm) with 4-5 months of dry season. In the South-central coast, low rainfall covers 29.91%, medium, 16.75%, and high, 5.03% of the sloping land areas.

With the exception of the west mountain ranges where the rainfall is relatively high and the dry season is short, most sloping areas have a long dry season. Ninh Thuan Region has an exceptionally low rainfall of 700 – 1000 mm and a 4-5month dry season. Tay Nguyen has the respective values of 10.94, 72.17, and 11.94% of sloping land in each of the high, medium and low rainfall categories. In the Southeast Region, the second grade rainfall (1500-1800) spreads over 81.36% of sloping land has 1500-1800 (medium) rainfall, and 4.64% has low rainfall (less than 1500 mm).

Soil toxicity: In general, increasing soil acidity is common for all 7 regions. This is the consequence of soil erosion causing the loss of basic metals and concurrent accumulation of aluminum and iron, which are toxic for soil. Low water holding capacity, a low ratio of stable soil aggregates, low cation exchange capacity (CEC), low basic saturation, high phosphorus absorption capacity, fast wash off of ions like NH_4^+, K^+, Na^+, Ca^{++}, Mg^{++}, etc. are general features of soil toxicity.

Production activities: Thai Phien and Nguyen Tu Siem (2002) indicated that the most important factor contributing to land degradation is human activity. However, human activity is also the decisive factor to improve the soil fertility and productivity if properly managed. On sloping lands, the mono-cropping of rice and cassava causes severe decrease in soil fertility. Similarly, the mono-culture of eucalyptus may cause severe degradation of soils.

Lack of laws surrounding sloping land use: Research in sloping land cultivation has received attention for many years, but the approach has not been systematic and the results obtained lack consistency. More importantly, there has not been long-term research on soil erosion, land runoff and land degradation and how the loss of productivity can be monitored. Vietnamese farmers have vast experience in irrigated rice production, but lack of experience in upland agricultural cultivation. The 1980 levels of more than 10 million hectares of bare land and more than 1 million hectares of severely eroded land exposing gravel and stones were the unavoidable consequence of careless cultivation and the lack of laws surrounding land resource protection.

4. Measures for soil fertility protection and improvement

To establish sustainable agricultural systems, the most important principle is rational use of land. An orientation towards intensification and efficiency needs to be coupled with protection and enrichment of soil fertility. In other words, sustainable agriculture needs integrated cultivation technologies combined with natural resources management.

4.1. Main principles of sustainable management of sloping land resources:

- *Retaining the soil cover as much as possible*
- *Disturbing the soil as little as possible*
- *Cutting the slope length at suitable intervals* - Dividing the slope lands into horizontal bands based on degree of slope:
  - (a) Making terraces on gentle slopes
  - (b) Making mini-terraces on steep slopes (say of more than 25°
  - (c) Planting hedgerows across the slopes, using suitable plant species
- *Rational arrangement of cropping systems:*
  - *(a)* Protection of the forest on the top, enrichment planting, prohibition of slash-and-burn, and forest planting in open places (For slopes of more than 25°)
  - (b) Development of different forestry, agro-forestry or agricultural systems depending on soil fertility, socio-economic and ecological conditions (For slopes of less than 25°).

4.2. Rational land use based on soil fertility and adaptation

Taking into consideration the potential of different plant species for adaptation, the following land use patterns are proposed (Table 12).

Land use type	Unit	**Total in 7 regions**	North west	Hoang Lien Son	North east	North central coast	South central coast	Tay Nguyen	East of the South
Two rice crops	Ha %	**323,991** **1.28**		24,437 0.58	59,554 2.17		130,000 3.56	60,000 1.17	50,000 2.48
Rice + Secondary crops	Ha %	**261,014** **1.03**		56,364 1.33	34,240 1.25	80,410 1.96			90,000 4.46
Cash crops and Industrial trees	Ha %	**1,274,196** **5.04**	116,741 3.44	59,402 1.40	60,053 2.19	200,700 4.89	281,300 7.71	150,000 2.93	406,000 20.11
Fruit trees	Ha %	**482,700** **1.91**	73,670 2.17	18,530 0.44	23,500 0.86	105,000 2.56	70,000 1.92	55,000 1.07	137,000 6.79
Long cycle trees	Ha %	**1,712,600** **6.78**	29,600 0.87	86,000 2.03	29,000 1.06	110,030 2.68	192,830 5.29	627,100 12.24	638,040 31.60
- Coffee	*Ha* *%*	***449,000*** ***1.64***	*19,000* *0.56*	*26,000* *0.61*	*15,000* *0.55*	*26,000* *0.63*	*14,000* *0.38*	*300,000* *5.86*	*49,000* *2.43*
- Pepper	*Ha* *%*	***49.000*** ***0.19***				*3,030* *0.07*	*4,830* *0.13*	*12,100* *0.24*	*29,040* *1.44*
- Tea	*Ha* *%*	***90,600*** ***0.36***	*10,600* *0.31*	*30,000* *0.71*	*14,000* *0.51*	*9,000* *0.22*	*2,000* *0.05*	*25,000* *0.49*	
- Rubber	*Ha* *%*	***644,000*** ***2.25***				*72,000* *1.76*	*22,000* *0.60*	*250,000* *4.88*	*300,000* *14.86*
- Cashew nut	*Ha* *%*	***450,000*** ***1.78***					*150,000* *4.11*	*40,000* *0.78*	*260,000* *12.88*
- Specialty trees	*Ha* *%*	***30,000*** ***0.12***		*30,000* *0.71*					
Pasture	Ha %	**336,710** **1.33**	70,855 2.09	50,340 1.19	25,515 0.93	80,000 1.95	40,000 1.10	70,000 1.37	
Total of used lands	**Ha** **%**	**4,391,211** ***17.38***	**290,866** ***8.58***	**295,073** ***6.95***	**231,862** ***8.46***	**576,140** ***14.05***	**714,130** ***19.58***	**962,100** ***18.78***	**1,321,040** ***65.44***
Total of sloping lands	Ha %	**25264924**	3389929	4242812	2740822	4101434	3647955	5123130	2018482

Table 12 Proposed land uses in 7 agro-ecological regions Suggestions take potential for adaptation into account.

4.3. Wise selection of farming systems:

Selection of farming systems is dependent on lands and soils, topography, socio-economic conditions, customs and traditions and household economy. Different systems are available on offer including:

+ Agriculture (SALT 1),
+ Agro-sylviculture and animal husbandry (SALT 2),
+ Sustainable agro-forestry (SALT 3)

It is necessary to follow different systems of inter-cropping, relay cropping and crop rotation, as well as applying new varieties of crops and new breeds of animal for higher yield and productivity.

4.4. Systems of sustainable management of sloping land resources:

- *Engineering:*
  1) Construction of terraces, irrigation and drainage canals, *and* levees for water reservation:

Terraces reduce the degree of slope in a cultivated field. For very high slopes (more than 25°) with a thin soil surface layer, it is not possible to make normal terraces. Terraces are recommended for agriculture and agro-forestry land with a 15-25° slope. For land with 12-15° slope, terraces could be useful for sustainability, but if the source and labor are lacking, it is possible to use alternative soil and water conservation techniques.

Identification of the width of terrace surface: The width of terrace surface is dependent on slope level, thickness of the surface soil layer, as well as types of plants. For large canopy species, the width should be from 3-6m, and for the narrower canopy species like tea, coffee Catimor, 1.5 to 2 m is sufficient for single row planting. In the places where degree of slope is low and soil layer is thick, the terrace surface may be 5 to 6 m for two-row planting. Additionally, the higher the degree of slope, the narrower the terrace surface; 10-12° slopes can be 6 m, while with 14-16° slope it will be reduced to 4 m, and then to 3 m when the slope is higher than 20°. The horizontal lines are defined using an A-frame.

  2) Planting in horizontal lines, construction of levees and canals for erosion control, without terrace-making:

This approach can be applied in low and medium slopes (less than 12-15°) with the following steps: Firstly, identify parallel horizontal lines to plant trees, dig trenches and make levees. Secondly, dig trenches and levees to prevent or slow down the runoff and reserve the soil moisture. The distance between trenches is 6-8m with slope of 8-15°, and 4-6 m if slope is 15-25°. The sizes of the trenches are 50cm wide at the soil surface, 30 cm wide at the bottom, and 50 cm deep. The soil removed in digging the trenches is used to make levees on the lower edge of the trench. The trenches built along slopes for water drainage must avoid direct streams, so as to reduce soil loss. At the foot of slopes, the surface of trenches must be widened. The trenches must have zigzag configuration with water and soil traps.

4.5. Systems of sustainable cultivation technologies

The core techniques of sustainable agriculture on slope lands are mulch-based, direct-sowing systems (DMC or SCV). DMC helps recover what has been destructed by slash-and-burn shifting cultivation. The most important role of mulch on sloping lands is the protection of soil from erosion.

Mannering and Bertrand (1963) found that 2.5 t/ha of wheat straw were sufficient to cover 87% of soil surface and completely eliminate run-off and erosion. R. Lal (1997) showed the relation between mulch and soil loss through the following equation:

$$\text{Soil loss} = C \times M^{-k}$$

Where: M is the mulch rate and C and K is constants.

Obviously, the thicker the mulch, the less the soil erosion. Besides, mulch has a wide number of positive effects, the most important of which can be listed as follows:

- Improvement of soil fertility by providing C, N, Ca, Na, P, K and micro-elements through the decomposition of organic mulch.
- Increase in soil pH because most of the released cations have base character that neutralizes the pH of acidic soils which are prevalent in mountainous areas.
- Detoxification of soils thanks to the formation of Al^{+++}, Fe^{++} humus complexes.
- Improvement of soil porosity/ infiltration due to biological activation of different organisms which are considered as the biological flowers. As a result, mulch help reduce the labour input for land preparation. Soil fauna and flora also play very important role in nutrition recycling, making soil fertility richer without the mineral fertilizers' input.
- Reduction of water evaporation or increase in soil humidity which help plants resist temporary drought.
- Regulation of temperature in the soil surface layer, which can play a role in extreme conditions.
- Improvement of the effects of external fertilizer input because they are protected by the mulch from being washed away by rain water.
- Decrease in weed growth, which means reducing the input for weed control (labour, herbicides).

With all these advantages, mulch contributes to a steady increase in crop yield, rather than the generally observed trend on sloping lands, of a decrease in yield over time. As land use becomes more efficient, farmers do not clear the forest for expanding fields, which means greater sustainability. As mulch reduces the external input (mineral fertilizers, pesticides, and burning), it greatly limits CO^2 emissions. Mulching has become a very important component of organic agriculture development. When applied to upland regions, the positive effects of mulch can be multiplied.

One of the most important constraints on sloping land is a water deficit. Accordingly, cultivation activities should follow rain patterns. Annual and perennial plants should all be planted during the rainy season. Soil disturbance should be minimised, especially during the dry season.

4.6. Sustainable cultivation technologies:

The following are the main techniques developed and recommended for sustainable agriculture (Rolf Derpsch, 2007):

- *All technologies/techniques must be based on the principle of maintaining permanent vegetal cover of soil by living or dead mulch - use of green manure (annual, fast growing, cover crops), no burning*
- *Crop rotation*
- *Increase soil OM by application of organic fertilizers, vegetal mulch, green manure, biological fertilizers, crop rotation, intercropping*
- *Non- or mini-tillage (little or no soil disturbance), especially for sloping lands*
- *Direct sowing of seeds through the mulch*
- *Shorten or skipping fallow period by intercropping with leguminous (peanut, perennial peanut, Cassia rotundifolia, Canavalia ensiformis, etc.).*
- *Making mini-terraces on steep slopes combined with soil mulch:* On steep slopes, it is generally advisable to plant forest and fruit trees. When, in certain circumstances, slopes are used for crop cultivation, mini-terraces with soil mulch improve sustainability.
- *Building living fences to protect cultivated fields:* Where there is free grazing, fences protecting cultivated fields play a fundamental role in ensuring a good harvest. To reduce costs and avoid annual re-fencing, living fences from propagated species are recommended. The following are the most popular and locally available species for living fences: *Bombax ceiba, Caesalpinia sapan, Ceiba pentadra, Erythrina variegata, Euphorbia pulcherima, Randia spp., Jatropa curcas, Oroxylum indicum.*

- *Hedge rows or bands:* On sloping lands, it is essential to plant green manure hedge rows to prevent soil erosion and produce in situ green manure (see definition above). For non-terrace fields, hedgerows can be planted in horizontal lines 6-8 m apart if the slope is 8-15°, and 4-6 m if the slope is 15-25°. For terrace fields, the green manure species can be planted on the outer edge of the levees. Species that are recommended are tephrosia, leucaena, stylo, pineapple, tea, and other suitable species, etc.

- *Biological weed control:* Dead vegetal mulch is a good means for weed control. However, living mulch from different legume species seems to be more effective. In addition, some high biomass climbers, especially mucuna can be used to smother very aggressive grasses like imperata and cyperus.

- *Integrating planting fodder into cropping systems:* Arable lands experiencing an idle period provide the best opportunity for fodder production. Some fodder species can be intercropped with food crops. Many others proved to be very suitable under thin forests or during their establishment period. Fodder can also be produced around fish ponds, along water reservoirs. This is useful not only in terms of animal feed production but also in protecting the soil from degradation and man-made items.

- *Household fodder production:* Besides planting fodder species, agricultural by-products are recommended to be used to produce animal feeds, especially fermented ones. Rice straw, corn cobs, dry grasses are commonly available ingredients. Planting of cassava and sweet potato is strongly recommended. When animal feeds are more available, animal husbandry will become the most important source of income generation. This shift to more intensive animal production will mean reduction in one of the most important factors of soil degradation and forest destruction, free animal grazing.

- *Application of mineral fertilizers:* Mineral fertilizers have not been popular in sloping areas, but they are necessary if market-oriented, intensive farming is to take place, to balance soil nutrition. However, users will need to follow protocols provided.

4.7. Protocols available for improvement, utilization and protection of sloping lands:

- Technical protocol suitable for protection and maintenance of forest soil fertility in the protection of Upper River Head forests.
- Technical protocol suitable for stabilization and improvement of soil fertility for agriculture and forestry production.
- Technical protocol suitable for restoration and improvement of soil fertility of degraded soils.

The results achieved by many models show that the correct application of available protocols for soil fertility protection and improvement can help:

- Create opportunities for changing cropping patterns in agriculture and forestry production to increase productivity and therefore peoples' living standards
- Increase farmers' capacity and knowledge, so they can use their lands in effective and sustainable ways
- Change detrimental cultivation practices of mountainous farmers

5. Ecological agriculture - an effective measure for natural resource management:

5.1. *Definition of ecological agriculture* (Teodorescu, 2008): 'Ecological agriculture is a reaction and an alternative to some of the strategies which have been used by government and donors during the last 50 years, and which have had a damaging effect on rural society and agricultural ecosystems. These damaging strategies include farming technologies which degrade the natural resource base and require high levels of external inputs (including toxic chemicals), and agricultural research and extension services which are based on the notion that technology should be developed by specialists and transferred to recipient farmers through messages and demonstrations.

Ecological agriculture practices are a holistic approach to agriculture encompassing the biological, social, animal and human aspects of the farm enterprise. Ecological farming is contrasted with industrial agriculture which relies on a wide range of off farm inputs such as fertilizers, pesticides and herbicides. In a time of rising oil costs and decreasing fossil fuel supplies industrial farming is becoming less environmentally and economically sustainable.'

5.2. Elements of ecological agriculture: Securing land for farming (cultivation and husbandry) and irrigation for growing, protecting forests, buffering against natural disasters, protecting the environment, producing clean farm products, ensuring food safety, raising output and product quality, maintaining materials for preserving and processing industries and combining closely industrial and agricultural growth.

Ecological agriculture entails farmers making decisions and applying practices with the aim of sustaining or enhancing natural regenerative processes and stabilizing interactions within local agro-ecosystems. In practice, this includes:

- the management of insect pests by taking account of population dynamics, natural enemies, and plant compensation

- the management of soil fertility by taking account of soil structure and composition, nutrient cycling and the action of micro-organisms
- the management of crop varieties by taking account of genetic diversity, the dynamics of resistance, and local adaptation
- the overall management of a cropping pattern by taking account of local landscape, the flow of inputs and outputs on the farm, and the multifunctional nature of agricultural production.

Ecological farming generally involves a diversity of crops, animals and methods. Management techniques include cover crops, green manures, composting, mulching, crop rotation, no-till cropping and the use of animal waste to maintain fertility. Properly managed soils can capture nutrients and energy from the air and sun to replenish fertility and make it available for an indefinite number of crop cycles.

Eco-farming:

- does not separate cultivation and livestock raising, does not implement intensive farming, involves crop rotation with plants, livestock and organic manure.
- implements “no-till” or "mini-tillage” in suitable places.
- uses safe fertilizers and takes integrated measures to kill insects (in cultivation, sanitation, biology...) and chemical solutions are applied only when necessary.
- does not burn forests for planting, has anti-erosion projects on sloping lands using crops and plant residues for soil mulch, combines farming with forestry with livestock; grows a diversity of plant species suited to the local ecological conditions; secures ecological balance.
- is an alternative approach to the exploitation of natural resources, involving innovation including aquaculture development, biogas production for farm waste utilisation, manufacture of protein from leaves...

A key question that is often asked about ecological agriculture, including organic agriculture, is whether it can be productive enough to meet the world’s food needs. While many agree that ecological agriculture is desirable from an environmental and social point of view, there remain fears that ecological and organic agriculture produce low yields.

In general, yields from ecological agriculture can be broadly comparable to conventional yields in developed countries. In developing countries, ecological agriculture practices can greatly increase productivity, particularly if the existing system is low-input, which is the largely the case for Africa. On average, in developed countries, organic systems produce 92% of the yield produced by conventional agriculture. In developing countries, however, organic systems produce 80% more than conventional farms.

This chapter will focus mainly on evidence from developing countries.

6. Successful models of ecological agriculture:

<u>In Africa:</u>

- Soil and water conservation in the drylands of Burkina Faso and Niger have transformed formerly degraded lands. The average family has shifted from being in cereal deficit of 644 kg per year (equivalent to 6.5 months of food shortage) to producing an annual surplus of 153 kg.
- In Ethiopia, some 12,500 households have adopted sustainable agriculture, resulting in a 60% increase in crop yields.
- In Tigray, Ethiopia, yields of crops from composted plots were 3-5 times higher than those treated only with chemicals.

- Projects in Senegal promoted stall-fed livestock, composting systems, green manures, water harvesting systems and rock phosphate. Yields of millet and peanuts increased dramatically by 75-195% and 75-165% respectively.
- In Kenya, 500 farmers on some 1000 hectares have seen maize yields improve from about 2 to 4 t/ha following the application of soil conservation, soil fertility and organic agriculture methods.
- A range of biological pest management methods together with legumes, cover crops and green manures for soil fertility improvement resulted in a doubling of beans and groundnut yields from 300 to 600 kg/ha in western Kenya.
- In eastern and central Kenya, smallholder farmers have been trained in natural soil fertility management; integrated environmentally friendly weed, pest and disease protection; on-farm soil and water conservation techniques; and farm level seed conservation, with a resulting 50% increase in productivity and 40% increase in income.
- More than 1000 farmers in low soil fertility areas in the North Rift and western regions of Kenya increased maize yields to 3,414 kg/ha (71% increase in productivity) and bean yields to 258 kg/ha (158% increase in productivity) as compared to traditional agriculture, by incorporating soil fertility management, crop diversification and improved crop management.
- Integration of pond fish culture into low-input farm systems with some 2000 farmers in Malawi increased vegetable yields from 2700 to 4000 kg/ha, with the fish ponds producing the equivalent of 1500 kg/ha of fish, a new source of food for households.

<u>In Latin America:</u>

- 45,000 families in Honduras and Guatemala have increased crop yields from 400-600 kg/ha to 2000-2500 kg/ha using green manures, cover crops, contour grass strips, in-row tillage, rock bunds and animal manures.
- The states of Santa Caterina, Paraná and Rio Grande do Sol in southern Brazil have focused on soil and water conservation using contour grass barriers, contour ploughing and green manures. Maize yields have risen from 3 to 5 tonnes/ha and soybeans from 2.8 to 4.7 tonnes/ha.
- The high mountain regions of Peru, Bolivia and Ecuador are some of the most difficult areas in the world for growing crops. Despite this, farmers have increased potato yields by three fold, particularly by using green manures to enrich the soil. Using these methods, some 2000 farmers in Bolivia have improved potato production from about 4000 kg/ha to 10-15000 kg/ha.
- In Brazil, use of green manures and cover crops increased maize yields by between 20-250%.
- In Peru, restoration of traditional Incan terracing led to increases of 150% for upland crops.
- In Honduras, soil conservation practices and organic fertilisers have tripled or quadrupled yields.
- In Cuba, there are more than 7000 organic urban gardens and productivity has grown from 1.5 kg/m^2 to nearly 20 kg/m^2.

<u>In Asia:</u>

- Participatory irrigation management in Philippines has increased rice yields by about 20%.
- Yield increases of 175% were reported from farms in Nepal adopting agro-ecological practices.
- In Pakistan, yields of mango and citrus fruits increased by 150-200% after adopting organic agriculture techniques such as mulching, no till production, composting and planting the fruit trees in double dug beds.

It is clear that ecological agriculture is productive and has the potential to meet food security needs, particularly in the African context. The International Assessment of Agricultural Knowledge, Science and Technology for Development concurs that an increase and strengthening of agricultural knowledge, science and technology toward agro-ecological sciences will contribute to addressing environmental issues while maintaining and increasing productivity (IAASTD, 2008). Moreover, ecological agricultural approaches allow farmers to improve local food production with low-cost, readily available technologies and inputs, without causing environmental damage.

7. Recent development of natural resource management for sustainable agriculture in Vietnam

7.1. Institutions involved in improved productivity, reduced poverty and improved environmental sustainability in mountainous areas

To contribute to achieving the above goals, in the past 5 years, the Vietnam Agricultural Science Institute (VASI) and Centre for International Cooperation in Agricultural Research for Development (CIRAD - France) had been jointly implementing a research project Mountain Agrarian Systems (SAM) in agricultural systems in the Northern mountainous region of Vietnam. The main activities of SAM were to test, improve, adapt and disseminate techniques suitable to the diverse agro-ecological conditions of these regions.

National agricultural institutions like the National Institute of Soil and Fertilizers (NISF), Hanoi Agricultural University (HAU), Thai Nguyen Agriculture and Forestry University, Hue Agro-forestry College and other members of the Vietnam Agro-forestry Capacity Building Network (VACB) are playing an active role in research and development of soil conservation technologies for the uplands. The most recent program, entitled Science and Technological Research for Upland Agriculture and Rural Development, has launched large-scale activities concerning development and scaling up of effective and sustainable technologies for upland agriculture. The cooperation between IWMI, IRD, IRRI, ACIAR, HU also concentrates on the improvement of natural resources management.

The main goals of these efforts are to develop techniques that help mountainous farmers overcome the above problems. The basis of these techniques is to maintain permanent vegetal cover of the soil. Other techniques are direct seeding with minimal-tillage, crop diversification, rotation, intercropping and integration of agriculture, forestry and animal husbandry. The results are being transferred to a large number of districts and provinces in the Northern mountainous regions of Vietnam through cooperation with other domestic and international projects and programs taking place in the region.

7.2. Technologies applied and their impacts

7.2.1. Adaptation of direct sowing on vegetal mulch (SCV) technologies to local upland conditions: Many countries, such as the USA, Canada, Brazil and Madagascar, have created diverse techniques, which are simple but economically and environmentally effective for sloping lands. A large area of more than 100 million ha has been cultivated with soil conservation techniques like mini- or zero-tillage, mulch based direct seeding (DMC) (Derpsch R; Dixon JM 2005). These technologies have been selectively tested and modified in the conditions of the Northern mountainous regions of Vietnam. Different DMC techniques have been used widely and yielded positive results (Tables 13, 14 and 15).

Mulch materials can be locally gathered (from areas surrounding farms) if availability of natural vegetation and of crop residues is sufficiently high. Mulch can also be produced *in situ* by using species indicated in Table 16. Bushy legumes like *Flemingia macrophylla, Desmodium*

triquetrum,Tephrosia candida, Senna spectabilis, etc. and other wild species like *Chromolaena odorata and Tithonia diversifolia* have been used for mulch. Fallow lands can be actively managed by planting of fast growing species, especially leguminous ones like *Acacia mangium, A.auriculiformis,Acacia hybrid, Leucaena leucocephala and Gliricidia sepium,* etc. Intercropping of main crops with some suitable legumes like *Arachis pintoi, Cassia rotundifolia, Stylosanthes guianensis* or *Aeschynomene histrix*, and even with climbing legumes like *Mucuna utilis, Vigna umbellata* and food legumes has been tested and recommended. The main purpose is to produce more biomass and higher coverage of the soil.

	Yield (T/ha)			Location	Source	Note
	Control	Mulched	Increase by %			
DK888	2.20	3.46	57.27	Na Ri	H.M.Tam, VASI	
LVN10	2.86	4.04	42.26	Na Ri	H.M.Tam, VASI	Miniterrace
CP	6.49	8.48	30.66	Mai Son	L.Q. Thanh, VASI	
LVN10	3.73	5.95	59.52	Song Ma	EU - VASI, 2004	
LVN10	1.33	2.11	59.28	Song Ma	EU - VASI, 2004	Miniterrace
LVN10	2.49	4.00	60.64	Tuan Giao	EU - VASI, 2004	
LVN10	1.41	4.87	245.39	Tuan Giao	EU - VASI, 2004	Terrace
LVN10	3.03	4.90	61.72	Dien Bien Dong	EU - VASI, 2004	
LVN10	3.50	4.77	36.29	Dien Bien Dong	EU - VASI, 2004	Terrace
LVN10	1.28	3.73	191.40	Phong Tho	EU - VASI, 2004	
LVN10	3.48	6.75	93.97	Song Ma	EU - VASI, 2004	
LVN10	4.00	6.48	62.00	Song Ma	EU - VASI, 2004	Miniterrace
CP 888	4.75	7.75	63.16	Song Ma	EU - VASI, 2004	
CP 888	4.78	7.00	46.44	Song Ma	EU - VASI, 2004	Miniterrace
LVN10	2.11	5.95	81.99	Song Ma	EU - VASI, 2004	Terrace
LVN10	1.32	3.72	81.82	Song Ma	EU - VASI, 2004	Terrace
LVN10	2.61	3.71	42.21	Song Ma	EU - VASI, 2004	Terrace
LVN10	1.50	2.50	66.67	Song Ma	EU - VASI, 2004	Terrace
LVN10	3.12	4.01	28.52	Song Ma	EU - VASI, 2004	Terrace
LVN10	1.58	2.10	32.91	Phong Tho	EU - VASI, 2004	Terrace
LVN99	3.56	4.52	26.97	Van Chan	NOMAFSI, 2009	Miniterrace
Average yield increase (%)			72.21			

Table 13 Impacts of soil mulch on maize yield

Variety	Yields (T/ha)			Location (District)	Source	Note
	Control	Mulched	Increase by %			
Bao Dam	1.25	2.25	80.00	Song Ma	EU and VASI, 2004	
Bao Dam	1.55	2.14	38.06	Song Ma	EU and VASI, 2004	Terrace
CIRAD141	0.75	1.26	68.40	Song Ma	EU and VASI, 2004	
Te Do	1.12	3.15	181.25	Van Chan	NOMARC, 2004	
CIRAD141	1.80	3.20	77.78	Van Chan	NOMARC, 2003	
Bao Dam	10.70	14.97	39.91	Tua Chua	NOMARC-DANIDA, 2004	
CIRAD 141	9.62	15.51	61.23	Tua Chua	NOMARC-DANIDA, 2004	

LC 93-1	7.54	11.19	48.41	Tua Chua	NOMARC-DANIDA, 2004	
Ma Cha	7.52	11.51	53.06	Tua Chua	NOMARC-DANIDA, 2004	
		Average	72.01			

Table 14 Impacts of soil mulch on upland rice yield

Crop	Replication	Cassava + *Stylo*	Cassava without *Stylo*	Yield increase (%)
Cassava	1	26.9	18.6	44
Cassava	2	29.7	20.0	49
Cassava	3	24.0	1.65	45

Table 15 Impacts of Stylosanthes guianensis living mulch on cassava yield Source: (VASI-CIRAD SAM Project, 2002)

The yield increase varies largely due to very high level of heterogeneity in mountainous regions. However, the average increase is very high (72.21 % for maize, 72.1% for rice and 46% for cassava). Such an increase is not easy to achieve even with high-tech methods that require enormous investment.

7.2.2. Increased soil fertility by application of organic fertilizers, vegetal mulch, green manure, biological fertilizers, crop rotation, intercropping: A rich collection of multipurpose cover crops, biological nutrition pumps and nitrogen fixation species have been assembled and tested (Table 16). Many of them performed well and proved their usefulness in soil protection and improvement, as well as fodder production. *Pennisetum purpureum* hedgerows, for example, or *Arachis pintoi* cover in fruit orchards have been warmly welcomed by many farmers. *Mucuna utilis*, locally collected, is resistant to pod miner and can produce huge nitrogen-rich biomass in a short time. It proved to be a very effective species for soil improvement and weed control. By using a Mucuna cover, alang alang grass (*Imperata cylindrica*) can be totally suppressed. The fields have better soil fertility after Mucuna, resulting in better growth and development of subsequent crops.

Arachis pintoi	*Eleusine corocana*
Avena sativa	*Flemingia macrophylla*
Brachiaria brizantha	*Mucuna utilis,*
B. decumbens	*Panicum maximum*
B. humidicola	*Pennisetum purpureum*
B. ruziziensis	*Setaria italica*
Canavalia ensiformis,	*Sorgum bicolor*
Cassia rotundifolia	*Stylosanthes guianensis*
Centrosema spp	*Vigna umbellata*
Coix lachryma	*Vigna sesquipedalis*

Table 16 List of tested and recommended cover and fodder species

7.2.3. Impacts of mulching upland maize on economic efficiency: To prove the economic benefits of mulching techniques, case studies and data analysis have been made in some localities. The first studied was made by H.D. Tuan et al. (2001). The results are shown in table 17

Items	Field land preparation	Chemicals for seed treatment and herbicides	Weeding	Total	Yield T/ha Output	Net benefits

No mulch	600	0	1200	1800	4200	2400
With mulch	240	300	300	840	8400	7560

Table 17 Economic effects of soil mulch on maize A case study by SAM-1 in Cho Don in 2001 - 1000 VND/ha.

Another study was subsequently conducted in 2004 by VASI staff working with the Son La - Lai Chau Rural Development Project (EU SLLC RD) in maize and upland rice. Results are summarised in Table 18 and 19.

Techniques Expenses/revenue	Yield (T/ha)			
	With mulch	Without mulch	Terrace + Mulch	Terrace + Without mulch
LVN10 (Yield = kg/ha)	5950	3725	3250	2150
Expenses on fertilizers (VND)	915,000	915,000	915,000	915,000
Expenses on labour/ha(VND)	3,400,000	3,600,000	3,000,000	3,400,000
Total expenses (VND)	4,315,000	4,515,000	3,915,000	4,315,000
Revenue (kg/ha x2500VND /kg)	10,710,000	6,705,000	5.850.000	3,870,000
Balance (VND)	6,385,000	2,190,000	1,935,000	-445,000

Table 18 Economic effects of soil mulch on maize A case study by VASI- EU SLLC RD in Song Ma district of Son La province, 2004, unpublished

Techniques Expenses/revenue	Terrace + Mulch	Terrace + Without mulch	Mulched field	Unmulched field
Dam Bao variety (Yield = Kg/ha)	2156	1550	2250	1250
Expenses on fertilizers (VND)	735,000	735,000	735,000	735,000
Expenses on labour/ha (VND)	3.600,000	4,000,000	4,000,000	4,200,000
Total expenses (VND)	4,335,000	4,735,000	4,735,000	4,935,000
Revenue (kg/ha x2500VND /kg)	5,390,000	3,875,000	5,625,000	3,125,000
Balance	1,055,000	-860.000	890,000	-1.810.000

Table 19 Economic effects of soil mulch on upland rice VASI-EU SLLC RDP in Song Ma, 2004

The dramatic yield increase in the mulched plots ensures that revenue is much higher than in traditionally managed plots. With time, the economic benefits of soil mulching will be increasingly high due to a reduced fertilizer requirement (as the soil fertility will be improved), and less labour for weeding and land preparation.

7.2.4 Making mini-terraces on steep slopes combined with soil mulch: On steep slopes, soil erosion is much more severe and the cropping cycle is very short. More importantly, the soil is quickly degraded to such a level that neither crop nor forest plants can be grown, except some bushes with little economical value. It is advisable not to plant crops, rather forest and fruit trees in these high and steep slopes. However, in certain circumstances, especially in North Vietnam, farmers have no choice, and they have to grow crops on very steep slopes of more than 45 degrees. In these cases, mini-terraces with soil mulch and direct sowing without soil tillage have proven most effective; results were surprisingly positive. The maize yield was high, stable and increased from year to year (Table 20) (Husson et al. 2001).

Field designation	Treatment	Yields (T/ha)		
		2000	2001	2002
1002-1	Mini-terrace + *Cassia rotundifolia*		1.44	2.39
1002-2	Mini-terrace + *A. pintoi*		1.77	4.01
1003-1	Mini-terrace + *B. ruziziensis* (Cuttings from outside)		1.35	2.83
1003-2	Mini-terrace + (Seeded and killed grass)		1.57	3.76
1003-3	Mini-terrace + *B. riziziensis* (seeded in 2000, killed in 2001)		1.59	2.11
1004-2	No mini-terrace	1.68	0.44	0.93
1010-1	Mini-terrace + *A. pintoi*		1.18	4.17
1012-1	No mini-terrace + Mulch		0.91	3.03
1012-3	No mini-terrace + weeding		1.07	
1012-3	Mini-terrace (1st year)			3.77

Table 20 Increasing trend of maize yield intercropped with *Chucrasia tabularis* in mini-terraced field (VN, SAM 2002)

Eroded soil from different treatments and localities was collected and weighed. The results are shown on table 21.

Crops	Soil loss (T/ha/year)		Decrease in soil loss (%)	Source
	No mulch	With mulch		
Maize + Miniterrace	16.4	0.2	98.78	H.M.Tam, VASI
Maize + No miniterrace	31.6	0.2	99.38	H.M.Tam,VASI
Plum	12.7	3.5	74.44	L.Q. Thanh, VASI

Table 21 Impacts of mini-terraces (MT) and soil mulch on soil erosion control

Mulch was shown to greatly reduce soil erosion, agreeing with earlier findings of various authors, including Lal (1989) who did a series of studies on soil conservation and management in the tropics.

Recently, the soil mulching techniques have been tested in perennial crops like tea (N.T.N. Binh et al. 2009). The authors' research results show that soil mulch using vegetal materials for tea can maintain the soil moisture by 7 to 9%, and reduce the eroded soil by 40-50%, compared to the control. As a result, the tea yield can be increased by 20 to 59% depending on the amount and type of mulch materials.

7.2.5 Shortening the fallow period: The results of intercropping cassava with legumes (peanut – *Arachis hypogeae*, wild peanut – *Arachis pintoi*, *Cassia rotundifolia, Canavalia ensiformis*, *Stylosanthes guianensis*, etc.) showed that not only did cassava yield increase, but the soil fertility was also improved and the weed growth suppressed. After the full harvest of cassava, the field was ready for a new cultivation cycle of food crops. Likewise, planting fast-growth species like hybrid acacia and paulownia with herbaceous legume species and grasses can greatly shorten the fallow period and provide income during vegetation and post-harvest of the trees.

7.2.5 Biological weed control: Dead vegetal mulch is one of the best and safe herbicides. However, living mulch from different legume species seems to be more effective in weed control. Some high

biomass climbers, especially *mucuna* can be used to smother very aggressive grasses like *imperata* and *cyperus*. This has been successgul in many farmers' fields in Cho Don District.

8. Diversification of SCV systems

Mountainous regions are very diverse in ecology, topography, climate and natural resources, as well as social, cultural and human aspects. Therefore, it is crucial to research and develop diverse cultivation technologies for mountainous regions. With this in mind, a series of technological packages for sustainable sloping land agriculture have been created. Depending on local conditions, farmers can select and apply suitable techniques and scale them up. For example, with soil mulching, many kinds of mulch materials and mulching methods have been recommended, such as utilization of crops and weed residues, *in situ* mulch production, imported mulch, permanent living mulch and using short duration and fast growing species as a soil mulch method when intercropped with long duration crops (e.g. peanut and soybean with cassava, pineapple and sugarcane).

9. Diversification of species and varieties

Together with research and creation of diverse cultivation technologies, high attention is paid to selection of diverse species and varieties of food and cover crops, so that farmers can select suitable ones. Several high-yielding upland rice varieties have been selected from Brazil, Madagascar and the International Rice Research Institute (IRRI). Many other species like oats, barley, wheat, triticale, fruit trees, and cover crops have been introduced and tested.

10. Integration of food production, animal husbandry and forestry production

Sustainable development in mountainous regions could not be a reality if its components (food production, animal husbandry and forestry production) were developed separately. In past years, research has been conducted to exploit the potential for local, integrated development of these components. For example, utilization of idle lands for planting fodder species to produce additional feed for dairy cattle and big ruminants, and intensification of crop cultivation in valleys to reduce the pressure on forest lands, facilitating forest regeneration and development.

10.1 Information, training and research approaches

Special attention has been paid to capacity building in research staff. A team of young engineers has been established and trained to live and work together with local farming communities. This is a novel approach to research and extension in mountainous regions. After several years of *learning by doing*, the team now has full capacity to scale up and manage their research activities. The team of graduate engineers can now implement innovations according to local context and demands of local communities. Many graduate students enjoyed this field practice, and a large number of farmers, extensionists and staff from different localities and projects have been invited to visit the pilot sites.

To introduce and scale up models for sustainable upland agriculture to smallholder production, a farmer-centered approach (farmers first and farmers last) has been followed. Participatory planning of research content and design, respecting farmers needs and addressing their problems, proved to be very helpful.

11. Application scale

At first, the soil conservation methods developed by th SAM project in Cho Don were disseminated to the nearby districts, Ba Be, Cho Moi and Na Ri in Bac Kan Province (Table 22).

Technologies	Number of households	Area (ha)	Purpose/Composition

Arachis pintoi cover	6	0.69	Soil improvement, fodder, fruit orchards
Pennisetum purpureum	72	16.8	Hedgerows, fodder, mulch material
B. Brizantha	4	0.15	Soil improvement, fodder, mulch material
B. decumbens	2	0.12	Soil improvement, fodder, mulch material
B. humidicola	2	0.12	Soil improvement, fodder, mulch material
B. ruziziensis	34	3.6	Soil improvement, fodder, mulch material
Panicum maximum	16	0.39	Soil improvement, fodder, mulch material
Paspalum atratum	1	0.12	Soil improvement, fodder, mulch material
Stylosanthes	3	0.22	Soil improvement, fodder, mulch material
Mucuna	3	0.4	Soil improvement, fodder, mulch material
Mini-terrace	12	7.2	Maize planting, fodder, soil improvement, sustainability
Agro-forestry models	7	4.5	*Chucrasia tabularis*, maize with mulch on mini-terraces, fodder species, Cinnamon with grasses
Maize with mucuna	5	4	High and stable yield, soil improvement, fodder
Mulch & direct sowing	10	5	Soil protection and improvement
Total	177	43.3	

Table 22 Adoption of SAM technologies in Bac Kan province Because most of the farms in Vietnam are small, the 'area of application' is not the most important indicator of adoption, but rather the number of farmers. It can be seen that the number of farmers adopting technologies are quite large. In addition, it is worth mentioning that no financial support was involved in this adoption.

Available data from the cooperation of the EU 'Son La–Lai Chau Rural Development Project,' from the National Science and Technology Research Program for Upland Agriculture and Rural Development show positive impacts of such techniques, particularly direct sowing of maize and rice in the mulched sloping fields, incorporation of fodder production into forest plantations, fruit orchards and fodder hedgerows.

Song Ma district of Son La province where 100 percent of communes applied these technologies over 1000 ha in 2005 is a very good example. In Mai Son, Yen Chau and Moc Chau districts of Son La province, hundreds of hectares of maize are now planted with SCV technologies. Along the state roads in Dien Bien Phu and Lai Chau provinces, one can see the mini-terraces with mulch in many places.

12. VIII. Conclusions

- The most important principles of soil erosion control are permanent soil cover, zero tillage and direct seeding onto mulch.
- Conservation agriculture aims at achieving high productivity, food safety and environmental sustainability. Its components are wise use of natural resources combined with conservation and enrichment, reduced to no use of mineral fertilizers and pesticides, promoting soil and water conservation, etc.
- Sustainable farming science involves integrated technology packages supporting intensive farming without harming soil fertility. DMC helps reduce soil erosion up to 99% and increase crop yield by at least 25%.

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