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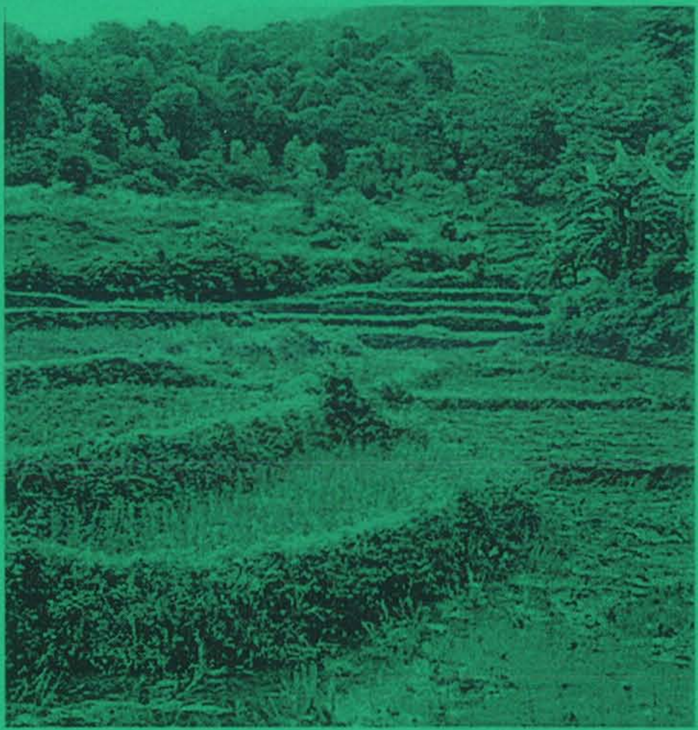
Possible Strategies for Sustainable Land Use in the Hilly Area of Northern Vietnam

Joakim Andersson



Examensarbete (Degree project)
Handledare (Supervisor): Stig Ledin

Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

Swedish University of Agricultural Sciences
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FOREWORD

It is difficult to acknowledge the many persons who have contributed to the accomplishment of this degree project without disregarding anyone. That said, it is equally important to recognize that this study could never had been written without assistance of numerous individuals and institutions.

The degree project is based on a minor field study (MFS) carried out in Bavi district, North Vietnam, by Åsa Wisén and me, Joakim Andersson. To be precise, the investigations at the sites of Goat and Rabbit Research Centre (GRRC) and Hop Son hamlet were performed as a mutual project within the framework of the MFS. Therefore I would like to especially thank Åsa Wisén for the preparations and our work in Vietnam. Her participation was crucial for the continuation of the project and I wouldn't have had the possibility to extend the project so far without her companionship in Vietnam.

Associate Professor Stig Ledin at the Department of Soil Science, SLU, offered assistance and modest criticism for planning and finalizing the project, which was crucial for the accomplishment. In Vietnam, our supervisor Dr. Dinh Van Binh at the Goat and Rabbit Research Centre (GRRC) provided us with the opportunity to perform the study in a very effective, smooth and successful manner, as well as paving the way for us with the local authorities. During the field work the assistance of Ngo Tien Dung and Nguyen Ky Son was inestimable.

The work with the GLEAMS simulations was made possible by the supervision of Faruk Djodjic and Karin Blombäck at the SLU and their positive support. Moreover, technical assistance from Per-Olof Hårdén at Uppsala University was essential for the creation of GIS presentations over Hop Son area.

Joakim Andersson

CONTENTS

ABSTRACT

In this study, different techniques are used to evaluate sustainable land use in Hop Son hamlet in Bavi district, Hatay Province, Northern Vietnam. First, five cultivation systems including cassava (*Manihot esculenta*), white mulberry (*Morus alba*) and *Flemingia macrophylla* were characterised and their effect on soil properties in a field trial at the Goat and Rabbit Research Centre (GRRC) were evaluated. Secondly, field observations were performed and soil profile descriptions were made in Hop Son hamlet in order to understand soil properties and the present land use in the area. Moreover, the plants, water erosion modelling and land evaluation were considered in a literature survey. Finally, soil loss simulations were performed with the GLEAMS model and a characterisation of the topography in Hop Son area was visualised with GIS software.

No significant differences could be found in soil properties between the cultivation systems. The chemical status of the soil and the wet stability of soil aggregates seemed to be similar in all the cultivation systems, with a tendency for higher total nitrogen content in soil with pure stands of *F. macrophylla* and stronger wet soil aggregate stability in the monocropped systems with *F. macrophylla* and white mulberry. Observations of root penetration through the soil profiles indicated that *F. macrophylla* and white mulberry produce more roots that are more widely distributed than those of cassava. Hop Son hamlet was in a hilly and mountainous landscape prone to erosion and the soil was mainly classified as an Acrisol, partly with high levels of aluminium saturation. Wet soil aggregate stability differed considerably between different land uses in the hamlet. Cassava is regularly cultivated within the village and is the most important crop, together with rice. *F. macrophylla* was introduced to the village during 2001 and some rows of plants have been established in the fields, whereas only one or two plants of white mulberry are grown in home gardens. There is no immediate interest in establishing white mulberry on a larger scale.

The GLEAMS model simulated large soil losses from cassava cultivations. These showed pronounced soil loss differences from *F. macrophylla* cultivations and forest. *F. macrophylla* cultivations showed higher soil losses than forest. Intense rains proved to be several times more severe regarding soil loss than ordinary precipitation. Sloping characteristics of the area were visualised based on a digital elevation map and land evaluation was estimated on the basis of tolerable soil losses due to cultivation systems and steepness of slopes.

Keywords: Cassava, *Flemingia macrophylla*, Mulberry, Erosion, Geographic Information System, GLEAMS, Sustainable Land Use, Vietnam

REFERAT

I denna studie har jag studerat olika tekniker för att utvärdera uthållig markanvändning i byn Hop Son som är beläget i Hatay provinsen, norra Vietnam. Till att börja med karaktäriserades fem odlingssystem med växterna kassava (*Manihot esculenta*), vit mullbär (*Morus alba*) and *Flemingia macrophylla* och deras påverkan på markegenskaper utvärderades i ett fältförsök på the Goat and Rabbit Research Centre (GRRC). Därefter genomfördes markprofilbeskrivningar i byn Hop Son för att förstå markegenskaper och markanvändningen i området. Växterna, erosionsmodellering och markevaluering studerades i litterturen och slutligen simulerades erosion med GLEAMS modellen och topografin i Hop Son området visualiserades med GIS.

Inga signifikanta skillnader kunde påvisas vad det gällde markegenskaper mellan de olika odlingssystemen. De kemiska resultaten och den våta aggregatstabiliteten varierade inte signifikant mellan odlingssystemen men det fanns en tendens för högre total kvävehalt i jorden från odlingen med rent *F. macrophylla* bestånd och stabilare jordaggregat i odlingarna med rent *F. macrophylla* respektive vit mullbärs bestånd. Undersökningarna av rotutbredningen påvisade att *F. macrophylla* och vit mullbär producerade mer rötter med större utbredning än kassava. Hop Son är ett område som är beläget i ett bergigt landskap känsligt för erosion och jordarna klassificerades i huvudsak som Acrisol som i vissa delar hade höga aluminiumkoncentrationer. Den våta aggregatstabiliteten varierade starkt mellan olika slags markanvändning i området. Kassava odlingen är utbredd i området och är tillsammans med ris den viktigaste grödan. *F. macrophylla* introducerades i byn i början av år 2001 och några rader av grödan är etablerade i fält medan vit mullbär endast odlas som trädgårdsväxt. Det fanns inget intresse att etablera vit mullbär i större skala.

GLEAMS modellen simulerade stora erosionsförluster från kassava odling vilket skilde detta system kraftigt från odlingssystem baserat på *F. macrophylla* eller skog. Odlingssystem med rent *F. macrophylla* bestånd bidrog till större erosionsförluster än skog. Intensiva regn visade sig orsaka stora erosionsförluster jämfört med erosion orsakat av alldaglig nederbörd. Topografi och sluttningslutning visualiserades i en 3D modell med hjälp av GIS och en uthållig markanvändning uppskattades på basis av erosion från olika odlingssystem och sluttningslutning.

Nyckelord: Kassava, *Flemingia macrophylla*, Mullbär, Erosion, Geographic Information System, GLEAMS, Uthållig markanvändning, Vietnam

INTRODUCTION

This report covers a methodology for evaluation of sustainable land use regarding erosion in different cultivation systems on sloping land, with the focus on cassava (*Manihot esculenta*), white mulberry (*Morus alba*), *Flemingia macrophylla* and forest in Hop Son hamlet, Bavi District, North Vietnam (Figure 1). The simulation programme "Groundwater Loading Effects of Agricultural Management Systems" (GLEAMS) is applied to calculate soil loss caused by water erosion. Certain characteristics of the cultivation systems are presented and suitable land use is visualized with GIS applications. It should be underlined that this study is not a proper evaluation of sustainable land use and there is no intention to apply it directly in practice. The study should be regarded as a rough methodology using different technical means to investigate issues related to sustainable land use.

Figure 1. Map of North Vietnam and Hatay province (ESRI, 2001).

BACKGROUND

According to FAO-UNESCO classification, the main soils in the Hanoi region are Acrisols/-Alisols, which are typical soils of undulating tropical landscapes with a monsoon climate. These soils have medium-low inherent soil fertility, weak aggregate stability and low cation capacity (A. Fahlén, 2000, pers. comm.). The heavy rains that are frequent during summer, in combination with soil characteristics make the soil sensitive to erosion. For that reason, it is desirable to use farming systems for sustainable land use as a preventive measure against water erosion.

Bavi District

Vietnam can be divided into seven major agro-ecological zones: the northern mountainous and middle highlands; the Red River delta; the north central coast; the south central coast; the central highland; the northeast of Southland; and the Mekong river delta (Jonasson, 1999). Bavi District is situated in a so-called buffer zone between the northern highlands and the Red River delta. The climate is characterized by two main seasons: the cool winter season and the hot summer, with rains concentrated in the summer. The mean ambient temperature is 23.5 °C and the humidity 83 %. Annual rainfall is around 1876 mm. Figure 2 shows how the rainfall, temperature and evaporation vary during the year. The data, based on a 10-year average (1990-2000), come from Bavi climate station, situated approximately one kilometre west of the GRRC (see Figure 3).

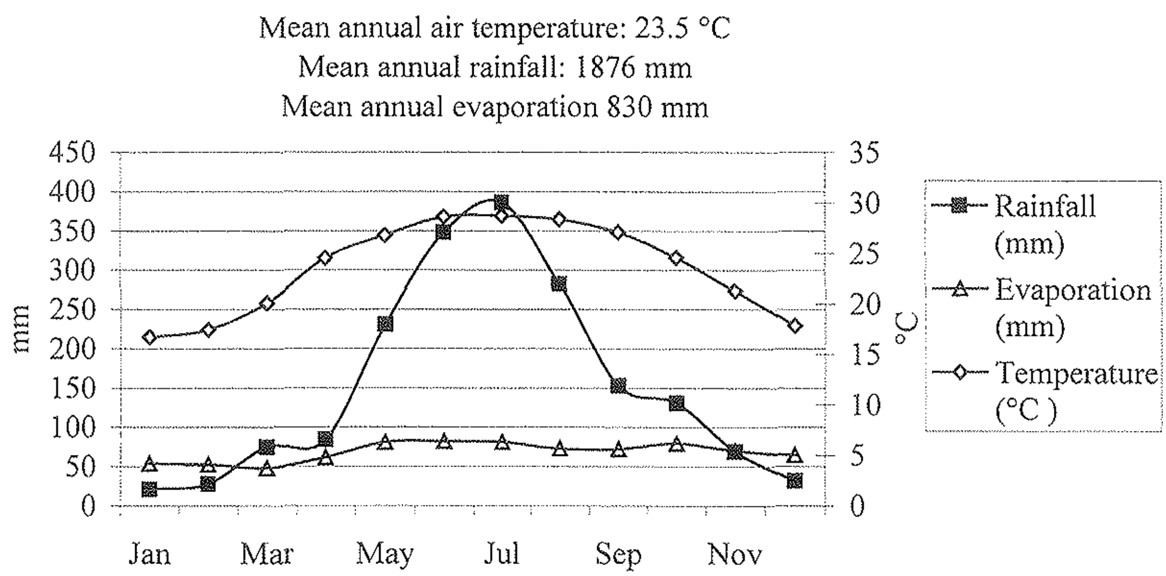

Figure 2. Climate data for Bavi district, data from Bavi climate station.

Bavi district is located in the west of Hatay province in North Vietnam. The area (which can be seen in Figure 3) is hilly to mountainous and consists to 80 % of sloping land. Due to this topography the intensity of land use is not high. The district comprises 421 km^2 of which about 14,900 ha (149 km^2) are used for agricultural purposes, although agriculture and forestry are the main activities in the district. Around 12,100 ha are used for crop production. The district consists of 32 villages and about 233,000 inhabitants. Seven of these villages are among the poorest in Vietnam. The traditional farming in the district is based on production of rice, cassava, root crops, fruit trees, vegetables and eucalyptus. Crop yields in the area are generally low due to extensive cropping systems with low inputs of fertilisers, pesticides, etc. Sloping land is generally poor and prone to widespread erosion within the district (Dinh Van Binh et al., unpublished). Almost all families keep livestock, with pigs, chickens, fish and ducks being the most common. Cattle and buffalo are kept mainly for draught purposes, both for land preparation and transport. Crop residues such as rice straw play a dominant role as feed resources for these animals. They are generally supplemented by grass from the edges of roads, fields and ponds. In tree-cropping areas, the most important feeds consist of leaves and branches (Nguyen Thi Mui et al., 1997).

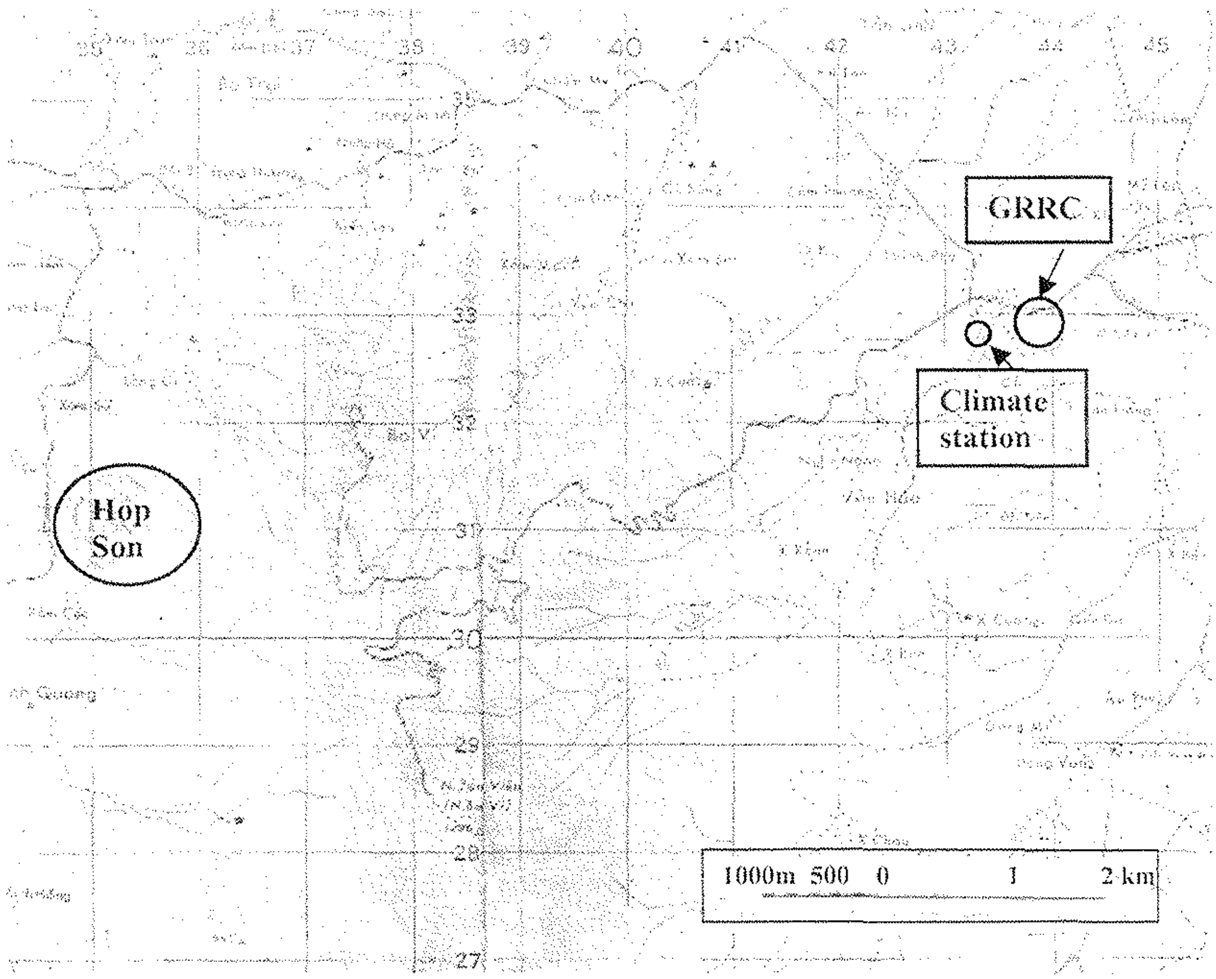

Figure 3. Bavi Mountain with surroundings within Bavi District. GRRC is situated north east of the summit, as is Bavi climate station. Hop Son village is situated west of the summit.

A Village in Bavi District

Hop Son is a village in Bavi district. It is located 105° 20 E and 21° 05 N, just northwest of Bavi National Park about 20 km west of GRRC. In order to describe the village, a discussion was carried out with Mr Duong Trung Tai and Mrs Trieu Thi Luyen. Mr Tai has lived in the village all his life and has been one of the leaders of Hop Son for about a year. His information forms the basis of the section "Hop Son hamlet" below. Mrs Luyen is a farmer within the village and a conversation with her resulted in the information in the section "The farmer" below.

<u>Hop Son hamlet</u>

Hop Son village consists of 116-117 ha of arable land and 24 ha of these are cultivated with rice. The population of the hamlet is about 320 individuals belonging to the minority Dao group; 97 are farmers and 130-140 are children. This hamlet is one of the seven poorest villages in Hatay Province and has only existed for eight years.

The cultivation in the village is based on rice and cassava. Rice is the most important and is grown as a food crop to be used within the village. Although rice grows well where the water supply is sufficient, (i.e. in depressions, valleys etc.) it does not give a large enough harvest, which is why cassava (described in Section 3.1.1) also forms a large part of their staple food. Cassava, which is thought to be well adapted to the conditions in the area, is also grown as fodder for the animals and for selling to the starch industry (starch is extracted from dried tubers). This makes cassava the second most important crop after rice.

Beside rice and cassava, many minor crops are cultivated and in addition some wild plants are harvested. For example, sweet potato and different grasses are both produced to be used as pig fodder. Cattle graze wild shrubs, and foliage is also collected for feeding pigs. Sweet potato, together with maize (for human consumption), are plants that are thought to grow well in the hamlet. Some edible canna is cultivated and sold for a good price for starch production. Edible yam is produced both for pig fodder and for human consumption. Maize is used as human food as well. In addition, trees, mainly for wood production, are planted in the higher parts of the slopes. Acacia has been planted intercropped with cassava in some places. Eucalyptus and acacia are the most planted trees, but this is not totally the choice of the hamlet. Since it borders Bavi National Park, the management of the forested parts of the village is supervised by the administration of the national park. The farmers have to contact the administration before planting and cutting. There are also some regulations, for example the minimum age for cutting acacia, which grows very fast, has been set to seven years. Earlier, the farmers tried to grow dry rice on the sloping land (on the mountains) but now this production has ceased.

Extension workers from GRRC introduced *Flemingia macrophylla* (described in Section 3.1.2) to farms with goat production during the spring of 2001. The success of the production of this plant varies between fields. This is thought to be due to different water status in the soil. White mulberry (described in Section 3.1.3) for silkworm production has been grown in 0.5 ha but now it is only grown in home gardens. Since the government does not subsidise silkworm production in this district it is not profitable to produce mulberry, although a neighbouring village still does and produces silkworms as well.

The main problem for the farmers is erosion. The worst erosion problems occur in connection with heavy rains. Soil, organic matter and fertilisers are discharged from the field with the run-off water. In the hamlet, different measures have been introduced to prevent erosion, i.e. covering the soil by planting trees to create a dense canopy. Additionally, hedgerows of pineapple and other crops have been created and water channels constructed to discharge the rainwater. The results of these measures are not very positive. The water channels are difficult to manage and are easily eroded. The hedgerows function somewhat better but are still not working satisfactorily. Villagers are now trying to implement a cultivation system where they plant forest in the highest parts of the slopes followed by strips of different crops, i.e. grasses in the higher parts and maize in the lower parts with some hedgerows in between (about ten rows of some leguminous shrubs or trees). At the bottom of the slope, a fishpond is situated. Since the cattle graze freely in the village, it is hard to collect their manure. As a result, the amount of manure produced in the hamlet is not enough for all crops and this scarcity is seen as a problem within the hamlet. The farmers are aware that application of manure might decrease the erosion problem, which, as mentioned above, is of growing concern among them. The manure they have is now mainly used in the rice fields. Chemical fertilisers are bought on the market at a fairly low price and are used both for rice production and other crops. In rice fields, phosphorus is normally added before planting and urea about two weeks after planting. Potassium is added about two months after planting.

Plant residues are mainly used as an animal feed but are sometimes burnt. For example, rice fields are normally burnt after harvest. Some farmers use cassava residues to cover the soil in the fields and acacia leaves are left on the ground if not eaten by goats. Kitchen waste is normally burnt and added as ash, generally to rice fields. Lime, which can be bought on the market at a fairly low price, is sometimes added to rice fields with very acid soils after the crop residues are burnt. Some fields receive an addition of lime every year and the result of liming is reflected in higher yields.

The farmer

Trieu Thi Luyen runs a farm together with her five sons, a daughter-in-law and a grandchild. In 1992 they moved to this farm, which consists of about 1.3-1.4 ha land. They have 10 goats, 50 chickens and 3 pigs. They grow mainly rice and cassava, which they have grown for eight years. About 1000 m^2 are used for rice production, which is planted and harvested twice per year. The first rice period runs from spring to midsummer and the second from midsummer to late autumn. The rice fields are irrigated by an irrigation system based on ponds, which are common for all the rice fields in the community. During the winter season, nothing is cultivated in the rice fields because they are too dry.

Cassava is planted only once per year. As in the whole hamlet, minor crops are sweet potato, of which stem and leaves are given to the pigs, and some grasses, also used as fodder. In addition they have some acacia, bamboo and some fruit trees; lychee, lime, banana, grape and pineapple. Some wild shrubs and grasses grow among the acacia and bamboo. The family have also made preparations to plant green tea intercropped with cassava but the tea factory that was to invest in the tea cultivation had not delivered the seedlings at the time of this study. It is planned to grow cassava intercropped with tea for two years and after that tea will be grown in monoculture. The neighbour already cultivates green tea. *Leucaena leucocephala* (a large nitrogen-fixing shrub) was introduced on the farm some time ago but was unfortunately killed by insects. *Flemingia macrophylla* was introduced in spring 2001 and seems to be successfully established. White mulberry (described in Section 3.1.3) has never been planted on the farm and Mrs Luyen does not seem to be interested in trying it. There are also doubts about whether the water status of the soil is suitable for white mulberry. The best crops are thought to be cassava on the slopes, and rice at the bottom of the slopes.

Erosion is a severe problem and Mrs Luyen has introduced various measures against, it i.e. small terraces and hedgerows of pineapple along the slope. As these measures have not proved satisfactory, she and her sons are now trying to implement mixed cropping on part of the slope. By planting two rows of *F. macrophylla* followed by two rows of cassava repeatedly, erosion can hopefully be controlled to some degree. The manure from pigs and goats is mainly used for the rice production. When cassava is grown, some manure may also be added but generally only chemical fertiliser is used on the slopes. No external manure is brought to the farm and the farmer emphasizes that the scarcity of manure is a problem. Plant residues are given to the animals but rice straw is also used for covering the soil on the slopes. The farmer says that the rice straw prevents erosion to some degree but the main reason for covering the soil seems to be weed control. The rice straw is placed in an unchopped state under the cassava so as not to be lost with runoff water. Cassava residues are chopped and dried for fodder. Kitchen waste is burnt in the kitchen and the ash is spread on the rice fields. Liming has never been done on the farm and this might be due to limited information about it, as Mrs Luyen does not see the advantages or disadvantages of using it.

The sloping field where Mrs Luyen mainly cultivates cassava today comprises approximately one hectare and is not completely homogeneous as regards form and steepness. In general, the field is a rectangular S-formed area about 140 m long and 70 m wide. The steepest part of the slope 70 m down from the top has a gradient of 40% and this flattens to about 10% in the upper and lower parts.

Goat and Rabbit Research Centre (GRRC) and the Field Trial

The GRRC is a research centre belonging to the National Institute of Animal Husbandry. It is located in Bavi District, 51 km north east of Hanoi (see Figure 1) 105° 25 E and 21° 06 N and about 220 m above sea level (Nguyen Thi Mui et al., unpublished). The centre was founded in 1978 and now consists of 65 ha, of which 50 ha are used for production of green fodder and forests (Jonasson, 1999). A fishpond is also included in these 50 ha.

A field trial was started some years ago at the GRRC. Five farming systems were established with: pure cassava (*Manihot esculenta*); pure white mulberry (*Morus alba*); pure *Flemingia macrophylla*; *F. macrophylla* intercropped with cassava; and *F. macrophylla* intercropped with white mulberry. These three plants are described in Section 3.1.

Arrangement of the field trial

The field trial is situated in an undulating, partially sloping area that was used for eucalyptus production before the establishment of this field trial (Ngo Tien Dung, 2001, pers. comm.). Three rows, named A, B and C consist of five plots each. The plots consist of cassava, white mulberry and *F. macrophylla* in pure stands, and *F. macrophylla* intercropped with cassava or white mulberry, as shown in Figure 4. Each plot is divided into five subplots, measuring 2 × 8.5 m, with different additions of manure.

Row A	Row B	Row C
Cassava	*F. macrophylla* & white mulberry	White mulberry
F. macrophylla	*F. macrophylla* & cassava	Cassava
F. macrophylla & white mulberry	White mulberry	*F. macrophylla*
F. macrophylla & cassava	Cassava	*F. macrophylla* & white mulberry
White mulberry	*F. macrophylla*	*F. macrophylla* & cassava
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Figure 4. Arrangement of the field trial at the GRRC.

Management of the field trial

Cassava was planted by inserting a woody stem cutting horizontally into the soil. White mulberry was also planted with a cutting, whereas *F. macrophylla* was planted by seed. The crops were planted in approximately 16 rows within each subplot. The field trial has now been running for three years and the plants have developed differently. The white mulberry variety grown in the field trial was imported from the Philippines. It had good growth in the first year but growth was then retarded and mulberry has, on the whole, had relatively poor growth (Ngo Tien Dung, 2001, pers. comm.). *F. macrophylla* had relatively poor growth in the first year but its growth improved in subsequent years and, on the whole, it has had excellent growth until the present time, according to Ngo Tien Dung. Cassava has also been reported to have had excellent growth. Organic fertiliser, mainly from cows and water buffalo, is added in amounts of 0, 10, 20, 30 and 40 tons/ha/year to each respective subplot in all five cultivation systems. This organic fertiliser is added on two occasions per year; before the monsoon period in March and again after the monsoon period in the middle of October; and is mixed into the soil when added. The crops are harvested four or five times a year when they have reached a height of 70 cm. They are cut at a height of 30 cm and the foliage is used as animal feed. Dead leaves are left to mulch on the ground. The cutting process takes about six days and thereafter weed control is performed by hoeing, leaving the weeds to mulch in the field. No irrigation, supplementary mineral fertilisation or addition of pesticides is carried out (Ngo Tien Dung, 2001, pers. comm.).

Objectives

In Hop Son hamlet, Bavi District, situated in the mountainous Hatay Province, North Vietnam (Figure 1), there is severe erosion due to heavy rains during the monsoon period, with subsequent losses of large quantities of soil from sloping fields. In order to prevent this erosion, several measures have been introduced, such as physical barriers, ditches etc., without very encouraging results. Recently, during 2001, cultivation systems with several crops intercropped along the slope have been proposed and introduced. The objective with this study is to characterise some plants that can be used in these cultivation systems, to evaluate the effects of these plants on erosion and soil loss and finally, to visualise an alternative sustainable land use based on the plants and cultivation systems studied. To characterise the plants and their effect on soil properties a field trial at the Goat and Rabbit Research Centre, GRRC, is evaluated and the literature studied. The GLEAMS model is used to study the effect of cultivation systems on soil loss. Finally, a GIS map is produced to give an overview of the area and to describe to what extent a sustainable land use can be achieved in the area.

LITERATURE REVIEW

Plants Used in the Field Trial

In this section, the plants used in the field trial are described as a background to the results presented later in this report.

Cassava

Cassava (*Manihot esculenta*), family Euphorbiaceae (Figure 5), is a perennial woody shrub native of tropical South America. It is grown in most tropical countries and its tubers are an important staple food in many parts of the world (Ahlgren, 1995).The plant may grow to a height of three or four metres (Silvestre, 1989) and has deeply distributed roots. During the first two months, the establishing phase, the foliage develops and the roots spread rapidly, first horizontally and then more vertically (Olsen 1995). During this period the photosynthesis in the leaves only creates enough energy for the stem to develop slowly. This changes during the next two months, when a large amount of foliage is produced and stems grow extremely fast. After this, about six months after planting, the roots start to swell and increase in size during the next five months (Silvestre, 1989).

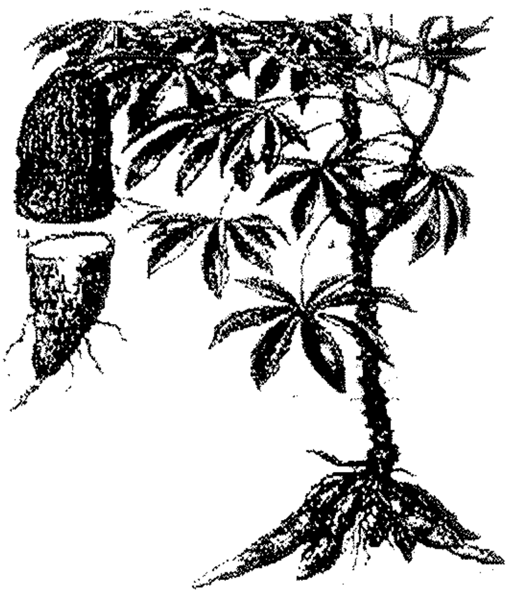

Figure 5. Cassava plant (Masefield et al. 1969)

Cassava grows best at 25°C and tolerates heights up to 2000 m above sea level. The optimal rainfall level is 1000-2000 mm/year but it grows well even between 500-5000 mm/year (Raznikiewics, 1990). This toleration of drought is due to its deep roots. However, very severe drought causes partial or total defoliation, but the plant seldom dies (Silvestre, 1989). Cassava is also well adapted to acid soils. In general, it tolerates soil pH as low as 4.6 and Al-saturation up to 80 % without any yield decrease (Lozano et al., 1981; Cock, 1985). However, one thing that cassava does not tolerate is to stand in water, since waterlogged soils can cause the roots to rot (Silvestre, 1989).

These characteristics mean that, although sandy soil with moderate nutrition status is the optimum for cassava production, the plant tolerates almost all types of soils. The only demand is that the soil must have good drainage and not contain too many stones (Raznikiewics, 1990). Cassava's reputation for depleting soils probably comes from its ability to grow in soils already so depleted that most other crops cannot be grown on them (Cock, 1985), but possibly also because cassava offers the soil little protection against erosion (Silvestre, 1989). As regards root yields, cassava is an efficient producer in low fertility soils. Thus, when grown in poor soils, cassava may not reach its full potential for total biomass production, but a larger proportion of total dry matter is found in the roots (Cock, 1985).

In Bavi District, cassava is the most important food crop after rice. The plant is also a source of animal feed, especially the leaves, although it contains some cyanide compounds that are toxic to animals. There are five varieties of cassava cultivated in Vietnam, two of them imported from China. The variety grown for biomass production in the field trial has a low cyanide content compared with the varieties grown for tuber production. Cassava has excellent growth during two years after planting but contributes unsatisfactorily to soil conservation, especially the varieties grown for tuber production (Ngo Tien Dung, 2001, pers. comm.).

Flemingia macrophylla

Flemingia macrophylla belongs to the family Fabaceae and is a leguminous shrub native in Asia (Figure 6). It is woody, deep-rooting and reaches a height of about 2.5 m. The species is found growing naturally along watercourses in forests. It can be found up to 2000 m above sea level on both clay and lateritic soils. Minimum rainfall required is about 1100 mm/year, but up to 3000 mm/year is acceptable. The plant can survive on poorly drained and occasionally waterlogged soils. It can adapt to acid soils (pH 4.5) with high soluble Al (80 % saturation) and is tolerant of mild shading (Budelman, 1989).

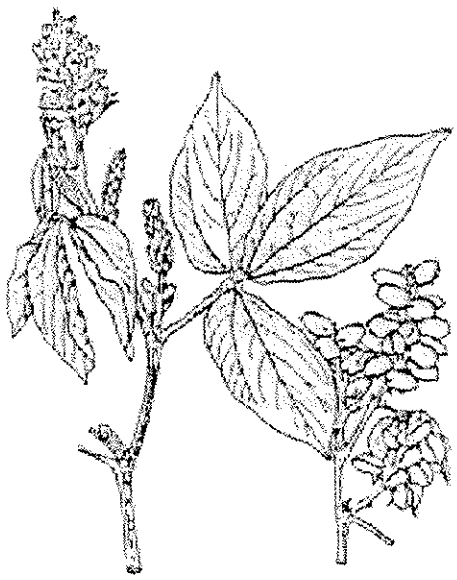

Figure 6. *Flemingia macrophylla* (Budelman, 1989).

The foliage of *F. macrophylla* can be used as fodder and is especially useful for mulching and weed control. In addition, the plant is convenient for soil protection thanks to the slow decomposition rate of its leaves along with its dense growth, moderate drought tolerance, capacity to withstand occasional flooding and coppicing ability. The mulch forms a relatively solid layer that effectively prevents germination of weed seeds and/or stunts their early development for 100 days. Soil moisture under such a mulch is also relatively high and temperatures at a soil depth of 10 cm can be 7-8°C lower in a mulched plot than under bare soil. Although *F. macrophylla* is a good weed controller when established, young plants grow slowly and weed control is important during the first two or three months (Budelman, 1989). A well-established plant can grow well for ten years or more (Ngo Tien Dung, 2001, pers. comm.). Probably the most interesting feature of the species is the relative resistance of its leaves to decomposition. Approximately 40% of a mulch layer composed of flemingia leaves (4 tons DM per hectare), was still left after 7 weeks, compared to 20% for *Leucaena leucocephala* (Budelman, unpublished).

In experimental rubber plantations in Ghana, a flemingia mulch was reported to decrease the number of required weedings per year from six to two. Temperatures at a soil depth of 10 cm were 7-8 °C lower in a mulched plot (5000 kg DM per ha) than under bare soil. Soil moisture under a flemingia mulch has been shown to be significantly higher than under mulches of *Gliricidia sepium* and *Leucaena leucocephala.* It has been observed that flemingia mulch forms a dense layer covering the soil surface that increases soil moisture and prevents weeds in flemingia cultivations (Din Van Binh et al., unpublished). *F. macrophylla* is a useful bush to plant together with creeping legumes as it provides support for them, is deep rooting and is used as a green manure in plantation crops (Skerman et al., 1988).

White mulberry

White mulberry (Morus alba), belonging to the family Moraceae (Figure 7), can form a big tree, up to 15 m high, with an umbrella-shaped crown. It is a native of China and its leaves have long functioned as fodder for silkworms, but the tree also provides timber and its fruits are delicious (Hora, 1981). In Bavi District, white mulberry is starting to be used as a fodder for ruminants. It does not have any harmful substances, like cassava's cyanide and F. macrophylla's tannins, and is thought to grow well during at least five years after planting (Ngo Tien Dung, 2001, pers. comm.). The root system of white mulberry is greatly influenced by the condition of the soil and the yield gets higher as the soil depth increases. It is very sensitive to hard pans, high water levels, gravel layers or strongly acidic layers. A cultivation layer of 20 cm will lead to extremely poor growth and a layer of 40 cm to poor growth. More than a 60 cm cultivation layer is said to be enough for desirable growth although the soil should be in good condition not only at the surface but also in deeper layers, as mulberry roots may penetrate down to 4 m. For a healthy root system the soil should have an aggregated structure with a good air content (Minamizawa, 1997).

In acid soil, the growth of mulberry becomes poor and the quality of the foliage deteriorates. This seems to be due to insufficient uptake of nutrients, thereby reducing the effect on growth of using fertilisers. Trials have shown that growth decreases when pH is less than 5.0, whereas growth is good when pH is between 5.8-6.0 (Minamizawa, 1997). The ideal soil temperature suited for root adsorption of soil solution and root growth is about 25°C, although the species tolerates temperatures between 10-15°C and 40-45°C (Minamizawa, 1997).

Figure 7. White mulberry (Brandis, 1874).

Universal Soil Loss Equation

To predict erosion, different mathematical models are used based on given parameters. One of the most used is the Universal Soil-Loss Equation (USLE), in which variable factors that influence erosion caused by rainfall are used to calculate soil-loss from a certain area. The amount of erosion depends on the soil`s ability to withstand the rain (erodibility) and the power of the rain (erosivity). The erodibility can be subdivided into three parts: 1. Soil characteristics (chemical, physical and mechanical composition). 2. Topography, where the slope is the most significant parameter. 3. Management treatments given to the soil (Hudson, 1981). The last part can in turn be subdivided into land management practices such as forestry, grazing and husbandry, while crop management includes issues such as type of crop, fertiliser treatment, harvesting etc. Contour ploughing and terracing are connected to both land and crop management.

As the model depends heavily upon the rainfall, this factor is of crucial importance. There is considerable evidence of a close association between erosion and intensity of rainfall. In temperate climates the rainfall seldom exceeds 75 mm/hour, while in many tropical countries intensities of rainfall regularly reach 150 mm/hour (Hudson, 1981). Rainfall rates of up to 340 mm/hour have been recorded in Africa by Hudson (1981) although these were only sustained for a few minutes. Kinetic energy in raindrops is very important for the erosion process and depends on the mass of the raindrops, i.e. their size as well as their velocity when they hit the ground. Energy is used for breaking down the soil aggregates, splashing them into the air and carrying the soil particles away. Under heavy rains, the detaching action of the raindrop splash is the most important part of the process, while the particles are mainly transported by the surface flow (Hudson, 1981).

To relate the vulnerability of soil to its physical properties, different methods and analyses have been used. One factor is the soil texture, where sand and silt increase the erodibility and clay decreases it. Another assumption is that the resistance to water erosion is linked to the aggregate stability of soil particles (Hudson, 1981). Steepness of a field is the dominant factor affecting erosion, in allowing surface run-off to build up and accelerate. Accordingly, the length of the slope, which allows a progressive build-up of both volume and velocity, is of crucial importance. A uniform slope loses more soil than a concave slope, but less than a convex slope. The difference in erosion caused by different management of the same soil is very much greater than the difference in erosion from different soils given the same management (Hudson, 1981). The optimal land management could be defined as the most productive and rational land use that does not cause degradation of the soil. There can be large variations in the amount of erosion depending on the detailed management of crops. For example, one experiment showed that the soil loss from two experimental plots was found to be 15 times greater from a plot with a badly managed crop of maize than from a plot with a good maize crop. Normally, close growing crops like grass tend to cover and protect the soil and row crops like cotton or maize will tend to give less protection, but it has been shown that a well-managed and well-grown row crop can minimise erosion and build up the soil and a badly managed pasture can produce serious losses of soil and plant nutrients.

Crop management is very complicated as there is an almost infinite number of different ways of managing the growing of crops. Conservation practices are mainly based on the ploughing, planting and tilling along the contour, terracing and contour ridging. The effectiveness of mechanical work along the contour is probably most effective in slopes 2 to 7 % and less effective on flatter and steeper slopes (Hudson, 1981). According to Hudson (1981) the soil loss can be more than 100 times greater from bare soil than from well-covered soil. The amount of erosion depends on how much of the soil is exposed to the rain, which is why row crops normally do not protect the soil to the same extent as grass and forage crops. In the range of cover which is usual for arable crops, variations in the density of cover will influence erosion more than any other management factor. Annual crops can neither provide cover in the early season nor after harvest.

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS)

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a continuous simulation, field scale model, which assumes that a field has homogeneous land use, soils and precipitation. It consists of four major components: hydrology, erosion/sediment yield; pesticides; and nutrient transport. In addition, the model uses the daily precipitation as input data to the modules. The hydrology and erosion/sediment yield modules were used in this study. Erosion in overland flow areas was estimated using a modified Universal Soil-Loss Equation. To estimate the erosion caused by rainfall, simulations were made with three different land/crop managements within the model and the parameters that differ between the different cultivation systems were specified. The cultivation systems simulated were cassava cultivated in pure stand, as is the actual case in the field today; *F. macrophylla* in pure stand; and forest such as hard wood. Cassava was assumed to be planted on March 12 and to be harvested on Dec 6.

In the hydrology module, the forest differs from the other land uses by a higher rainfall interception as a function of the forest type and leaf area index. Moreover, soil and climate properties are set in this module but these parameters are constant for the different land uses. Crop specifications such as leaf area index, planting and harvesting dates, crop-rooting depth and crop height as well as annual or perennial crop type, are specified in the module. This module would represent land management in the USLE.

In the erosion/sediment yield module the slope characteristics and the soil erodibilty factor are specified. The soil erodibility is based solely on the soil texture and no consideration is given to the soil aggregate stability. These factors were constant for the three cultivation systems. The soil loss ratio factor represents crop management in the USLE and is very sensitive if the profile has a uniform or convex slope. The slope studied was S-formed i.e. the higher parts of the slope were very sensitive to this parameter. Modified default values of potatoes were used for cassava, while the soil loss ratio was set to 0.2 for both *F. macrophylla* and forest. Furthermore, the management practice factor represents crop management in the USLE and is mainly based on the effect of contouring. This factor depends on the length and steepness of the slope. In the slope studied, contour tillage lost its effectiveness, as the slope was too long and too steep to derive positive effects from contouring. Finally, soil cover and soil roughness slow overland flow and reduce its sediment transport capacity. They are combined in a parameter called Manning's "n" and also represent a part of the USLE crop management. This factor increases by a factor of 40 from bare soil (0.01) to dense grass (0.40). It was set to vary between 0.01 and 0.02 over the season for cassava, a constant value of 0.07 was used for *F. macrophylla* and 0.10 for forest.

Run-off Water and Sediment Yield Experiments in Conventional and Alternative Cultivation Systems

Alternatives to monocropping or forest could be cultivation systems with many crops integrated such as agroforestry and alley cropping as a measure to alter the land and crop management. Experiment carried out in Kenya where Fanya juu terraces, bench terraces, trees on grass strips and hedgerow intercropping were studied as soil conservation technologies lead to the conclusion that contour-aligned hedgerow intercropping offers a practicable alternative to earth structures and grass strips as a method of controlling runoff and erosion (Kiepe and Young, 1989).

In a minor field study performed in Hoa Binh Province, Northern Vietnam, Brodd and Osanius (2002) evaluated a run-off water and sediment transport experiment consisting of a randomised block design with three replicates of each treatment with respect to run-off water and sediment yield from the various plots. These were situated on a slope with an average steepness of 22-24°. Three cultivation systems with upland rice monocropping, upland rice intercropped with hedgerows of *Tephrosia candida* and fallow with *Tephrosia candida* were studied. The distance between the hedgerows was six metres in the plots. Significant differences in run-off water were found between monocropped upland rice and the two other cultivation systems. No significant difference could be found between the intercropped upland rice with *Tephrosia candida* and the fallow with *Tephrosia candida* (Brodd and Osanius, 2002). The average run-off water from the plot during 1996-2000 was 235 m^3/ha for the fallow system, 325 m^3/ha for the intercropped system and 956 m^3/ha for the monocropped system. No significance could be found in sediment yield from any plots but there was a trend for the monocropped system plot to deliver more sediment than the other two and for the fallow system with *Tephrosia candida* to deliver the lowest amount of sediment (Brodd and Osanius, 2002).

Another experiment was conducted at the Ecological Research Station of Red Soils, Academia Sinica, located in the central subtropical China in 1992-1997 (Zhang et al., 2000). The soil contained 42-50% clay and was classified under the Ferrisols order according to Soil Taxonomy Classification (USDA, 1998). Plots with peanut, sweet potato, corn, soybean, buckwheat, rape, grassland, *Pinus massoniana*, *Eucommia ulmoides* and *Choerospondias* were used in different combinations and with different types of crop management. The actual slope was 7°. Zhang et al. (2000) concluded that run-off and soil erosion vary distinctly with different cropping patterns and soil management measures. Minimum tillage with mulching, ridge tillage and agroforestry strongly decreased soil erosion and run-off. In addition, soil and water loss were an important route of nutrient loss (Zhang et al., 2000).

ICRAF conducted an experiment at the Claveria Research Site MOSCAT, Misamis Oriental, Philippines (Mercado et al., 1997) where natural vegetative filter strips, i.e. a hedgerow system were evaluated to examine soil erosion. An often-recommended practice has been to space the hedgerows every one metre drop in elevation, which results in a relatively close spacing. Fewer hedgerows were tested in a 50 m long and 45% sloping experimental field. A single hedgerow (8 m elevation drop) reduced soil loss by one half compared with open field conditions. Closer hedgerows decreased soil loss further but at a declining rate. No significant difference was found for hedgerows spaced at one metre and at two metre elevation drops. It was concluded that the most practical establishment was to plant hedgerows at a two or four metre elevation distance (Mercado et al., 1997).

Likewise water run-off and soil loss were studied in an experiment at the Visayas State College of Agriculture, Baybay, Leyte, Philippines. It was reported that the addition of hedge-rows approximately reduced the run-off by half at steep experimental plots (Presbitero et al., 1995). The addition of intercropping with groundnut further reduced run-off and soil loss from the experimental plot.

A field trial in India at the Chandigarh Research Centre affiliated with India's Central Soil and Water Conservation Reasearch and Training Institute at Dehradun evaluated run off and soil loss from a cultivation system with Eucalyptus tereticornis and Bhabar grass (Eulaliopsis binata) compared to the cultivation of a pure crop. The trees were planted in rows with three meter spaces (Grewal, 1992). Between the rows the grass was planted on earth bunds (50*50 cm). The trees attained a height of 11 meters after six years and the grass yields was 4 tons/ha on average. Data from six years, 1985-1990, showed that no run off or soil loss occured in the eucalyptus-Bhabar grass system except from during two severe storms, while annual run off from the pure crop plot was about 30-35% of rainfall (Grewal et al., 1992) and thus, the agroforestry system proved superior to the cropping systems.

Results from experiment plots in Phu Wiang watershed, Thailand, reveals run off and soil loss from four categories of land use. The categories were bare soil, cash crops, agroforestry and forest plantation situated in slopes, 8-10%. The cash crops used were cassava and groundnut. Agroforestry included eight treatments representing the two cash crops intercropped with two different tree species *(Eucalyptus camaldulensis* and *Leucaena leucocephala*) with eight or four meters spacing between the rows. The forest plantation consisted of the two tree species in different combinations. The conclusion was that bare soil contributed to the largest soil loss and the forest plantation to the smallest. Run off on the other hand was greatest on the agro-forestry treatments but still smallest in the forest plantation (Thongmee, 1990).

Furthermore, trials conducted to measure soil erosion on mountain slopes 54% steepness, at Mae Muang Luang, Huai Thung Choa research area in northern Thailand showed that soil losses from agroforestry test plots were 4-9 times lower than from plots with traditional high-land rice (Hurni et al., 1983).

According to Aina et al. (1976) a study in western Nigeria showed that monocropped cassava and intercropped maize and cassava reduced water run-off by 37%, 10%, 23%, and 22% on 15%, 10%, 5% and 1% slopes respectively. In the same study, intercropping reduced soil losses by 38%, 31%, 43% and 0% on 15%, 10%, 5% and 1% slopes respectively. The infiltration capacity in the intercropped cultivation system was 700mm and in the monocropped cultivation system 450mm. The positive results in the intercropped system were related to greater degree of groundcover and greater level of rainfall interception. Aina et al. (1976) conclude that intercropped cassava increased earthworm activity, which in turn increased water transmissivity and thus, increased infiltration rate. Hence, these effects lower the rates of water runoff and soil erosion (Nilantha et al., 1989).

Plant residues can be used to cover the soil and scattered maize residues have been found to reduce soil and water losses on a Nitisol with an average 16.4% ground slope at Kabete in Kenya (Bekele and Thomas, 1989). The scattered maize residues were found to be more effective at reducing soil and water losses during low-intensity rains than high-intensity rains. Furthermore, the residues were found to be more effective in controlling interrill erosion than rill erosion due to the residue to protecting soil from particle detachment caused by raindrop impact on shallow overland flow (Bekele and Thomas, 1989).

Although hedgerow intercropping is popular and an often applied system, Samir et al. (1989) state that the prevailing impression that alley cropping is an effective erosion control management system on steep slopes has not been proven. It has been reported that tree canopies alone not only render the soil more vulnerable to erosion than canopies with litter but even more than bare soil. Samir et al. (1989) claim that the effectiveness of trees in forest is due to the accumulated litter layers and short vegetation at the forest floor. Leaves from legume trees, often used in these kind of systems, are high in nitrogen content and low in lignin and may decompose quite rapidly, a desirable feature for nutrient release but not for imparting effective protection to the soil as a surface residue (Samir et al., 1989). Half-lives for leaves of *Leucaena leucocephala* in humid tropics may be one month or less.

Soil Cover

In the FAO manual on integrated soil management and conservation practices (FAO, 2000) it is stated that soil cover is an important factor in the control of erosion by water through interception and absorbing the kinetic energy in the rain. The soil cover prevents the direct impact of the raindrops and hinders the surface becoming sealed and preserves the soil structure just beneath the surface, as well as reducing the run-off velocity and transport capacity of the surface flow. Moreover, the successful use of crop residues left on the surface in order to cover the soil depends on the quantity, the quality, the soil cover, the management and the degree of decomposition of the residues (FAO, 2000).

Aggregate Stability

The USLE and GLEAMS model are based on the fact that the erodibility is solely based on soil texture. However, other models and theories apply the stability of wet soil aggregates as an additional important factor. In Mochoge and Mwonga (1989), it is shown that water stable soil aggregates were relatively more abundant in uncultivated soils when Luvisols, Andosols and Nitisols were studied. This suggests that different land management affects the stability of soil aggregates. It is considered natural that soils with low aggregate stability have weak structural stability. When subject to tillage or the battering of heavy rainstorms, they detach easily, giving rise to soil erosion, poor drainage and poor aeration conditions in soil (Greenland, 1981). Studies have shown that aggregate stability correlates positively with organic carbon and clay content of most soils (Harris et al., 1966; Kilewe, 1984; Elwell, 1986). As a change in land use will probably affect the input of organic carbon to the soil, it is possible that an effect on soil aggregates will occur in time.

Regarding the effect of phenolic compounds on soil aggregate stability, research has shown that phenolic compounds play an important role in biological aggregate formation through stabilisation of the organic matter that bonds together soil particles (Osozawa et al., 1989). In addition, organic substances, especially polysaccharide gum and fungal hyphae, have been shown to be important contributors to aggregate formation (Harris et al., 1966). An overall consequence of change in soil quality that affects several soil characteristics was studied by Islam and Weil (2000), who conducted an investigation in Bangladesh into land use effects on soil quality. They concluded that degradation of natural forest and subsequent cultivation of soils resulted in surface compaction and significant losses in silt and clay content, porosity, aggregate stability, nitrogen, fulvic and labile carbon and microbial biomass carbon. The use of a soil deterioration index showed that soil quality deteriorated by 44% under cultivation, while in sites revegetated with fast growing acacia and grasses it improved by 6-16% (Islam and Weil, 2000). Research on long-term soil fertility at the Biological Management of Soil Fertility Project site in North Lampung, Sumatra, showed that soil aggregate stability increased in alleycropping cultivation systems with addition of organic matter from prunings and crop residues (Prijono et al., 1996). The alley cropping system was based on hedgerows with five tree species (*Gliricida, Flemingia macrophylla, Peltophorum dasyrachis, Leucaena leucocephala* and *Calliandra calothyrsus*) with four metres between the hedgerows. These species were intercropped with maize for ten years before this evaluation.

Soil Organic Matter

Soil organic matter (SOM) is of fundamental importance for the fertility of the soil as it affects various soil properties. The level of soil organic matter is maintained by an equilibrium depending on creation of new humus substances and the break-down of existing humus. The stabilisation at a certain level is achieved after a considerable time. Several investigations conclude that the change in SOM is relatively quick for a couple of decades but needs several additional decades to stabilise (Persson et al., 1994). The climate affects the equilibrium of SOM, especially the temperature and precipitation. Warm and humid conditions hasten the activity of microorganisms and the SOM decomposition. In addition, it is known that soil preparation accelerates the decomposition of humus (Persson et al., 1994). Addition of fresh organic matter is necessary for humus formation, so plant residues, manure and green manure are important inputs to the soil. Normally, fertilised land contains more C and the main reason for this is probably higher production and more plant residue inputs to the soil. Furthermore, it is possible that higher N levels contribute towards stabilising the humus substances (Persson et al., 1994). Several experiments have shown a positive correlation between input of plant residue and levels of N and C in the soil.

Several long-term experiments have considered the effect of application of organic matter in different forms, see Figure 8 (Persson et al., 1994). It is obvious that the quality of the organic matter input is essential for the formation of SOM (Persson et al., 1994). The positive effect of manure is probably due to the high content of lignin in manure, caused by more easily decomposed substances being broken down during digestion and storage. Moreover, lignin is thought to break down into smaller molecules that are transformed biochemically and finally polymerised to humus (Persson et al., 1994). The consequence of these reactions is that lignin is transformed to humus without passing through microorganisms. Due to the features of lignin, one could expect that manure would contribute more to the formation of humus than fresh organic matter that contain large amounts of cellulose and easily decomposable molecules (Persson et al., 1994).

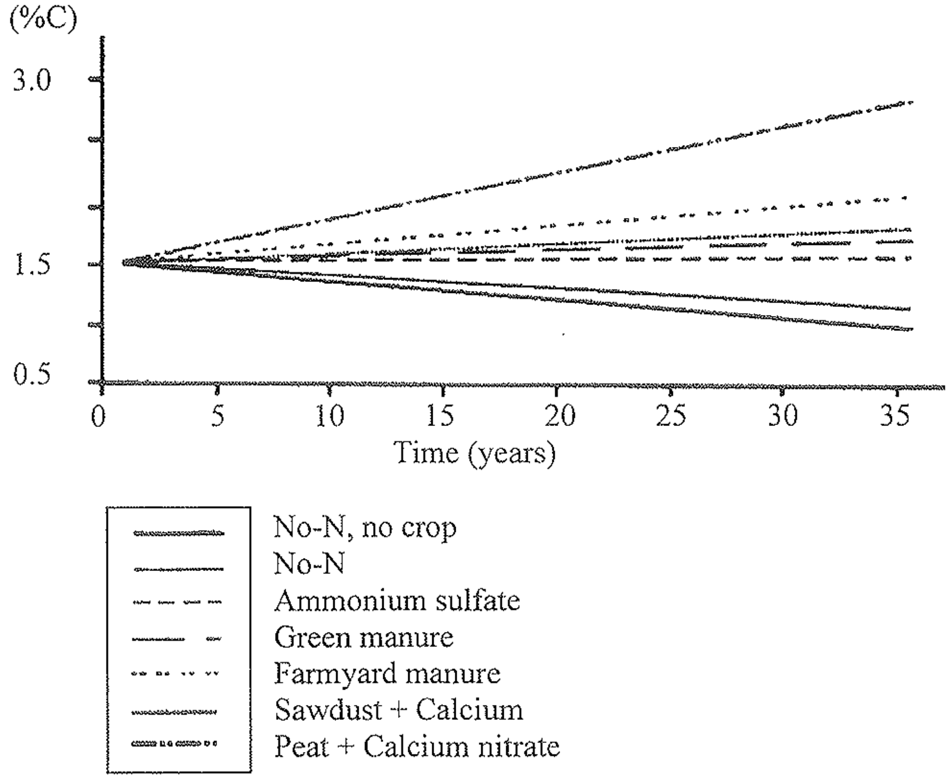

Figure 8. Soil carbon content with different quality organic matter additions (Persson et al., 1994).

Land Evaluation

To describe a sustainable cultivation system, land characteristics and qualities have to be investigated. A land characteristic is an attribute of land that can be measured or estimated (FAO, 1976). Examples are slope angle, rainfall, soil texture, available water capacity, biomass of the vegetation, etc. A land quality is a complex attribute of land, which performs in a certain manner in its influence on the suitability of land for a specific land use (FAO, 1976). Land qualities may be expressed in a positive or negative way. Examples are moisture availability, erosion resistance, flooding hazard, nutritive value of pastures, accessibility. Land qualities can sometimes be estimated or measured directly, but are frequently described by means of land characteristics. Qualities or characteristics employed to determine limits of land suitability classes or subclasses are known as diagnostic criteria. A diagnostic criterion is a variable which has an understood influence upon a specified use, and which serves as a basis for assessing the suitability of a given area of land for that use (FAO, 1976). This variable may be a land quality, a land characteristic, or a function of several land characteristics. For every diagnostic criterion there will be a critical value or set of critical values that are used to define the suitability for a specific land use. According to FAO (1976) some land qualities that can be appropriate to distinguish productivity from crops or other plant growth are:

- Crop yields
- Moisture availability
- Nutrient availability
- Oxygen availability in the root zone
- Adequacy of foothold for roots
- Conditions for germination
- Workability of the land (ease of cultivation)
- Salinity or alkalinity
- Soil toxicity
- Resistance to soil erosion
- Pests and diseases related to the land
- Flooding hazard (including frequency, periods of inundation)
- Temperature regime
- Radiation energy and photoperiod
- Climatic hazards affecting plant growth (including wind, hail, frost)
- Air humidity as affecting plant growth
- Drying periods for ripening of crops

Furthermore, qualities related to management and inputs could be:

- Terrain factors affecting mechanization (trafficability)
- Terrain factors affecting construction and maintenance of access roads (accessibility)
- Size of potential management units (e.g. forest blocks, farms, fields).
- Location in relation to markets and to supplies of inputs.

Plants cultivated in the region of Bavi District obviously suit the climatic conditions and could be used as a basis for plants is possible to produce in the area. The following flora include some of the plants cultivated in the district:

Groundnut	*Arachis hypogea*
Soya bean	*Glycine soya*
Green bean	*Phaseolus ayreus*
Longan	*Euphoria longana*
Lychee	*Litchi senensis*
Mango	*Mangifera indica*
Papaya	*Carica papaya*
Cassava	*Manhiot esculenta*
Jack fruit	*Artocarpus heterophyllus*
Pine apple	*Ananassa sativa*
Water spinach	*Ipomoea aquatica/reptans*
Custard apple	*Annora squamosa*
Sweet potato	*Ipomoea batatas*

Potato	*Solanum tuberosum*
Lime	*Citrus aurantifolia*
Eucalyptus	*Eucalyptus*
Acacia	*Acacia mangium*
Elephant grass	*Pennisetum purpureum*
Guinea grass	*Panicum maximum sp.*
Ruzi grass	*Brachiaria ruziziensis*
Para grass	*Brachiaria mutica*
Pangola grass	*Digitaria decumbens*
Bamboo	*Bambuseae bambusinae*
Banana	*Musa paradiaca*
Sugar cane	*Saccharum officinarum*
Rice (wet and dry)	*Oryza sativa*
Maize	*Zea mays*
White mulberry	*Morus alba*
Flemingia macrophylla	*Flemingia macrophylla*
Trichantera gigantea	*Trichantera gigantea*
Sesame seed	*Sesamum indicum*
Tea	*Camellia sinensis*
Coffee	*Coffea arabica*
Chilli	*Capsicum*
Grape fruit	*Citrus paradisi*
Peach	*Prunus persica*
Leucaena leucocephalla	*Leucaena leucocephalla*
Fine-stem stylo	*Stylosanthes guianensis*

Acrisols

Acrisols are distinguished by their low base saturation (BS) and low cation exchange capacity (CEC) due to strongly weathered and acid conditions. The soils are characterized by an advanced soil formation that has led to a dominance of low activity clays and lack of plant nutrients. Furthermore, clay dispersion has taken place in the topsoil and clay transport down the profile has formed a clay accumulation in deeper layers. Aluminium toxicity, strong phosphorous sorption, slaking/crusting and a high susceptibility to erosion are common features and limit the use of the soils for agricultural purposes (Driessen and Dudal, 1991). Generally, sesquioxides are lowered in the surface horizon by eluviation and accumulated in the profile by the process of "ferralitization" (Driessen and Dudal, 1991). The sesquioxides are positively charged, which induces an anion exchange capacity (AEC). The positive charges in sesquioxides combine with the negatively charged clay minerals to create stable aggregates. Due to the eluviation of clay and sesquioxides, the soil structure is weak in the surface horizon and individual elements collapse readily under the impact of tropical rains (Driessen and Dudal, 1991). Many Acrisols show signs of periodic water saturation especially in depressed areas. To preserve the surface soil, input of organic matter is essential. Acid tolerant crops can be grown with success but the best use of this land is probably for natural forest.

The soil physical characteristics of the surface horizon at the sites 1a and 2a on sloping land in Hop Son (described in Section 5.2) are based on the high content of silt. A high content of clay induce strong cohesion between the soil particles while a high content of sand and gravel bring about strong friction between soil particles (Emmerman et al., 1990). Unfortunately, a high content of silt neither create strong cohesion nor friction. Consequently, soils with a high silt content are characterized by weak coherent powers according to Figure 9. This fact, in combination with factors mentioned in the previous discussion about Acrisols bring about a surface horizon that is prone to erosion.

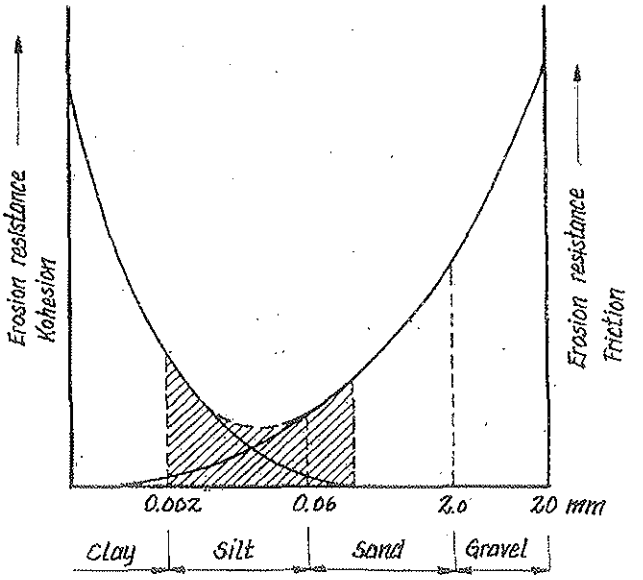

Figure 9. Mohr-diagram, cohesion and friction correlation to texture.

Al-toxicity

The aluminium toxicity in the soil solution relates to the amount of base cations in the solution, i.e. the concentration of free Al^{3+} ions is lowered at a high amount of base cations present. Through addition of organic matter base cations are added to the soil and hence the Al-concentration most likely will decrease (I. Nilsson, 2001, pers. comm.). Moreover, the N_2-fixation in leguminous plants reacts to the Al-concentration in the soil solution. High Al-concentration will decrease the N_2-fixation and vice versa (I. Nilsson, 2001, pers. comm.).
Hairiah (1996) discusses the possibilities that soluble organic matter, especially fulvic acid, may detoxify aluminium by complexation. No clear conclusion is drawn in this matter but it should be kept in mind as an alternative to input of cations for Al-detoxification.

MATERIALS AND METHODS

Analyses of the Field Trial

Different tests were carried out to determine the effect on soil characteristics in the different farming systems in the field trial and to investigate the systems' potential for biomass production. In this chapter, the methods used for these tests are described.

Topography

As the field trial is situated partially on a slope, we measured the inclination within the field with a clinometer. This was done to understand the soil erosion processes in the field and the extent to which the land has been affected by erosion. If the soil showed large variations in erosion, this would cause differences across the field regarding soil properties that we would have to consider. The slope in each plot was measured separately and a compass gave the direction of each slope. We also made a visual observation of signs of water erosion in the different plots.

Soil structure

During soil sampling we performed rough observations regarding soil structure in the topsoil at the different subplots. This was done by comparing the different structures with each other and grading them in relation to each other.

Properties of unaffected soil

To get background information about unaffected soil in the field trial, we carried out a soil profile description close to the site. In that way, we got information about what characteristics the soil had down to a depth of 100 cm. The soil profile description was made according to Guidelines for Soil Description (FAO, 1990). The classification of the soil was made according to two soil classification systems: World reference base (WRB) for soil resources (FAO, 1998) and Soil taxonomy (USDA, 1998). A simple compass and a clinometer were used to measure the aspects and steepness of slopes. The compass used was based on 400 degrees.

Chemical analyses

To get representative soil samples for chemical analyses of the field trial soil, seven samples were taken in each subplot where no manure had been applied. In the cassava plots, however, samples were taken in all subplots (without and with 10, 20, 30 and 40 kg manure application). The samples were taken between the crop rows 2-3, 4-5, 6-7, 8-9, 10-11, 12-13 and 14-15. Soil samples from each subplot were mixed to give a bulk sample, of approximately 2.5 litres that was collected in a plastic bag. In addition, soil samples, approximately 2.5 litres, from different horizons in the soil profile next to the field trial, plus samples from four profiles in Hop Son village, were collected for soil classification. These samples were also collected in plastic bags. All the soil samples were sun-dried before being sent to the National Institute for Soils and Fertilisers in Hanoi for textural and chemical analyses. The equipment and methods used for the chemical analyses can be seen in Table 1 below, which also shows which methods were used to analyse soil samples from Hop Son village. The textural analysis of all the soil samples was conducted with the pipette method with the intervals: clay < 0.002, silt 0.002-0.02 and sand 0.02-2 mm.

Table 1. Equipment and methods used for the chemical analyses

Quality	Method
pH	Measured with KCl (1.0 M)
Total C	Walkley-Black method
Total N	Kjeldahl method
CEC	ISRIC 1987 (NH_4OAc 1.0 M pH=7 (8.2)) / Kjeldahl
P	Bray2 method (0.03 M NH_4F / 0.10 M HCl) measured with a Jasco 7800 UV/VIS Spectrophotometer
Ca^{2+} & Mg^{2+}	ISRIC 1987 (NH_4OAc 1.0 M pH=7) measured with a Perkin Elmer Atomic Absorbtion Spectrophotometer 3300
Al^{3+}	Extracted with 1 M KCl
K^+ & Na^+	ISRIC 1987 (NH_4OAc 1.0 M pH=7) measured with a Corning Flame photometer 410

Root distribution

In order to study the development of roots in the different cultivation systems, we performed a visual observation of the roots in the five different farming systems without manure application (see Table 2 and Table 17). To minimize the effect of variations of erosion along the field trial, we chose to make three observations per subplot in five trial plots, situated on almost plain ground and bordering each other, instead of making one observation in all 15 trial plots. The subplots chosen were the cassava and *F. macrophylla* cultivations in the A row, *F. macrophylla* plus cassava and the *F. macrophylla* plus white mulberry cultivations in row B, and the white mulberry cultivation in row C. To observe the roots we used a profile wall method, meaning that we dug pits to expose a vertical soil profile. The pits were dug across the rows of plants and measured about 60 × 30 cm with a depth of 25 to 30 cm depending on the depth of the profile horizons. First the pit was dug with the vertical profile about 3 cm from the plant and the soil profile was then cut back carefully with a knife toward the base of the plant. When this was done the profile's horizons were noted and the size, abundance and distribution of the roots were studied. To determine the size and abundance of roots, the scales in Table 2 (based on Hodgson's Soil Survey Field Handbook from 1976) were used. Roots larger than 10 mm were described separately in general terms.

Table 2. Size and abundance of roots

Frequency class	Number of roots per 100 cm^2			
	Very fine roots (Ø < 1 mm)	Fine roots (Ø 1-2 mm)	Medium roots (Ø 2-5 mm)	Coarse roots (Ø > 5 mm)
Few	1-10		1 or 2	
Common	10-25		2-5	
Many	25-200		> 5	
Abundant	> 200		-	

Soil aggregate stability

A soil stability measurement was carried out according to C. W. Watts and A. R. Dexter's water stability test (Arvidsson and Håkansson, 1996). Soil aggregates were collected from the top 5 cm in the profiles from the field trial at the GRRC as well as at the sites in Hop Son hamlet. The soil samples were brought to the Swedish University of Agricultural Sciences where the measurements were carried out. 2*10 soil aggregates was collected at sizes 8-16 mm and weighed. The aggregates were wet-up under a 5 cm tension during 20 hours. The wet aggregates were mixed with 125 ml deionised water and shaken in an end-over-end shaker for 30 minutes. The samples were left to settle for 24 hours and 20 ml portions of the collected suspension of dispersed clay were measured by turbidimetry. Finally, a certain number of the 20 ml samples were dried and the amount of clay determined.

Soil Properties in Hop Son Village

With the intention of describing the soil properties in Hop Son village as accurately as possible, we also carried out soil profile descriptions and classifications there. This was done to investigate the possibilities of transferring the farming systems used in the field trial to the village. Four sites in the village were chosen for the soil profile description. Site 1a was situated on the upper part of a slope with cassava production; Site 1b in a rice terrace on levelled ground; Site 2a on a slope covered with acacia and shrubs; and Site 2b is situated on sloping shrub land. In the soil profile descriptions and classifications, the same methods and guidelines were used as in the description and classification of the soil next to the field trial. These are presented in Section 4.1.3 in this chapter.

Erosion modelling

The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model version 2.1 was employed to simulate run-off and soil loss from Mrs Luyen's cassava field. Different land use at this field was evaluated regarding soil loss as well as how changes in steepness would affect soil loss in relation to different land use. The model consists of different modules that are based on a precipitation file with daily rainfall. The precipitation data used was default values from North Vietnam in the WaNuLCAS model (Iwald, 2001). The results were compared with input of high intensity rainfall data from Bavi climate station to evaluate the effect of single thunderstorms on run-off and soil loss. An average 10-year value of the most intensive rainfall during the year was 68 mm/hour, while the maximum intensity over ten years was 99 mm/hour. As the model only uses daily input of rainfall, these values were set as a daily precipitation, i.e. 68 and 99 mm/day respectively. Moreover, the hydrology and erosion modules were parameterized with the features of the climate, topography, land use and crop management etc. Unfortunately GLEAMS assumes that a field has homogeneous land use and does not allow simulation of hedgerows etc. within a specific field.

Several parameters had to be estimated from default values in the model. Although Leaf Area Index (LAI) for cassava was found in the CIAT Cassava Program (1984) for the cultivar M Col 1684, default values for cotton were used for *Flemingia macrophylla* leaf area index (LAI) and default values for hardwood were applied for the forest option. The soil loss ratio (CFACT) represents the crop factor in the USLE. The soil loss ratio depends on the management conditions and the type of crop. This factor is very sensitive in slopes that are uniform or convex (steepening along the slope). If the slope is concave (flattening along the slope) or complex (convex-concave) the parameter is not nearly as sensitive (Knisel and Davis, 1999).

The soil loss ratio for cassava was based on table values for potato and the soil loss ratio for *Flemingia macrophylla* was based on table values for cotton. The soil loss ratio for forest was set to 0.2. Another parameter that ought to be mentioned is the Management Practice Factor (PFACT). This factor depends on the management, mainly the contour tillage. The effectiveness of the parameter depends on the length and steepness of the slope. Due to the size and steepness of the fields studied, this factor was 1.0 for all the crops. Soil loss ratios and other parameters for a number of management conditions and selected crops were published by Wischmeier and Smith in 1978. The tables were reproduced by Foster et al. in 1980 and are applied in the GLEAMS model today (Knisel and Davis, 1999). The values are good references, and can be used as guides for estimating several parameters in GLEAMS. The so-called Hydraulic Roughness parameter (Manning´s "n") describes the soil cover and roughness properties that slow overland flow and reduce its sediment transport capacity. The values for Manning's "n" applied in this study were estimated for the cultivation systems based on given table values. The hydrological properties of the soil were estimated from default values considering the soil's textural composition. The cassava planting date was set to March 12 and the harvesting date to December 6. *Flemingia macrophylla* and the forest are perennial without re-planting during a normal year.

In order to discuss the land use in the area of Hop Son village, an interpolation of the properties at Mrs Luyen´s sloping field and the properties of the soil at the other sites in the village was made. Simulations of fields 100*100 m with a uniform slope were performed at 10 %, 20 %, 30 %, 40 % and 50 % steepness for the three cultivation systems. The *F. macrophylla* cultivation system was used to describe an agroforestry system.

Soil loss tolerance

Skidmore´s soil loss tolerance method was employed for theoretical calculation of a soil loss value in a sustainable land use system. The method is based on the assumption of a critical depth of topsoil to be maintained by the renewal rate of soil, while depletion of soil properties (e.g. depth) in excess can be used for present or predictable future requirements. Stated in mathematical terms, the equation is (Skidmore, 1982):

$$T(x,y,t) = (T_1 - T_2) / 2 - (T_2 - T_1) / 2 \cos [\pi (x - z_1) / (z_2 - z_1)]$$

$T(x,y,t)$ = allowable soil loss at a certain point and time (mm/yr)
T_1 = lower limit of allowable soil loss rate (mm/yr)
T_2 = upper limit of allowable soil loss rate (mm/yr)
z_1 = min. allowable soil depth (m)
z_2 = optimum soil depth (m)
x = present soil depth (m)

GIS

To create digital elevation map (DEM) that could be used to study slopes, aspects and areas in the Hop Son region, an ordinary map sheet was used as the basic topographic input. The map, scale 1:50 000, was digitalised with an Altek digitizer and the software programme Rootspro and built up as polygons. The polygons were coded according to the average elevation. The digitalised data were then transferred to ArcInfo as an e00-file and the height values were set to the polygons, as well as reference coordinates for the map in long-lat-decimal degrees. In this way, a polygon topography was shaped. Furthermore, the file was exported as an e00-file via the software programme import 71 to ArcGIS 8.1 and the module ArcTools was used to determine spatial data such as coordination- and reference system as well as projection. WGS 84 (World Geodetic System 1984) was used for this. It is a global system that represents both a reference system and an earth ellipsoid (P.O. Hårdén, 2002, pers. comm.). Finally, the file was opened in ArcView 3.2 and a TIN (Triangulated Irregular Network) model was produced from the features. Slopes, aspects and contours were derived from this model. Different intervals of slopes were set and the areas of the certain intervals were calculated. In order to form hydrological properties the basic digital topographic map imported from ArcInfo was converted to grid format in ArcView 3.2. By the module Spatial Analyst extension the water flow accumulation, flow direction and sinks were calculated and used to visualise a water stream network within the area. To create a proper elevation visualisation the data was transferred to the 3D scene in the module 3D Analyst based on the TIN model to specify the elevation. Finally, a suitability map was produced regarding water erosion due to different cultivation systems.

Statistics

Variance analysis is used to investigate differences between different treatments (Mattsson, 2001) or as in this case the effect of different cultivation systems on soil characteristics. The result describes any significant difference that can be found between the examined treatments.

The following characters are used in the analysis:
SS=Square sum
n=number of observations
bl=block (repetitions)
l= treatment
e=error
C=correction term=$(\sum x)^2/n$
SS_T=Square sum for total=$\sum x^2$-C
SS_{bl}=Square sum for block=$\sum(x_{bl}^2/n_l)$-C
SS_l=Square sum for treatment=$\sum(x_l^2/n_{bl})$-C
SS_e=Error for square sum= SS_T- SS_{bl}- SS_l
LSD=Least Significant Difference=$t_\alpha*\sqrt{(SS_e*2/(DF_{SSe}*b))}$
t_α=to be found in tables, depends on degree of freedom and significance.
DF=degree of freedom
b=number of blocks
SSmean=SS/DF
F-quota= SSmean(SS_{bl} alt. SS_l)/SSmean(SS_e)

The F-quota tells us how much larger the variation is between different treatments than between the repetitions and is compared to a table value (Fisher and Yates, 1957) for a certain level of significance. This value corresponds to a probability that there are significant differences. If the F-quota fulfils the requirements for significance at 5 %, the next step is to calculate the LSD at 5 % significance. This value (Fisher and Yates, 1957) tells us how large the difference between two average values has to be to show a significant difference between the treatments. To find out which treatments differ from each other, they are grouped into different categories. Eventually, by final grouping those treatments that do not differ from each other by more than the LSD value are grouped together. See Table 3 for an example.

Table 3. Variance analysis for water stability test from sites in Hop Son hamlet

Tretament:	1	2	Sum	Average	group	final grouping
1A	0.0140	0.0226	0.0366	0.0183	a	a
1B	0.0041	0.0052	0.0092	0.0046	b	b, c
2A	0.0087	0.0087	0.0174	0.0087	c	b
2B	0.0004	0.0005	0.0009	0.0004	d	c
Sum	0.0271	0.03701	0.0642	0.0080		

Corr. term: 0.000514534

	SS	DF	SSmean	F-quota	Min. 5 % sign.	Min. 1 % sign.
SSbl	0.000012157	1.0	0.0000121572	1.9		
SSl	0.000351321	3.0	0.0001171069	18.7	6.6	16.7
SSe	0.000025101	4.0	0.0000062752			
SSt	0.000388579	8.0	0.0000485724			

LSD (5 % sign.) = 0.0070

RESULTS

Results from the Field Trial

In this section, the results from analyses from the field trial at the GRRC, Hop Son hamlet and GLEAMS are presented in the same order as in the presentation of Materials and Methods.

Topography

The field trial is situated on a slope that fluctuates in steepness across the field. As shown in Figure 10 below, the plots in the northwest corner have the steepest slopes and are therefore more affected by water erosion than other plots. By visual observation it seemed that water erosion clearly affects the plots with a slope of 7 % or more. The plots with a slope steeper than 3 % seemed to be slightly affected by erosion. The signs of erosion we observed were mainly a reduced thickness of the surface horizon (extending from 12-13 cm, on average, in the plots on slopes ≤ 3 %, to a lack of surface horizon in the most affected plots).

Row A	Row B	Row C
Cassava Slope: 4 % Direction: 50° NE Soil structure: porous, no gravel	***F. macrophylla* & white mulberry** Slope: 3 % Direction: 20° NNE Soil structure: porous, no gravel, crust	**White mulberry** Slope: 3 % Direction: 380° NNW Soil structure: porous, some gravel, crust
F. macrophylla Slope: 1 % Direction: NNE Soil structure: porous, no gravel	**Cassava & *F. macrophylla*** Slope: 3 % Direction: 20° NNE Soil structure: porous, some gravel	**Cassava** Slope: 6 % Direction: 380° NNW Soil structure: porous, some gravel
***F. macrophylla* & white mulberry** Slope: 0 % Direction: - Soil structure: porous, no gravel	**White mulberry** Slope: 3 % Direction: 380° NNW Soil structure: porous, some gravel	***F. macrophylla*** Slope: 9 % Direction: 380 NNW Soil structure: porous, medium gravel
Cassava & *F. macrophylla* Slope: 4 % Direction: 390° NNW Porous soil structure, no gravel	**Cassava** Slope: 7 % Direction: 370° NNW Soil structure: porous, some gravel	***F. macrophylla* & white mulberry** Slope: 12 % Direction: 370° NNW Soil structure: porous, much gravel
White mulberry Slope: 7 % Direction: 390° NNW Porous soil structure, some gravel	***F. macrophylla*** Slope: 9 % Direction: 370° NNW Soil structure: clods, some gravel	**Cassava & *F. macrophylla*** Slope: 12 % Direction: 370° NNW Soil structure: porous, much gravel
	⇓ **NNE 20°**	

Figure 10. Slopes, aspects and soil structure across the field trial.

Soil structure

During soil sampling for chemical analyses we observed that the structure of the topsoil was porous in every plot except for the *F. macrophylla* plot in row B, which was characterised by large, relatively hard aggregates (clods). The content of gravel fluctuated within the field (see Figure 10), with least gravel in the southeastern plots and most in the northwestern ones.

Soil aggregates were, in general numerous and their size was fairly large, about 1 cm^3, with some variation in both aggregate size and frequency. In row B, the plot with *F. macrophylla* had smaller soil aggregates than average, and pure cassava in the A- and B-rows as well as white mulberry in the B-row had fewer soil aggregates than average. In the C-row, the plot with *F. macrophylla* and white mulberry intercropped had more small aggregates and fewer large ones than the general situation.

In the paths between rows A and B, as well as between B and C, clods characterized the soil. As in most plots, soil aggregates were numerous and fairly large. The path between rows A and B had no gravel, but some gravel was found between rows B and C.

Properties of unaffected soil

The soil profile close to the field trial is classified as an Acrisol according to World Reference Base (WRB) and is described in detail in Appendix 1. The profile description was carried out at a site not visibly affected by erosion, in contrast to the field trial that was clearly affected by erosion. This difference explains the fact that of the four different horizons found in the described soil profile, the top horizon was not present in the field (and is therefore not presented in the tables below).

According to the extent of erosion in the field trial, the topsoil has been thinned and has an increased content of gravel, originating from horizons below. At 42 cm depth, an abrupt textural change occurs in the soil profile (since the topsoil horizon is absent in the field this change probably occurs at about 32 cm depth there). 75 % gravel is found in the horizon below 42 cm and the clay content of the fine earth fraction increases at this depth. This means that although Table 4 shows that all the horizons have a high content of clay, the horizon called $2B_t$, discussed above, has the highest content of clay which, together with its high gravel content, makes it very compact.

Table 4. Particle size in the horizons of soil close to the field trial

Soil depth (cm)	Particle size (%)		
	Clay (< 2 μm)	Silt (20-2 μm)	Sand (> 20 μm)
A_h 10-23	35.2	34.4	30.4
AB 23-42	34.4	33.6	32.1
$2B_t$ 42-100+	41.8*	34.4*	23.9*

* The sample from horizon $2B_t$ contained 75 % gravel, which was removed before the analyses were done.

The soil has a low pH value through the whole horizon (Table 5). In our analysis, pH was measured in KCl but an estimation of the pH in water can be made from this. For soil conditions in Sweden a pH_{KCl}-value of 3.75 corresponds to a pH_{H2O}-value of about 4.73, which means that there is almost a difference of 1 when the pH-value is low (pH_{KCl} 3.5 = pH_{H2O} 4.5) (Persson, unpublished). A soil profile description of an Acrisol in Hatay province, not made by us, shows that this is roughly correct for Northern Vietnam soils too (Anonymous, unpublished). This means that you can get an approximate pH in water by adding 1 to the pH_{KCl}-values.

The cation exchange capacity (CEC) is 10.0 me/100 g soil in the topsoil but decreases down the profile. Effective cation exchange capacity (ECEC) through the profile is about 3-4 me/-100 g soil and the base saturation (BS) is around 6-7 % in the top 32 cm. The saturation of aluminium is very high in the soil, varying between about 77 % and 88 % as shown in Table 5.

Table 5. Chemical data for the soil close to the field trial

Soil depth (cm)	pH_{KCl}	CEC (me/100 g soil)	Apparent ECEC (me/100 g soil)	Al-saturation (Al^{3+}/ ECEC-soil)	BS (%)
A_h 10-23	3.8	10.0	3.9	82.2	7.0
AB 23-42	3.8	7.0	3.5	87.8	6.1
$2B_t$ 42-100+	3.8*	5.9*	2.8*	76.5*	10.9*

* The sample from horizon $2B_t$ contained 75 % gravel, which was removed before the analyses were done.

Chemical data

The results from the chemical analysis show no evident differences in chemical status between the cultivation systems. There might be higher total nitrogen content in the subplots with pure *F. macrophylla* although this does not fulfil the requirements of 5 % significance. There was no trend with respect to the carbon content between different cultivation systems. This could be based on the fact that the amount of added manure only corresponds to a small part of the total carbon content in the soil, which could explain why no clear trends were found in the results of the chemical analysis with different amounts of added manure (Table 6).

The handling and storage of the soil samples were not optimal. The samples were sun dried and it could take one or two days to dry them depending on the weather. Further on, the samples were probably stored for one or two weeks, although dry and in plastic bags, before the analyses were done at the Soil and Fertiliser Institute in Hanoi. This probably affected the results i.e. microbial activity involving nitrogen etc.

Table 6. Chemical data from plots without addition of manure (A, B and C represent the three rows presented in Figures 4 and 8, the two controls are taken from the paths between rows A and B, or B and C)

	pH_{KCl}	OM %	Tot C %	Tot N %	C/N	P mg/100g	K me/100g	Ca me/100g	Mg me/100g
A. Cassava	3.8	5.0	2.9	0.17	17.2	1.30	0.08	0.94	0.17
B. Cassava	3.8	4.4	2.5	0.15	16.9	1.29	0.06	0.54	0.12
C. Cassava	3.8	4.9	2.8	0.15	18.8	1.81	0.09	0.62	0.13
A. *F. macrophylla*	3.8	5.6	3.3	0.18	18.2	1.30	0.08	0.74	0.13
B. *F. macrophylla*	3.7	5.2	3.0	0.20	15.2	1.32	0.08	0.87	0.15
C. *F. macrophylla*	3.8	4.8	2.8	0.22	12.6	2.37	0.09	0.58	0.13
A. White mulberry	3.7	5.0	2.9	0.18	16.2	2.09	0.09	0.78	0.15
B. White mulberry	3.7	4.8	2.8	0.15	18.5	2.30	0.08	0.49	0.10
C. White mulberry	3.8	4.6	2.7	0.14	19.0	1.92	0.08	0.92	0.15
A. *F. macrophylla* & cassava	3.6	4.5	2.6	0.17	15.4	1.09	0.08	0.46	0.11
B. *F. macrophylla* & cassava	3.7	5.2	3.0	0.18	16.7	1.59	0.09	0.69	0.14
C. *F. macrophylla* & cassava	3.7	5.0	2.9	0.16	18.3	1.38	0.09	0.66	0.16
A. *F. macrophylla* & white mulberry	3.7	4.5	2.6	0.16	16.4	1.29	0.07	0.48	0.12
B. *F. macrophylla* & white mulberry	3.8	4.5	2.6	0.14	18.7	1.60	0.06	0.75	0.14
C. *F. macrophylla* & white mulberry	3.8	4.8	2.8	0.19	14.6	1.62	0.09	0.64	0.16
AB Control	3.8	5.0	2.9	0.16	18.1	1.51	0.08	0.58	0.12
BC Control	3.9	5.4	3.1	0.18	17.3	3.62	0.13	1.50	0.26

Variance analyses were carried out for N and C content of the chemical data. No significant differences could be found between the different treatments with regard to these two elements at a level of 5 % significance.

Root distribution

The horizontal distribution of cassava roots reaches a width of about 15 cm from the stem while *F. macrophylla* roots mainly are distributed within 20 cm from the stem. *F. macrophylla* normally consist of few/common medium-sized roots that grow more than 50 cm from the stem (see classification method presented in table 2). White mulberry roots normally are distributed within 20 cm from the stem although a few/common medium-sized and one or two coarse roots are found more than 50 cm away from the stem. We did not observe any consistent differences between the root development in subplots with and without manure application. On the roots of *F. macrophylla* we found N-fixing nodules (≤ 1mm). On some mulberry roots we also found nodules that were somewhat larger (≤2 mm), but we were unable to identify them.

According to table 17 (Appendix 6) it is obvious that cassava roots mainly consists of very fine, fine and medium roots in the A_h horizon. Further down in the soil layers almost only very fine roots can be found. The horizontally distribution keep within 15 cm from the stem.

The roots of *F. macrophylla* consist of many/common roots of all qualities in the A_h horizon and few/common/many roots of different qualities in the AB horizon. Down in the B_t-horizon we found mainly few very fine and coarse roots, whereas the coarse roots grow vertically. As we already mentioned few/common medium roots are found further away than 50 cm from the stem.

Mulberry roots seems to have many/common/few roots of different qualities in the A_h horizon and the distribution in the AB horizon consists of few/common roots of different quality. In the B_t-horizon we mainly found few very fine roots, although larger plants had few medium/-coarse roots growing vertically further down. In the same way as *F. macrophylla,* mulberry have few/common medium roots growing more than 50 cm away from the stem. For more developed plants these roots could be coarse.

To conclude it should be said that the horizontal distribution of roots differed between cassava and the other two plants, which had a similar root development. While cassava roots grew to about 15 cm from the stem, *F. macrophylla* and mulberry roots were distributed within 20 cm from the stem with few or common medium roots growing more than 50 cm from the stem. Cassava roots were mainly found in the Ah-horizon and consisted of medium, fine and very fine roots. *F. macrophylla* and mulberry normally had many or common roots in the Ah-horizon of all qualities. *F. macrophylla* had few, common or many roots of different qualities in the BA-horizon while mulberry had few or common roots of different qualities. In the B_t-horizon only few very fine and coarse roots were found for both *F. macrophylla* and mulberry.

In general, *F. macrophylla* seemed to be healthier and to have better growth than mulberry at the field trial, which could explain why it had slightly more roots than mulberry. Considering this aspect, these two plants had a similar root development at the field trial. Cassava on the other hand grew well but had a modest root development.

Soil stability measurement in the field trial

The water stability test did not demonstrate significant differences at the 5 % level of significance in the field trial at the GRRC (Table 18, Appendix 7). However, the cultivation systems with *F. macrophylla* and white mulberry in pure stand indicated that there was a tendency for higher aggregate stability in these two cultivation systems than in the others. The correlation between the turbidimeter value and clay content in the soil solution can be studied in Figure 11. This revealed that a high turbidimeter value indicates that a large amount of clay from the soil aggregates is suspended in the soil solution and hence point towards a weak wet aggregate stability.

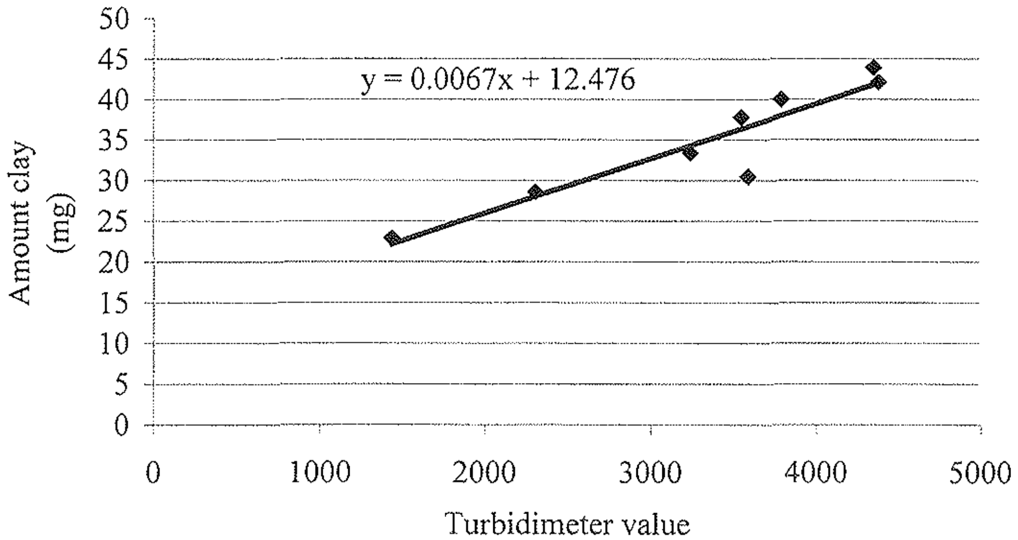

Figure 11. Correlation between clay content and turbidimeter value at the field trial, GRRC.

The variance analysis on the results of the water stability test revealed that the samples from the field trial gave a low F-quota, which indicates that there was no significant difference at 5 % significance level between the samples. However, there was a 20 % significance between the cultivation systems with cassava and *Flemingia macrophylla* that points towards a tendency of higher stability in the soil aggregates found in the *Flemingia macrophylla* cultivations compared with cassava cultivations.

Soil Properties in Hop Son Village

The soil classifications and soil profile descriptions were made at four sites along two slopes at Hop Son village. The sites were named 1a on slope one, 1b at the bottom of slope one and 2a, 2b on slope two. The complete results are described in Appendix 2 (for 1a), Appendix 3 (for 1b), Appendix 4 (for 2a) and Appendix 5 (for 2b). In general, soils on slopes fulfil the requirements for Acrisols according to FAO-World Reference Base (FAO, 1998). i.e. strongly weathered acid soils with a low base saturation evolved in a monsoon climate, and textural data indicate that clay eluviation has taken place and formed an argic B-horizon typical for Acrisols. Site 2b does not show evidence of clay eluviation and is therefore classified as a Ferralic Cambisol (FAO, 1998). The profile does not fulfil the requirements for an argic horizon, which could be explained by human mechanical activities, including movements of soil in the area due to earlier constructions of soil terraces. The soil texture at the sites is dominated by silt (50-90 %) within the size class 2-20 μm and high contents of clay are found (10-45 %) along slope two. Relatively high contents of organic matter are found at the sites (0.5-5 %). The Al-saturation is high at slope two (70-90 %). The pH varies between 3.7 and 5.15 (KCl) where the highest values were found at site 1b situated on a levelled wet rice field. This site has a high base saturation (55-90 %) compared with the other sites (3-35 %). Site 1b is classified as an Anthrosol (FAO, 1998) created by man. CEC is low at all sites.

The sites 1a, 2a and 2b are situated in slopes but site 2b had been exposed to physical soil movements by human activity why this site doesn't seem to reflect a natural soil profile found in slopes in the area and are therefore excluded as a representative soil profile in the area. Site 1a and 2a are presented more closely below.

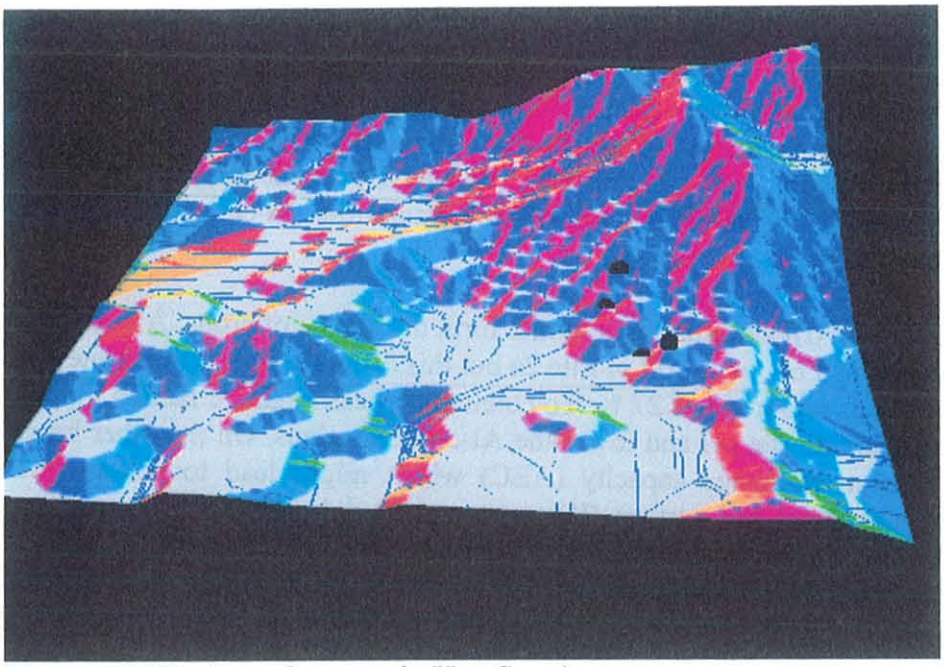

Figure 27. 3D view of aspects in Hop Son Area.

Figure 26 and 27 disclose the aspects of the fields studied. Mrs. Luyen's cassava field (between the sites farthest to the right) mainly faces the north while Sites 2a and 2b (to the left) face the west.

Land Evaluation

In this case the sensivity to soil erosion limits the sustainable land use in Hop Son and would be the preliminary land quality to consider. In addition, pH, nutrient, moisture and oxygen availability in the root zone as well as soil Al-toxicity, temperature regime, radiation energy, photoperiod, air humidity and drought periods are important qualities in my project. Among qualities related to management, the absence of mechanization and roads as well as the mountainous landscape restrict the management options.

Regarding the moisture availability, the soil investigated in Hop Son mainly consists of silt, 0.02-0.002 mm, in the surface layer, which retains 20-35 mm water/dm soil (default values, Emmerman et al., 1990). Deeper layers consist of silty clay loam or silty clay that retain about 15-30 mm water/dm. From the beginning of March until the middle of November the precipitation exceeds the evaporation (Bavi climate station, 2001) and, hence, the soil moisture will be maintained for this period. However, plants have to surmount a dry and colder period from November to March. When it comes to oxygen availability, the high content of silt might indicate a small air-filled volume at field capacity as the precipitation is high (Emmerman et al., 1990) but in the field investigation, the site was classified as somewhat excessively drained and never saturated. With this in mind and the fact that there were no impervious layers in the profile together with a very deep watertable, I conclude that the oxygen availability is most likely satisfactory at field level.

The nutritional status of the soil seems to be low as the cation exchange capacity (CEC) and the base saturation (BS) are low. Generally, this type of soil, Acrisol, has nutritional limitations that include widespread aluminium toxicity and strong P-fixation (Driessen and Dudal,

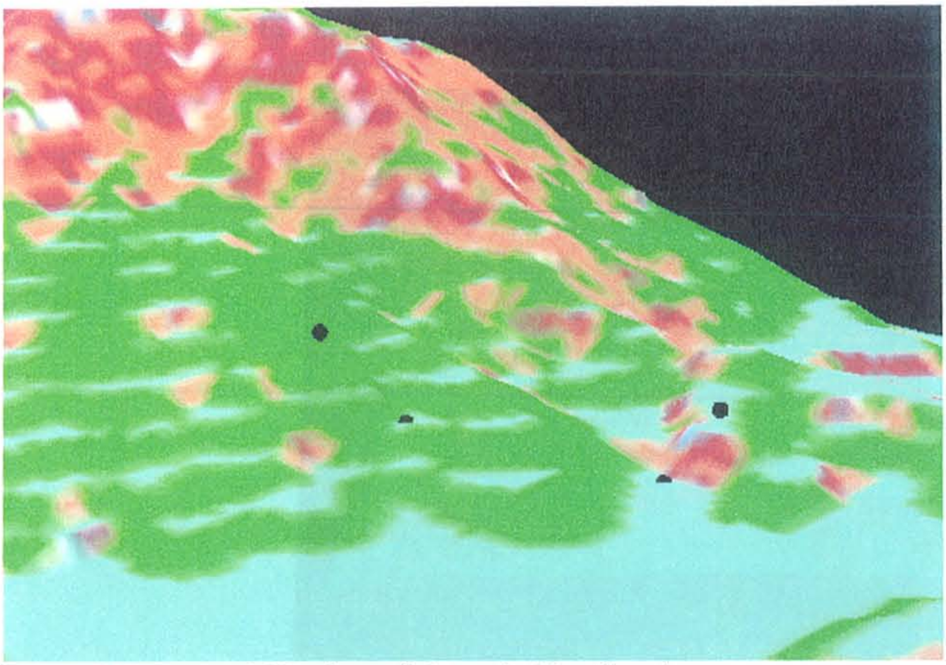

Figure 25. Zoomed 3D view of slopes in Hop Son Area.

Furthermore, the aspects of the mountainous area can be viewed below (Figure 26). This view is constructed upon the digital elevation model and further transferred to a 3D shape, which is presented in Figure 27.

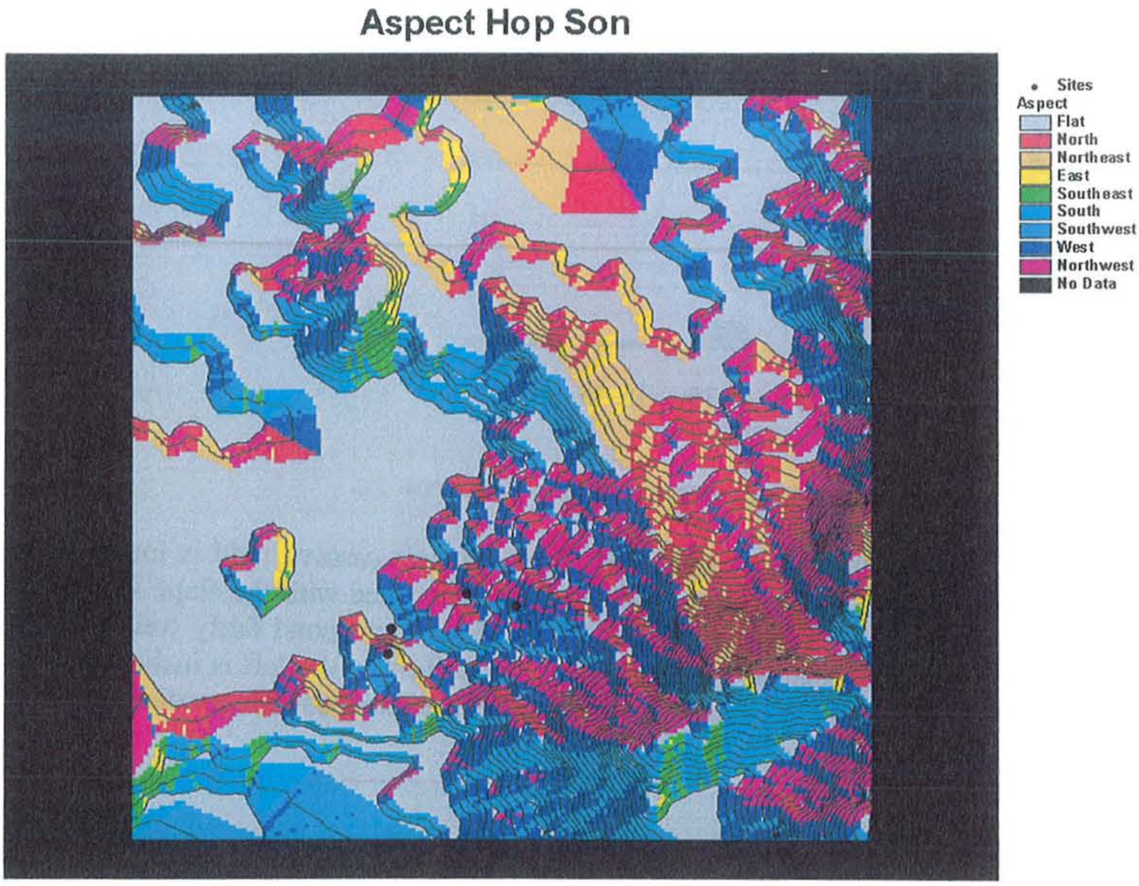

Figure 26. Aspects of Hop Son Area.

The slope map can be transformed into a 3D view and zoomed as in Figure 23 and 25.

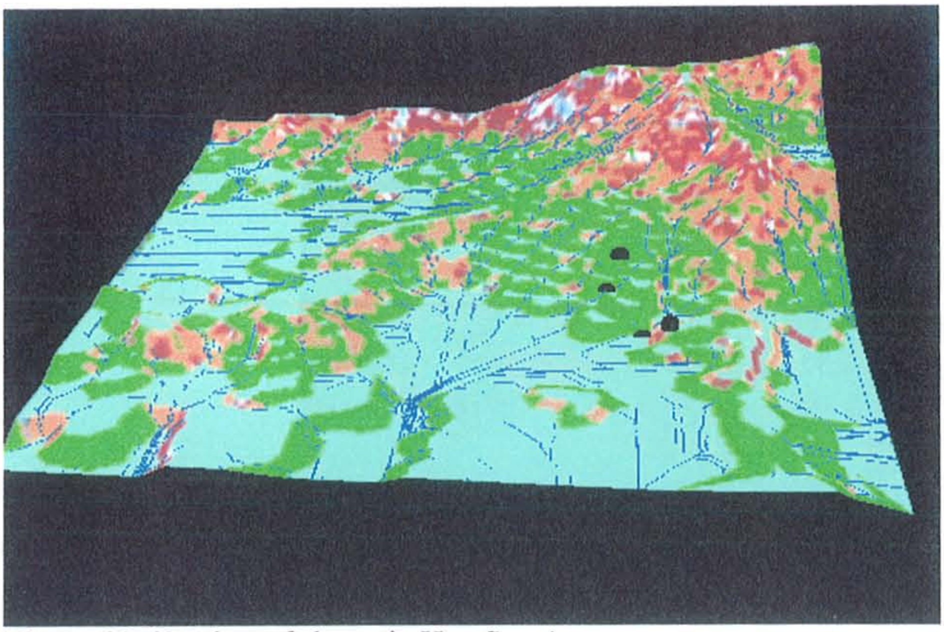

Figure 23. 3D view of slopes in Hop Son Area.

The total surface area in this model is calculated to 21 848 km^2 with ArcView 3.2. The surface areas within the different slope intervals are presented in figure 24.

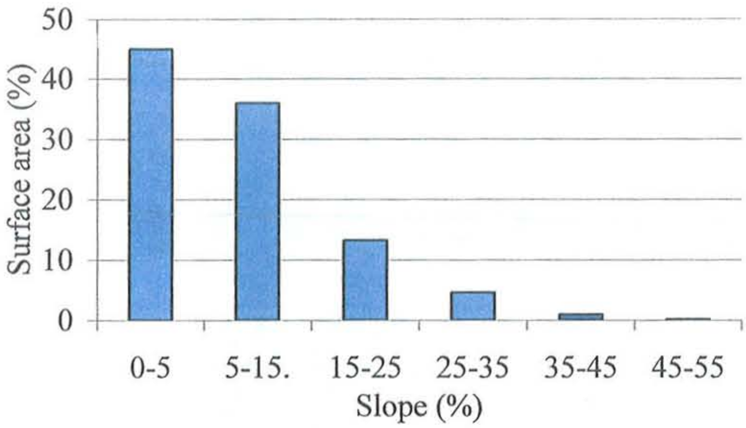

Figure 24. Surface area within slope intervals in Hop Son Area.

In Figure 25 the sites can be seen more closely. Mrs. Luyen's cassava field is found in the slope between Site 1a and 1b, furthest to the right. In accordance with the slope legend the steepness of this slope varies between 15 and 35 %, which correspond fairly well with the observations in the field. The slope at Sites 2a and 2b, furthest to the left is included in the steepness interval 5-15 %, which seems to be reasonable in reference to observations made at field level although these were up to 25 %.

To establish a pedagogic view of the studied sites a closer zoom exposes the area (Figure 21).

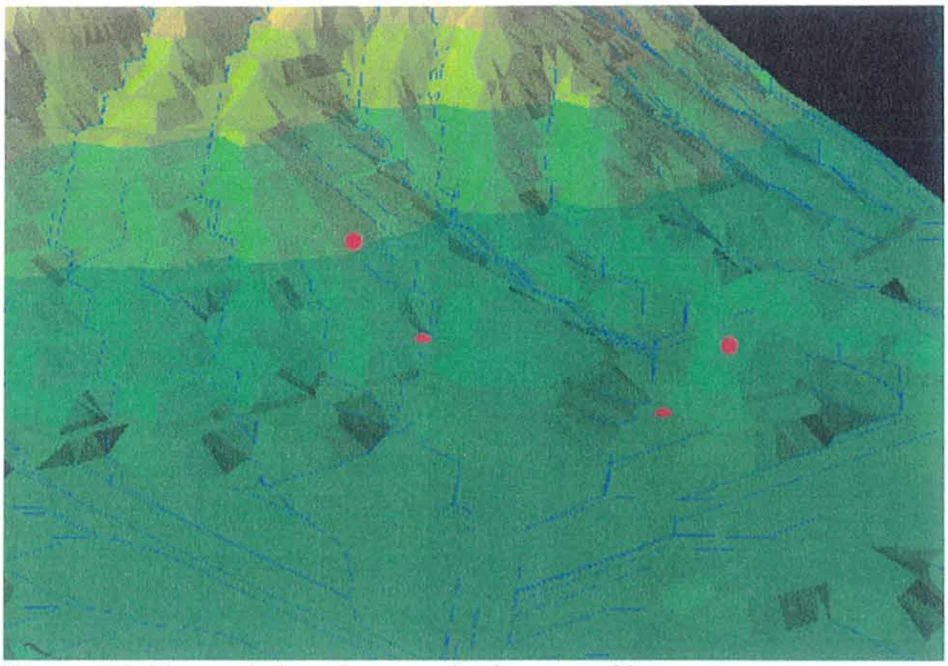

Figure 21. Zoomed elevation map in the area of interest.

The digital elevation model can be used to reveal the steepness of the slopes in the topographic view as can be seen in Figure 22.

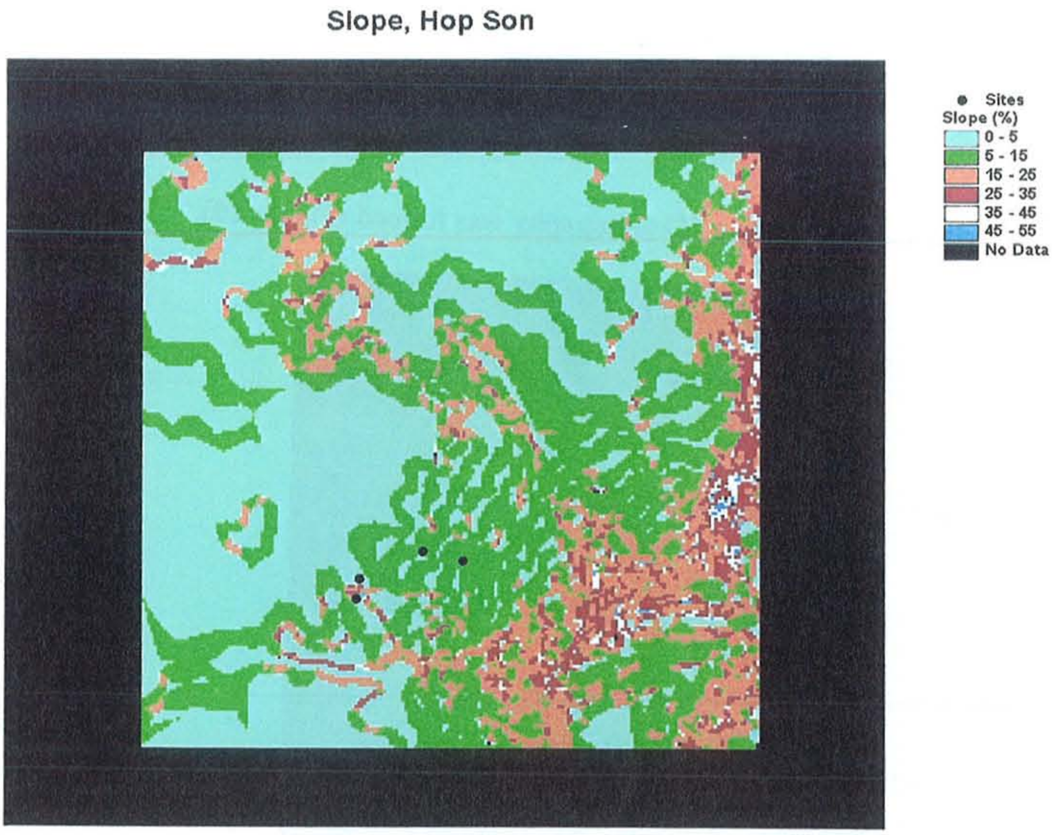

Figure 22. Steepness of slopes in Hop Son Area.

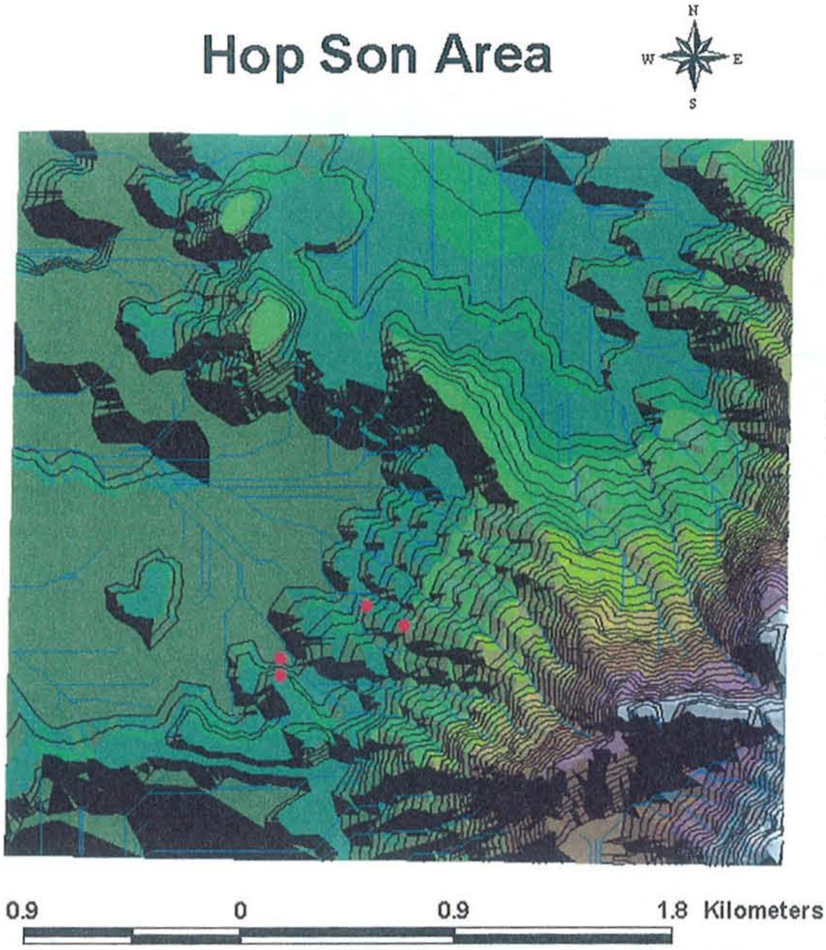

Figure 19. Hop Son Area.

Based on this digital elevation map a 3D topography was formed (Figure 20).

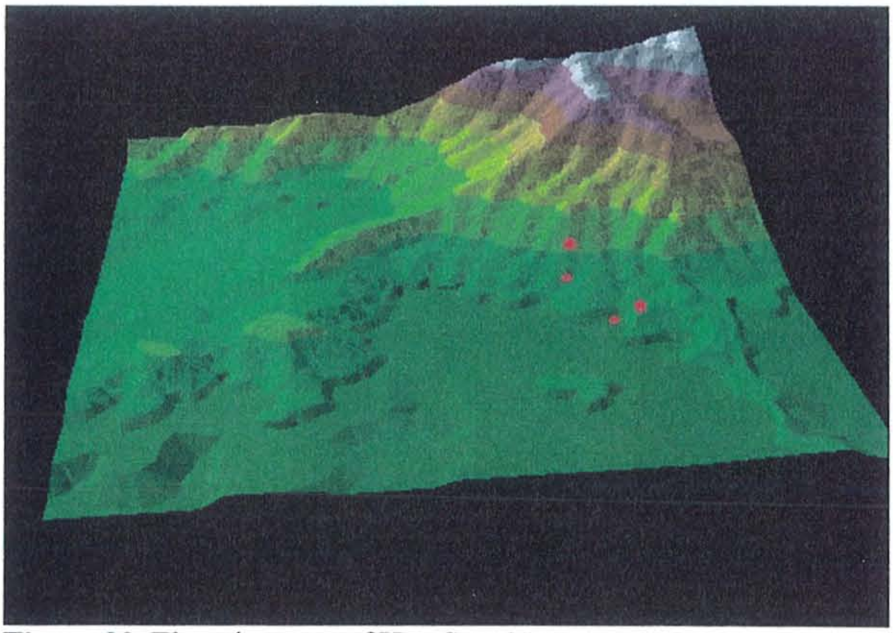

Figure 20. Elevation map of Hop Son Area.

It might be said that the *F. macrophylla* cultivation system would be appropriate in slopes with a steepness up to about 20 % according to the discussion above regarding soil loss for a sustainable system. As can be seen, the soil losses from the cassava cultivation system are extremely high and even at a 10 % slope the losses are too high to be called sustainable according to the previous discussion. The results point towards the conclusion that soil loss should be classified according to the intensive rainfall that is several times more severe than average day to day precipitation, as regards water erosion in the sloping lands of Hop Son hamlet.

Soil Loss Tolerance

According to Skidmore´s (1982) soil loss tolerance method the following parameters are assumed:

T_1 = lower limit of allowable soil loss rate (mm/yr) = 0.2 mm/yr
T_2 = upper limit of allowable soil loss rate (mm/yr) = 1.0 mm/yr
z_1 = min. allowable soil depth (m) = 0.5 m
z_2 = optimum soil depth (m) = 2.0 m
x = present soil depth (m) = 0.8 m

The result would be:

$$T(x,y,t) = (T_1 + T_2) / 2 - (T_2 - T_1) / 2 \cos [\pi (x - z_1) / (z_2 - z_1)] =$$
$$= (0.2 + 1.0) / 2 - (1.0 - 0.2) / 2 \cos [\pi (0.8 - 0.5) / (2.0 - 0.5)] = 0.276$$

T(x,y,t) = allowable soil loss at a certain point and time (mm/yr) = 0.276 mm/yr

Assuming the bulk density to be 1.15 g / dm^3, the value 0.276 mm/yr corresponds to 3.2 tons/ha/year. Notice, that the lower limit of allowable soil loss rate is identical with the soil renewal rate. The present soil depth used was the actual soil depth at Site 2a in Hop Son. The slightly thicker soil layer at Site 1a, approximately 1.1 m, would correspond to an allowable soil loss at present time to 0.476 mm/yr, which corresponds to 5.5 tons/ha/year. It's clear that the soil renewal rate is the limiting factor in a long perspective and the tolerable soil losses will slowly approach the soil renewal rate over several centuries. The soil renewal rate is of crucial importance in deciding the sustainable land use regarding water erosion and should be thoroughly investigated in place at Hop Son hamlet before this method is applied in practice. The soil loss tolerances could be compared to tolerable values for USA between 2.5 –12.5 tons/ha/yr (Wishmeier and Smith, 1978), as well as for former Chechoslovakia 1.0 – 16 tons/ha/yr and to soil loss tolerances in Nigeria ranging from 0.2 – 3.6 tons/ha/yr depending of different soil properties (Igwe, 1999).

Geographic Information System (GIS)

A digital elevation model over Hop Son area was created in the WGS 84 and contains hydrological features and an appropriate scale. The visualization can be studied below (Figure 19).

died. Below, the soil loss during intensive rainfall is described for 10-50 % slopes at two high rain intensities (Figures 17 and 18).

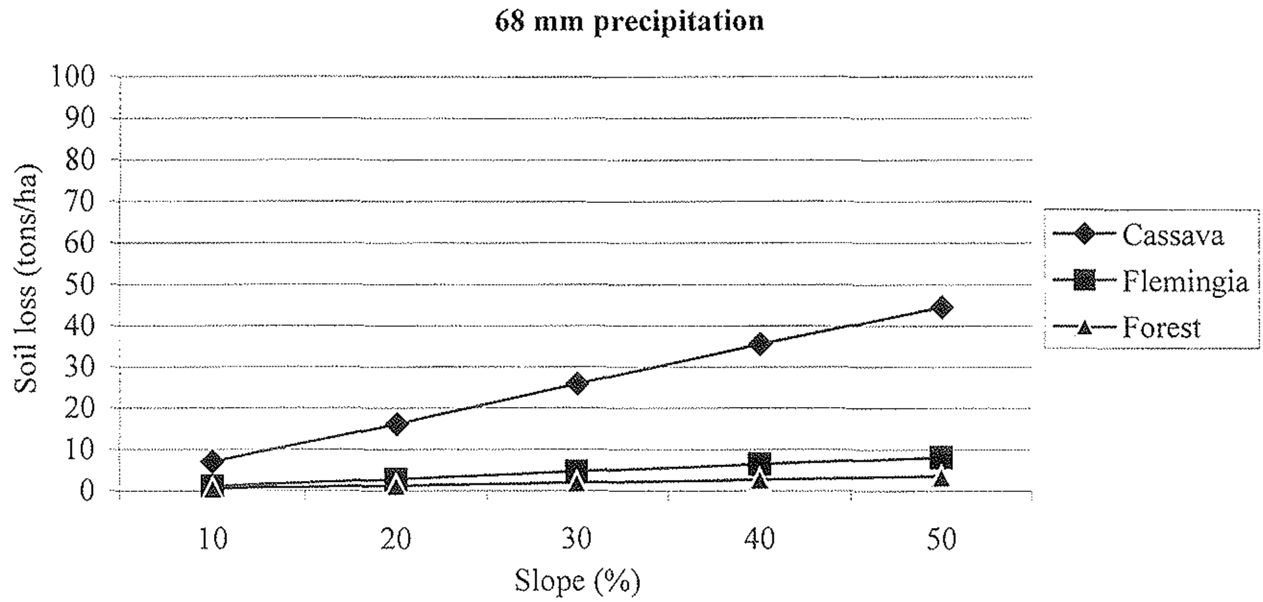

Figure 17. Soil loss from slopes 10-50 % at 68 mm precipitation.

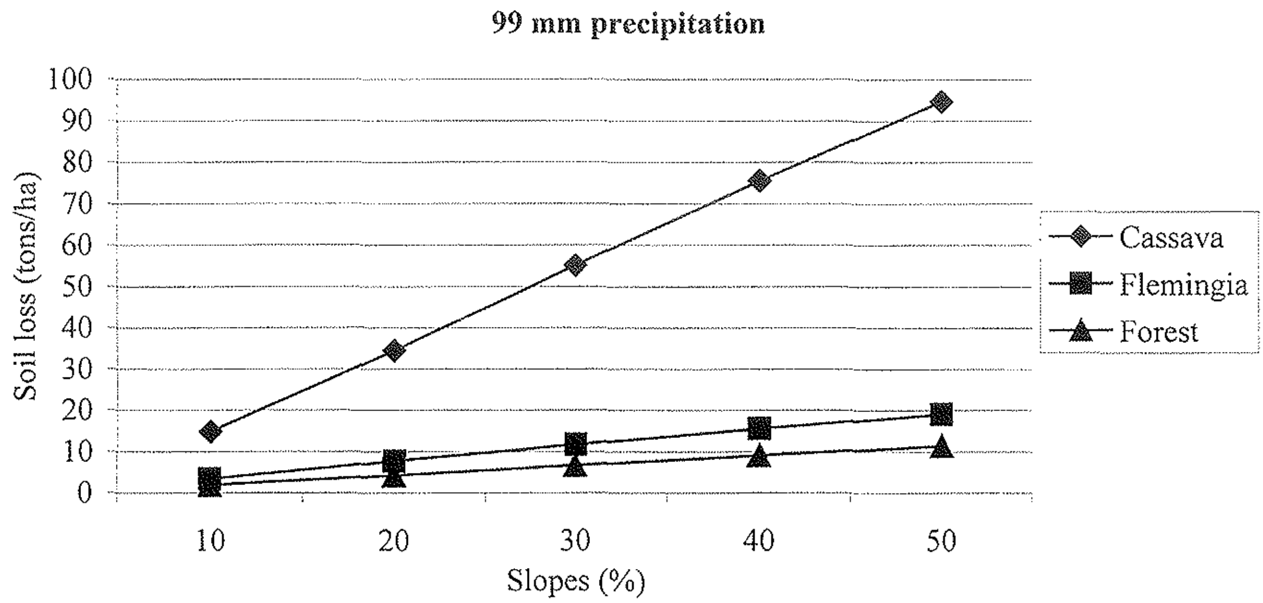

Figure 18. Soil loss from slopes 10-50 % at 99 mm precipitation.

Obviously, soil loss is a linear function of the steepness of the slope according to the model. It is clear that forested hill slopes allow some soil loss to occur, as was shown in Mrs. Luyen's field as well. The 68 mm precipitation option is an average value based on a 10-year climate data and would therefore be a value that occurs frequently as time passes and a suitable value on which to base a discussion of sustainability. The 99 mm precipitation as a maximum value, on the other hand, for these ten years seldom occurs once every ten years or less and it could be too randomized to base a discussion on that fact.

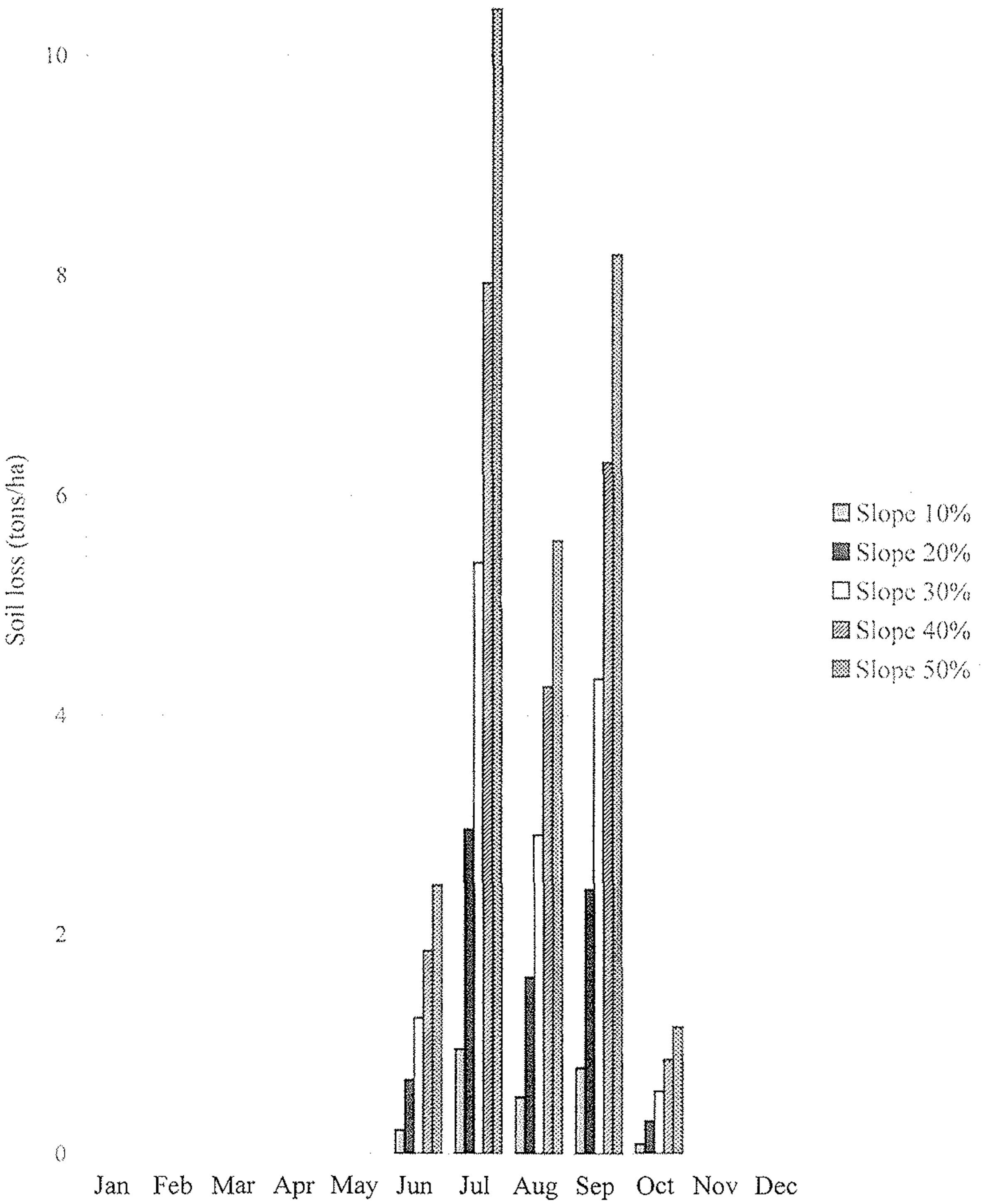

Figure 16. Soil loss from cassava cultivation in slopes 10-50 % without rainstorms.

It should be noticed that the cassava cultivation causes several times more soil loss than *F. macrophylla* cultivation even at 10 % steepness. The intensive rainfalls also have to be stu-

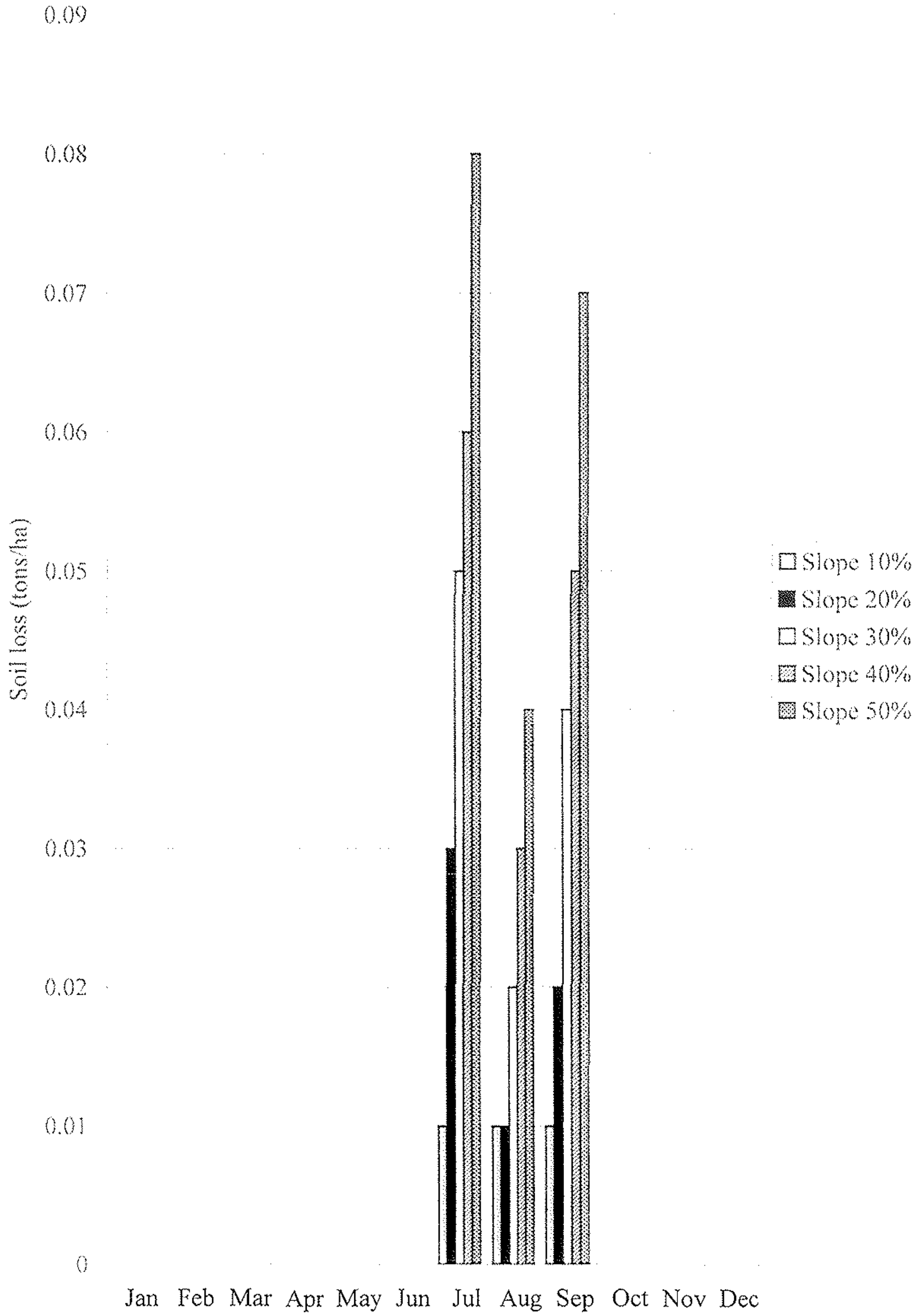

Figure 15. Soil loss from *F. macrophylla* cultivation in slopes 10-50 % without rainstorms.

The cassava crop produces about 3.67 tons of soil loss from the field during the year while *Flemingia macrophylla* produces 0.04 tons and no soil loss at all is found in the forest system. As can be seen in the figure below, the monsoon period from June to October is affected by water erosion and the most severe soil loss is found during July to September. When considering storms that occur frequently during the monsoon period two simulations were made with 68 mm respectively 99 mm precipitation during one day. The results are visualized in Figure 14.

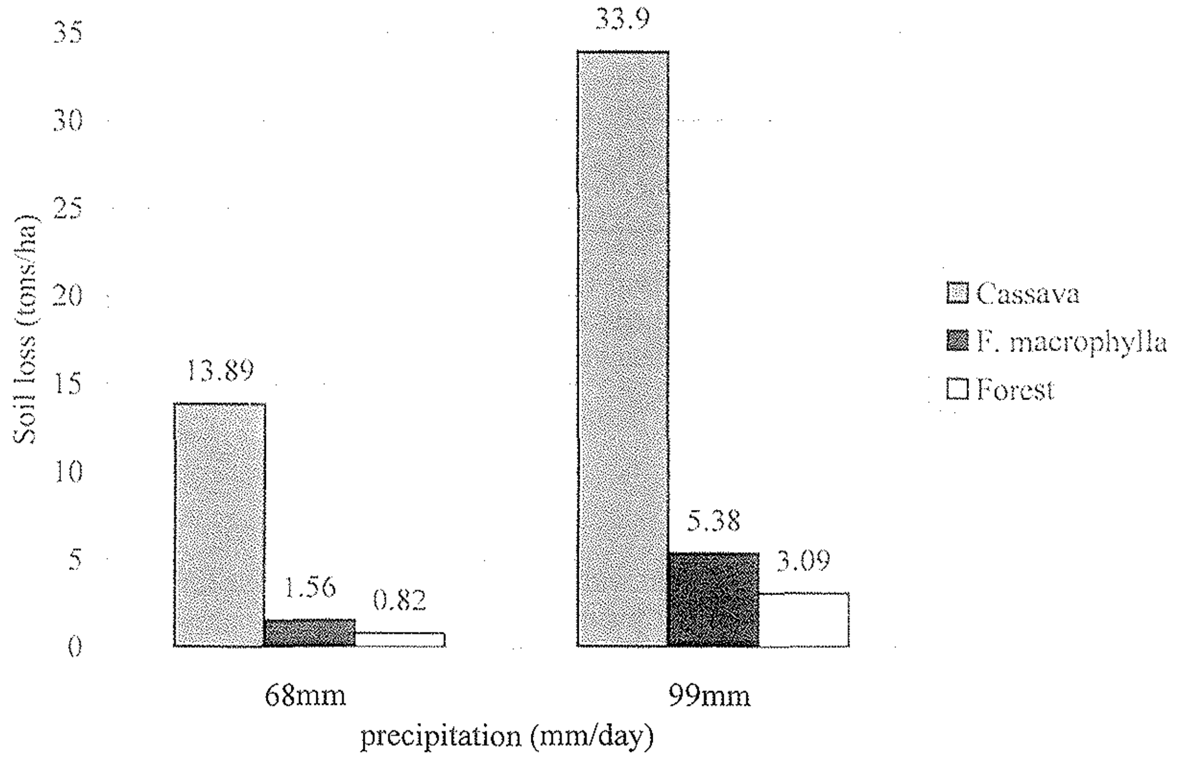

Figure 14. Soil loss from Mrs Luyen's field due to thunderstorms.

The soil loss from the field accelerates with an increase in precipitation. The cassava option shows the most severe increase but it should be noticed that the forest produces some soil loss as well during these intensive rainfalls. It could be argued that the soil loss from the forest corresponds to a natural soil loss occurring in this area not affected by human.

Results from the simulation of 100*100 m fields with uniform slopes at steepness 10 %, 20 %, 30 %, 40 % and 50 % respectively present a slightly different influence on soil loss relative land use. The forest option without considering intensive rainfall does not contribute to any soil loss. Cultivation systems with *F. macrophylla* and cassava produce soil loss according to figure 15 and 16.

Table 13. Results from the water stability test of soil aggregates in Hop Son hamlet

Subplot	Weight soil g	Turbidi-metervalue (20 ml suspension)	Weight clay g	Estimated clay content (20 ml suspension) (y=7E-06x+0.0125)	g clay /g soil
1A1	20.620	5619	0.0463	0.2894	0.0140
1A2	16.597	10736	0.0600	0.3750	0.0226
1B1	27.944	583	0.0182	0.1138	0.0041
1B2	25.271	762	0.0209	0.1306	0.0052
2A1	22.304	3535	0.0310	0.1938	0.0087
2A2	18.289	2946	0.0256	0.1600	0.0087
2B1	28.011	57	0.0016	0.0100	0.0004
2B2	21.326	49	0.0017	0.0106	0.0005

The variance analysis on soil samples from Hop Son showed a high F-quota that indicates significant differences between the treatments (sites) and the LSD-test proved that the sites in sloping land, 1A, 2A and 2B show significant differences from each other even at 1 % level of significance regarding aggregate stability.

Erosion modelling

The results from the GLEAMS simulation without consideration of storms imply that the soil loss from Mrs. Luyen's sloping field is considerable with pure cassava cultivation compared to perennial cultivation systems such as *F. macrophylla* or forest (Figure 13). In this evaluation the *F. macrophylla* system will be used to estimate the soil loss from an agroforestry system.

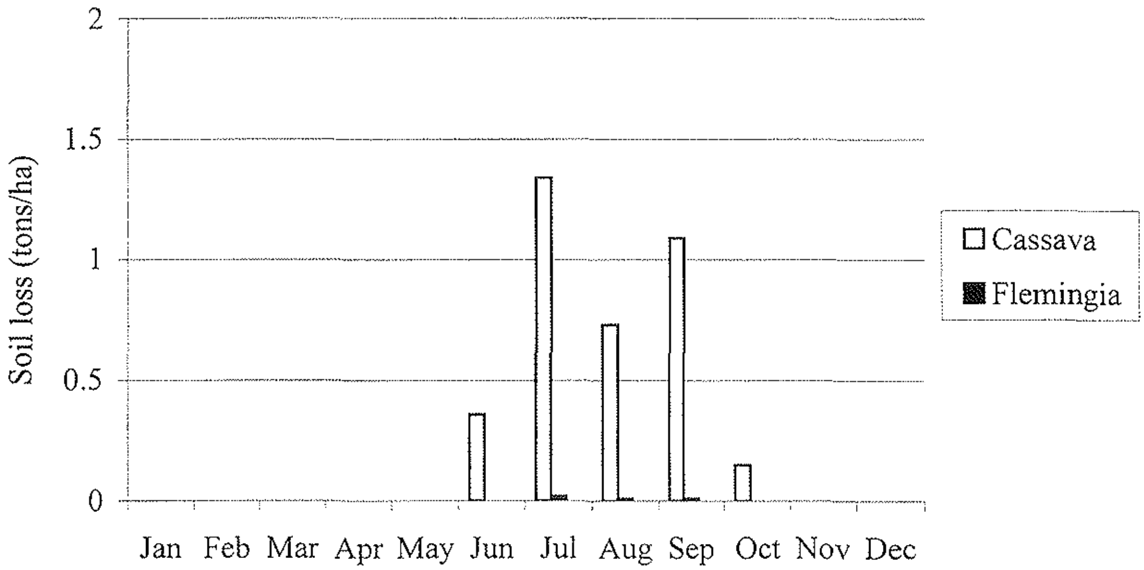

Figure 13. Soil loss from Mrs Luyen's sloping field.

Table 12. Soil properties at Site 2a

Soil depth (cm)	Al^{3+}	Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	Apparent ECEC (me/100 g soil)	Al-saturation (Al^{3+}/ECEC-soil) (%)	BS (%)
	(me/100 g)							
0-10	2.56	0.15	0.04	0.07	0.08	2.9	88.3	3.5
10-51	1.52	0.17	0.02	0.04	0.05	1.8	84.4	12.1
51-81	0.66	0.12	0.01	0.06	0.05	0.9	73.3	6.4
81-100+	0.58	0.13	0.01	0.04	0.05	0.8	71.6	6.2

According to WRB, the horizons B_{t1} and B_{t2} are probably classified as an argic horizon with the same remarks regarding the thickness as above. The A_h horizon classifies as an ochric horizon. The profile thereby presumably keys out as an Acrisol. It fulfils the requirements for the following lower level units: humic, vetic (the H^+ content is assumed to be low as the Al^{3+} content is relatively high, which would fulfil the requirements for vetic properties), alumic (the Al-saturation is calculated on Al^{3+}/apparent ECEC (H^+ is assumed to be low and not included)), hyperdystric and chromic. Finally, the profile keys out as a Veti-humic Acrisol (alumic).

According to Soil taxonomy (USDA, 1998) the horizons B_{t1} and B_{t2} are presumably classified as a kandic horizon although the coarser A_h horizon does not fulfil the criteria of a thickness of 18 cm. Since the topsoil is prone to erosion and situated in a sloping area, parts of the topsoil could have been removed with surface run-off and thereby thinned within a relatively short period of time. Considering this and the fact that clay eluviation are commonly found in soil profiles in the area, these horizons presumably are classified as a kandic horizon. The A_h horizon is classified as an ochric epipedon. The base saturation is supposed to remain below 35 % to a depth of 135 cm from the mineral soil surface and the profile keys out as an Ultisol. If the clay content were assumed to not decrease by more than 20 % from the maximum clay content within a depth of 150 cm from the mineral soil surface, the profile would key out as an Ustic kandihumult. As this is uncertain, we chose to classify the profile as an Ustic kanhaplohumult.

Soil stability measurement in Hop Son hamlet

The water stability test (table 13) revealed that soil samples from the sites at Hop Son hamlet showed significant differences at 5 % level of significance and even at 1 % level of significance between the sites in sloping land.

Site 2a

The soil profile at Site 2a is classified as an Acrisol according to World Reference Base, WRB (FAO, 1998) and is described in detail in Appendix 4. The site is slightly affected by erosion. This soil is similar to the soil at Site 1a although the surface horizon has a relatively high input of organic matter and the biological activity is fairly high down to 81 cm depth. The steepness of the slope is about 25 % in the steep parts and faces west-north-west. The external drainage is somewhat excessively drained and the internal drainage is classified as never saturated (FAO, 1990). The groundwatertable is situated deeper than 150 cm. The soil texture mainly consists of silt with a clear increase of clay below 10 cm below the mineral soil surface according to Table 10.

Table 10. Textural data from the Site 2a

Soil depth	Particle size (%)		
(cm)	Clay (< 2 μm)	Silt (20-2 μm)	Sand (> 20 μm)
0-10	9.8	85.1	5.1
10-51	42.0	52.0	6.0
51-81	44.7	49.3	6.0
81-100+	39.3	53.9	6.8

The soil has a low pH value (Table 11), the cation exchange capacity (CEC) is very low and so is the base saturation (BS). The saturation of aluminium is extremely high in the soil due to the low base saturation and high hydrogen ion activity as shown in Table 12. The C/N ratio is around 15-16 in the top soil.

Table 11. Soil properties at Site 2a

Soil depth (cm)	Organic matter (%)	Organic C (%)	N (%)	C/N	P (mg/100 g)	pH_{KCl}	CEC (me/ 100 g soil)	CEC (me/ 100 g clay)
0-10	5.6	3.3	0.21	15.6	0.40	3.7	9.8	-
10-51	2.2	1.3	0.19	6.7	0.23	3.9	5.3	12.6
51-81	1.4	0.8	0.06	13.5	0.20	4.2	3.8	8.5
81-100+	1.3	0.8	0.08	9.6	0.22	4.3	3.7	9.5

Table 9. Soil properties at Site 1a

Soil depth (cm)	Al^{3+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Apparent ECEC (me/100 g soil)	Al-saturation (Al^{3+}/ ECEC-soil) (%)	BS (%)
	(me/100 g)							
0-7	0.76	1.54	0.48	0.00	0.08	2.9	26.6	30.4
7-17	0.52	1.59	1.02	0.00	0.05	3.2	16.4	34.0
17-67	0.12	0.99	0.61	0.01	0.05	1.8	6.7	27.8
67-110+	0.12	0.94	0.55	0.02	0.03	1.7	7.2	27.8

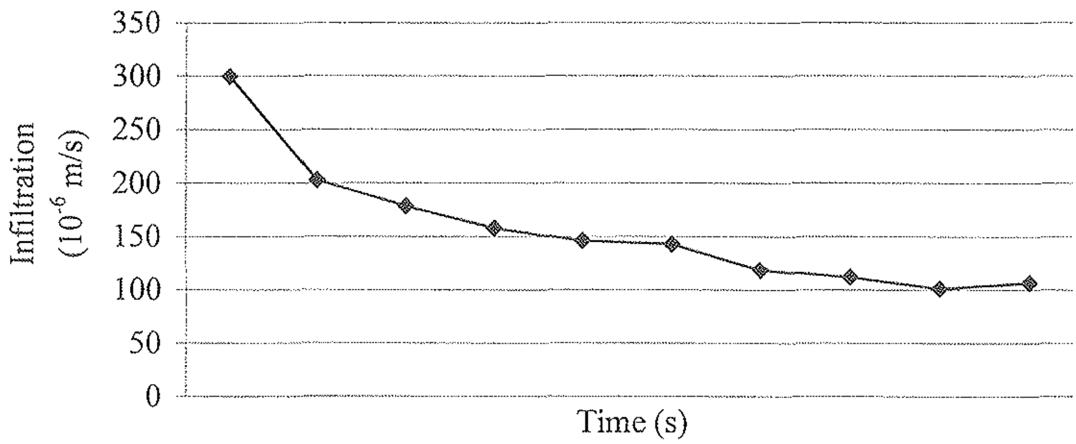

Figure 12. Average infiltration rate of three measurements within a few metres of the site for soil profile Hop Son 1a.

Down the slope from Hop Son 1a towards Hop Son 1b, the thickness of the Ah horizon was examined. About 35 m downwards from 1a it measured 17 cm and approximately 70 m further down it measured 22 cm. The slope is approximately 140 m and at the bottom rice fields are situated (Site 1b).

According to WRB the A_h- and BA-horizons are classified as an ochric horizon. The B_t- and B_{t2}-horizons are classified as an argic horizon. Thereby, the soil keys out as an Acrisol. It fulfils the criteria for the following lower level units: humic and chromic. (If the clay content were assumed not to decrease more than 20 % down to a depth of 150 cm from the mineral soil surface it would fulfil the criteria for the lower level profondic, but this is uncertain and not assumed in this case.) The final classification is Chromi-humic Acrisol.

According to Soil taxonomy (USDA, 1998), the Ah- and BA-horizons are classified as an ochric epipedon. The B_t- and B_{t2}-horizons are classified as an argillic horizon. The base saturation is supposed to remain below 35 % to a depth of 142 cm from the mineral soil surface and thus the profile keys out as an Ultisol. If the clay content were assumed not to decrease by more than 20 % from the maximum clay content within 150 cm from the mineral soil surface the profile would be classified as an Ustic palehumult. However in this case, that was not assumed and the profile keys out as an Ustic haplohumult.

Site 1a

The soil profile at Mrs Luyen's sloping field, Site 1a, was classified as an Acrisol according to World Reference Base, WRB (FAO, 1998) and is described in detail in appendix 2. The site is moderately affected by erosion. This soil, developed in a mountainous monsoon region, is prone to erosion and presumably a result of strongly weathered quartzitic sandstone. The red colour indicates a high content of iron oxides. The surface horizon is thin and relatively low in organic matter as a result of the land use. The steepness of the slope is about 35 % in the steep parts and faces north-north-east. The external drainage is somewhat excessively drained and the internal drainage is classified as never saturated (FAO, 1990). The ground-watertable is situated deeper than 150 cm. The soil texture mainly consists of silt with a clear increase of clay below 17 cm below the mineral soil surface according to table 7.

Table 7. Particle size in the horizons of Site 1a

Soil depth	Particle size (%)		
(cm)	Clay (< 2 μm)	Silt (20-2 μm)	Sand (> 20 μm)
0-7	9.1	86.1	4.9
7-17	10.1	84.2	5.7
17-67	32.3	63.0	4.7
67-110+	33.3	62.1	4.6

The soil has a relatively high pH value compared with the other sites in Hop Son hamlet. The cation exchange capacity (CEC) is very low (Table 8) and so is the base saturation (BS) (Table 9) but still it is relatively high compared to the other sites at sloping land in Hop Son hamlet. The saturation of aluminium is low in the soil, probably thanks to the relatively high base saturation as shown in Table 9. The C/N ratio is about 13-14 in the topsoil. The infiltration rate at the site was measured and is shown in figure 12.

Table 8. Soil properties at Site 1a

Soil depth (cm)	Organic matter (%)	Organic C (%)	N (%)	C/N	P (mg/100 g)	pH_{KCl}	CEC (me/ 100 g soil)	CEC (me/ 100 g clay)
0-7	4.8	2.8	0.20	14.0	2.83	4.0	6.9	-
7-17	3.9	2.3	0.17	13.3	0.34	4.3	7.8	-
17-67	4.0	2.3	0.08	28.8	0.23	4.7	6.0	18.5
67-110+	1.0	0.6	0.06	9.7	0.21	4.8	5.5	16.6

1991). Adapted cropping systems with complete fertilization and careful management are required if these soils are to be taken into agricultural production (Driessen and Dudal, 1991) Use of fertilisers in the erosion prone slopes of Hop Son has to surmount still more obstacles as water erosion often carries newly applied fertilisers down the slopes with surface run-off. Consequently, the nutritional status of the soil limits the productivity and hence, the crop selection. Driessen and Dudal (1991) report that undemanding acid-tolerant crops can be grown with success in these soils.

Low pH and high aluminium (Al) concentrations further limit the choice of crops. Aluminium saturation up to 88 % was found in the topsoil of Site 2a but this differs seriously from site 1a, which only had an aluminium saturation of 27 %. To counteract these negative factors liming could be a possibility to increase the pH and lower the Al-concentrations. On the other hand liming may lower the anion exchange capacity (AEC) which might lead to collapse of structure elements and slaking at the surface (Driessen and Dudal, 1991) and hence, an increase in water erosion. Frequent applications of small doses of lime are therefore preferable over a massive application (Driessen and Dudal, 1991). In any case, production of acid tolerant crops without liming does not expose the soil to a possible decrease in AEC and a further increase in water erosion.

Several climate qualities have to be considered before the introduction of new crops but present crops cultivated in the region including the plants studied in this project are not limited by the climatic conditions. Therefore the climate parameters will not be studied closer in this land evaluation.

Finally, it should be stated that water erosion from sloping land, low pH, high aluminium concentration and low nutritional status are limiting factors apart from the climate in Hop Son hamlet. As a result, low demanding acid- and Al-tolerant crops should be grown in cultivation systems that limit the soil loss through water erosion to a certain extent. Water erosion from sloping land is the most restrictive parameter, as it limits the possibilities to increase the fertility of the soil by fertilisation and liming, as well as limiting sustainable land use in Hop Son hamlet.

To visualize suitable cultivation systems for preventing excessive soil loss, a suitability map was created (Figure 28). Wet rice is the most important crop and is cultivated in the flat lowlands. The higher elevations of Bavi Mountain are a National Park and restricted for crop production. The areas not classified within these land uses can be divided into steeper slopes that only fulfil the diagnostic criteria of limited soil loss when managed as forest. Less steep slopes could be used for agroforestry purposes or forest management depending on the soil loss tolerance set but these slopes are preferably managed as forest. Slopes of 5-15 % are well suited for agroforestry production. Only slopes less than 5 % would be appropriate for use for monocropping crops such as cassava and it should be noticed that the major proportion of this category is being used for wet rice production. A technical consideration has to be taken into account with the suitability map. The slopes in the digital elevation model are built up from polygons in a step-like manner and therefore the slopes seem to be flatter in certain parts and steeper in other parts, while in reality the slopes are more continuous. Consequently, several levelled "lenses" in the sloping areas should be viewed with caution.

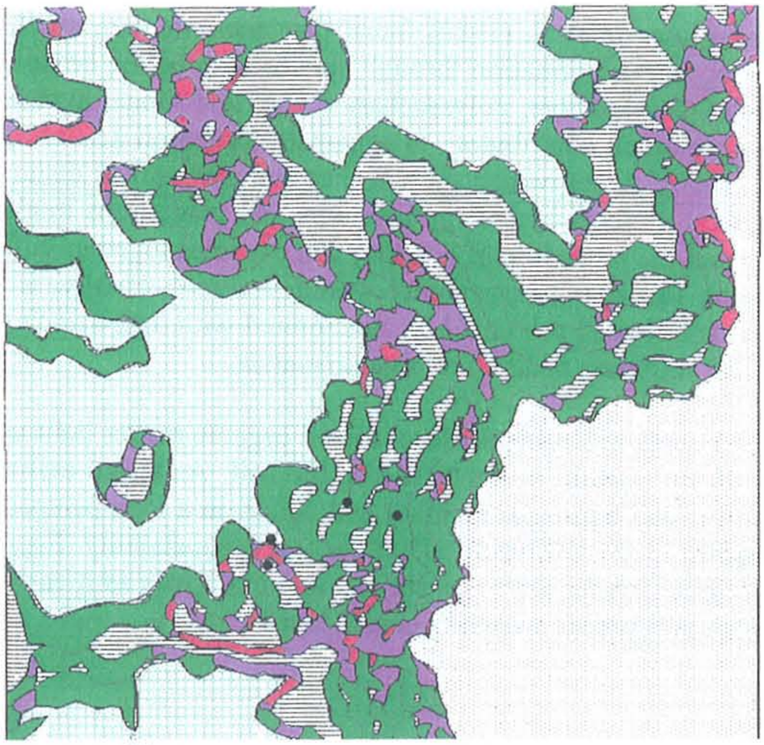

Figure 28. Suitability map of Hop Son Area.

DISCUSSION

The Effect of Different Cultivation Systems on Erosion

Several field trials have been conducted to evaluate the effect on soil loss and water run-off from agroforestry systems and the use of hedgerows in sloping land. The overall impression is that the use of intercropping systems restrains water erosion in a positive manner. Results from the ICRAF experiment conducted at the Claveria Research Site MOSCAT, Misamis Oriental, Philippines concludes that the most practical construction with hedgerows to minimize soil loss includes hedgerows at every two or four meter elevation drop. Aina et al. (1976) conclude that a higher infiltration rate appeared in systems with cassava intercropped with maize relative to monocropped cassava, thanks to an increased activity of earthworms in the intercropped system. In turn, a lower water run-off and soil loss was found in the intercropped system. Furthermore, scattered maize residues decreased soil and water losses in Kenya as they hindered the impact of raindrops and preserved the structure in the surface soil. According to FAO, the effect of plant residues as soil cover depends on the quantity, the quality, the management and the degree of decomposition of the residues. Samir et al. (1989) reported that the effectiveness of forest in preventing water erosion was due to the accumulated litter layers and short vegetation at the forest floor.

Soil aggregate stability correlates well to clay and organic carbon content (Elwell, 1986; Harris et al., 1966; Kilewe, 1984). In addition Mochoge and Mwonga (1989) state that different land use affects soil aggregates. Osozawa et al. (1989) found that phenolic compounds play an important role in biological aggregate formation through stabilisation of the organic matter that bond together soil particles. Furthermore, polysaccharide gum and fungal hyphae in particular have been shown to be important contributors to aggregate formation according to Russel (1973) and Harris et al. (1966). A cultivation system that includes annual disturbance of soil biology and soil physical systems by soil preparations and plantations might obstruct the development of hyphae and the procedure of bonding soil particles together with organic substances. Consequently, the soil aggregate stability would decrease. Finally, it's found that soil aggregate stability in deteriorated soil could be ameliorated with intercropping systems including perennial plants and sufficient addition of organic matter.

In line with the long-term field experiments in Ultuna the level of soil organic matter built up in the soil depends on the quality of the organic matter added to the soil. As stated earlier organic carbon content correlate well to soil aggregate stability and hence, in a long perspective, the quality of added organic matter to the soil would affect the aggregate stability. Especially, the amount of lignin in the organic matter seems to play an important role as it easily transforms to stabile forms of decomposed organic material, named humus.

The Field Trial

Due to the fact that the field trial is partially sloping, the plots have been exposed to erosion depending on the steepness of the slope in their particular spot and it seems that the gravel content is correlated to the slope of the plot. Plots with a modest slope do not contain much gravel, in contrast to the steeply sloping plots, where the gravel content is high.

The textural change, at a depth of 42 cm in the soil profile next to the field, results in a dense $2B_t$-horizon, probably with low porosity and water percolation that makes it less suitable for root penetration. According to dissimilarity in thickness of the surface horizon in various parts of the field trial, the volume of porous topsoil accessible to the roots differs. This soil quality is of crucial importance for root development and, hence, plant growth. It should be noted that the field trial has only been in use for 2.5 years before this evaluation and changes in soil properties are slow processes that might be hard to discover after such a short period of time.

Chemical data

The results from the chemical analyses show no evident differences in chemical status between the cultivation systems. There might be higher total nitrogen content in the subplots with pure *F. macrophylla* although this does not fulfil the requirements of 5 % significance. There is no trend to be found regarding the carbon content. The handling and storage of the soil samples were not the best possible. The samples were sun-dried and it could take one or two days to dry them, depending on the weather. In addition, the samples were probably stored for one or two weeks, although dry and in plastic bags, before the analyses were made at the National Institute for Soils and Fertilisers in Hanoi. This probably affected the results, i.e. microbial activity involving nitrogen, etc.

Root distribution

The horizontal distribution of roots differed between cassava and the other two plants that had a similar root development. While cassava roots grow to about 15 cm from the stem, *F. macrophylla* and mulberry roots were distributed within 20 cm from the stem with few or common medium-sized roots growing more than 50 cm from the stem (see classification method presented in table 2). Cassava roots are mainly found in the Ah-horizon and consist of medium-sized, fine and very fine roots. Notice that the cassava plant not yet had reached the development stage when the cassava roots start to swell. *F. macrophylla* and mulberry normally have many or common roots in the Ah-horizon of all qualities. *F. macrophylla* has few, common or many roots of different qualities in the BA-horizon while mulberry has few or common roots of different qualities. In the B_t-horizon, only few very fine and coarse roots of both *F. macrophylla* and mulberry are found.

In general, *F. macrophylla* seems to be healthier and to have better growth than mulberry in the field trial, which might explain why *F. macrophylla* has slightly more roots than mulberry. Considering this aspect, these two plants have a similar root development in the field trial. Cassava, on the other hand, grows well but has a modest root development. The larger root growth and distribution found for white mulberry and *F. macrophylla* will most likely have an effect on the soil in a longer term. This should create better aeration and porosity after root penetrations and an increased content of organic matter from dead roots in deeper soil layers. Moreover, the root distribution affects erosion control as the roots contribute to the physical stability of the soil, thereby making soil aggregates and particles less vulnerable to displacement with run-off water.

Soil aggregate stability

Although the water stability test on soil aggregates from the field trial, GRRC, do not fulfil requirements for 5 % level of significance, the cultivation systems with *F. macrophylla* and white mulberry in monoculture indicate that there is a tendency of higher aggregate stability in these two cultivation systems than in the others.

Land Evaluation in Hop Son

The land is mainly used for agriculture and forestry. Main agricultural crops are rice, planted in the lower wet parts, and cassava cultivated on the slopes. Acacia and eucalyptus are the most common planted trees and are used for wood production. Water erosion is considered to be one of the main problems connected with agriculture in the area. *F. macrophylla* has been introduced to the village and seems to be successfully established at Site 1a and could be a future crop for cultivation in the village. Tea cultivations are planned within the village in the near future. Other crops and fruits grown in the area are, e.g. sweet potato, edible canna, maize, bamboo, lychee, lemon, banana, grape and pineapple.

The soils in the village are many thousand years old and developed due to the natural conditions in the area. The land use of today affects the soil to some extent, although it is mainly the surface horizon that changes. The texture of the soil together with the hilly/mountainous topography and the heavy rains makes the land prone to erosion. Certain forms of land use expose the surface soil to water erosion and soil material is transported down the slopes to lower lying areas. Due to this loss of surface material, the fertile surface horizon is thinned out, with a negative effect on crop production in the sloping areas.

The sloping land in Hop Son seem to be mainly Acrisols (FAO, 1998) although Site 2b did not fulfil the requirement of clay eluviation. This site has been affected by earlier constructions of terraces and soil movements that probably have changed the original soil horizons and thus the classification. The soils on the sloping land are prone to erosion, have a high content of silt (2-20 μm), and have a low pH; the sites in shrub- and wood-land (2a and 2b) have high aluminium saturation. Generally in Acrisols, low contents of sesquioxides and clay particles are found in the topsoil due to eluviation and this creates a weak structure at the surface

When it comes to land evaluation, water erosion in sloping land can be singled out as the most restrictive factor limiting sustainable land use in Hop Son hamlet. The area consists of a hilly, mountainous landscape with a mixture of levelled land and slopes with up to approximately 55 % gradient. The higher elevations have been declared national park and flat areas at low elevations with hydrological properties that provide access to surface water are primarily used for wet rice production.

The soil loss and water run-off from sloping land depend on several factors where land use is an important parameter that can be changed from a time to another. As discussed different land use affects the soil loss and certainly involves a multitude of factors. One parameter to consider is soil aggregate stability. Land use seems to affect aggregate stability, which is emphasized by the results on wet aggregate stability from the different sites in Hop Son hamlet. The soil aggregates at Site 1a released about the double amount of clay when treated than soil aggregates at Site 2a. These sites have a similar texture and organic carbon content in the topsoil but Site 1a is a pronounced cassava field and Site 2a a forested field.

Additionally, plants used in cultivation systems affect several factors regarding water runoff and soil loss. The root distribution affects erosion control as the roots contribute to the physical stability of the soil, thereby making soil aggregates and particles less vulnerable to displacement with run-off water. Organic substances are produced that can alter physical conditions of the soil and soil biological systems are shaped including fungal hyphae that further transform the soil physical properties. Regarding the physical distribution of roots the investigations at the field trial at GRRC concludes that *Flemingia macrophylla* and white mulberry produces more extensive root systems than Cassava. This implies that the two former plants provide a more distinct stability of the soil in general.

GLEAMS

The GLEAMS simulation illustrates that single short-time high intensity rain causes considerable soil loss that is several times larger than soil loss induced by normal precipitation for a month during the monsoon period. Therefore, single high intensity rainstorms should mainly be used to evaluate soil loss regarding sustainable land use in the region. The model calculates that loss from a *F. macrophylla* cultivation is roughly double than from forest at slopes 10-50 % during heavy rains. Soil loss for a corresponding cassava cultivation is several times larger. The relationships are about the same as those observed at Mrs Luyen's field, which is S-formed and on a uniform slope. One should take into account that the GLEAMS model does not consider soil aggregate stability, which might further affect the soil loss. The model bases its physical and hydrological soil properties on soil texture.

Soil loss tolerance

If, we agree on a discussion of sustainable land use based on an annual average maximal rainstorm with 68 mm precipitation, forested land on 40-50 % slopes allows 3-4 tons of soil loss/ha/thunderstorm and forested land on 20-30 % slopes allows 1.3-2.0 tons of soil loss/ha/thunderstorm. Let us say that forested land allows a sort of background erosion that could be looked upon as natural erosion in landscape development. Then, it might be appropriate to say that 2 tons soil loss/ha/max. rainstorm is allowable during the monsoon period for a sustainable land use. Bear this in mind when considering Skidmore´s soil loss tolerance method, which resulted in an allowable yearly soil loss of 3.2 (Site 2a) or 5.5 tons/ha (Site 1a) depending on the soil depth.

Now suppose that 3-4 heavy rainstorms occur every monsoon period and the heaviest produces 68 mm precipitation and the others produce somewhat less precipitation. In this scenario the 2 tons soil loss/ha/max. rainstorm might produce about 6 tons soil loss/ha/yr while Skidmore´s method would allow from 2.3 tons soil loss/ha/yr and more, depending on the soil depth, in our case values around 3.2 to 5.5 tons soil loss/ha/yr seem realistic. The synthesis of these results would be that an allowable soil loss/max. rainstorm ends up at approximately 1.5 tons soil loss/ha/max. rainstorm. This soil loss tolerance would allow *F. macrophylla* on slopes in the interval 5-15 % steepness, forest on steeper slopes and monocropped cassava only on slopes less than 5 %. In another extrapolation, let the *F. macrophylla* cultivation correspond to an agroforestry system based on perennial bushes. If a larger soil loss was allowed, e.g. if areas with deep fertile soil occured, it could be reasonable to have agroforestry in the slope interval 15-25 % steepness as well but this would not be recommended.

GIS

The topology formed by GIS was based on a map of the area with the scale 1:50000 and 20 m height difference between the contours. This signifies that the following topology will be coarse and that more detailed information will be left out. Furthermore, the topology was built up with a TIN (Triangulated Irregular Network) based on height data in the form of polygons with relatively coarse height differences. This resulted in a topology that had a tendency to be "step-like". Consequently, certain lenses of levelled land were created in otherwise sloping land. These lenses should be viewed with caution. To create a GIS map with more reliable topology, a more detailed scale and height difference must be applied.

Land qualities

The low pH and at least partly the high aluminium (Al) saturation impose restrictions when it comes to crop choice. Addition of organic matter might lower the Al-saturation and liming could increase the pH and decrease the Al-saturation. However, it is necessary to consider the possibility that liming could negatively affect the soil structure by inhibiting the aggregation between sesquioxides and clay particles. In theory the content of sesquioxides as well as clay particles are low in the topsoil and there would be little aggregation to inhibit and, hence, the negative effect would be negligible. In reality the effect of liming should be evaluated in field trials before large scale application of lime is suggested. The possibility of adding lime and nutrients is restricted due to surface water runoff that tends to carry away material added to the surface. Water and oxygen availability appear to be good during March to November but the crops have to withstand a dry and cold period from November to February.

The plants

Cassava, white mulberry and *F. macrophylla* are present in this region and respond well to the climatic conditions. Cassava and *F. macrophylla* grow well and seem to tolerate acid condition and high aluminium saturation without problems. White mulberry is more sensitive to low pH, soil depth and the porosity of the soil. The leaves of *F. macrophylla* have a particular composition with special mulching properties due to slow decomposition rates that would favour some soil properties in a longer term. This plant is nitrogen-fixing, which would create nitrogen-rich mulch and thus a more nutrient-rich environment for plant production. Such effects were not found in the present study but they could likely appear in a more long-term field trial. An agroforestry system could preferably be based on *F. macrophylla* and cassava, the former being a well adapted plant with positive mulching properties for soil cover and soil aggregate formation and the latter being an important crop not recommended to be grown in monocultures in sloping land.

Administration

The choice of crops to be cultivated within the village depends on several factors: The village council takes mutual decisions on plant production in the village, the administration of the national park bordering the village controls some of the tree plantations, subsidies from the authorities encourage movement towards large-scale goals in Vietnam, and finally, the local markets govern the demand for the village's goods. Considering these stakeholders, the private farmer does not seem to fully take part in the decision on what to be cultivated on his/her field. In Hop Son village, no white mulberry was grown due to lack of subsidies, and the farmer Trieu Thi Luyen planned to grow tea due to a decision made by the village council.

It is urgent to find cultivation systems that prevent erosion on slopes to a larger extent than today in Hop Son village. White mulberry and *F. macrophylla* might be two plants to be used in cultivation systems designed to prevent erosion. There are several stakeholders involved in the decision-making of crops to be produced, and thereby it is necessary that all stakeholders are informed about the problems and the possible measures to take against erosion. The erosion from slopes within the village is seen as a large problem as the fertile topsoil disappears and the soils degrade. As at least the villagers seem to be eager to counteract this problem it is my opinion that efficient measures can be taken with thorough planning and supervision. New cultivation systems might include new crops and fruit trees that are in demand at the local markets. Therefore, it would be of interest to further study market and economic aspects for different products.

CONCLUSIONS

Hop Son

Agroforestry systems would be suitable for establishing on slopes up to 15 % with plants such as *F. macrophylla* that tolerate acid environments, high Al concentrations, low nutrient status and the climate conditions in the region. These systems would allow intercropping with cassava, which is one of the most important crops in the region. In any case, the system should be based on perennial plants that cover the soil all the year and allow soil biology systems to form and accordingly positively alter the physical properties of the soil. Plants included in an agroforestry system should have properties that build up soil organic matter and offer an extended soil cover i.e. specific qualities of the organic material such as high lignin content and slow decomposition rate. An extended root distribution further improves the positive properties that are demanded.

Methodology

During this project a number of techniques were used to evaluate sustainable land use in Hop Son hamlet. Regarding the evaluation of a field trial at the GRRC it would have been more rewarding if it had had more time to develop in order to show evident changes in soil properties. When it comes to erosion simulation and soil loss estimation with GLEAMS, the model worked satisfactory although it would have been interesting to do a more extended simulation for the area with more soil sampling in the vicinity and more climate data from the site. To perform a reliable study to be used in reality, this extended step is necessary. In addition, a model that could handle intercropped systems would be needed to more thoroughly investigate the properties of more detailed agroforestry and forestry systems. Finally, to create a GIS map with unfailing slope visualisation, a more detailed topographic map would be necessary. A rough estimate is that a map scaled 1:10,000 with height differences between the contours of 2 m would give a proper view of the hamlet. In order to study the present land use, satellite photos of the area could be analysed and possible changes in land use could be suggested for areas where they would be most efficient.

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APPENDIX 1. SOIL PROFILE DESCRIPTION, GRRC

General Information

Registration and location

Soil name: GRRC, 105° 25 E and 21° 06 N
Soil profile description status: routine soil profile description
Date of description: 2001-06-25
Authors: Joakim Andersson and Åsa Wisén
Location: trial plots at the Goat and Rabbit Research Centre, Bavi district, Hatay province, about 3 km west of Sontay, about 50 km west of Hanoi, Vietnam
Elevation: about 120 m above sea level
Map sheet number, grid reference, coordinates: Bavi 6051 II, 1:50 000, 105° 25 E and 21° 06 N

Soil classification

Soil taxonomic classification:
According to Soil Taxonomy: Typic Kanhaplustult
According to World Reference Base: Hyperdystri-alumic Acrisol (endoskeletic)
Soil climate: Ustic, hyperthermic

Landform and topography

Topography: rolling
Landform: hill
Land element: slope
Position: upper slope
Slope: 10 %, sloping (5-10 %), straight
Aspect: NNW, 20°
Micro-topography: no micro-relief

Land use and vegetation

Land use: rain fed arable cultivation, trial plots with cassava *(Manihot esculenta)*, *Flemingia macrophylla* and mulberry *(Morus alba)*
Human influence: vegetation strongly disturbed
Vegetation: grass cover 15-40 %

Parent material

Parent material: in situ weathered, quartzitic sandstone
Effective soil depth: roots down to 100+ cm

Surface characteristics

Rock outcrops: none
Surface coarse fragments: few stones
Erosion: main category: water erosion, rill erosion, area affected: 10-25 %, degree: slight, activity: period of activity not known

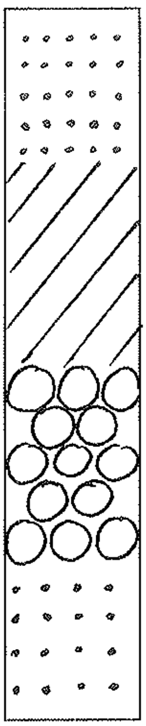
Surface sealing: none
Surface cracks: none
Other surface characteristics: none

Soil-water relationships
Drainage class: moderately well to well-drained
Internal drainage: never saturated
External drainage: moderately runoff
Flooding: none
Groundwater: very deep >150 cm, fresh
Moisture conditions: slightly moist through out the profile

Brief General Description of the Soil

A soil most probably developed from two different parent materials. Soil structure is well developed within 10-42 cm in depth with a fairly high biological activity, mainly ants. The top 10-cm of the profile seems to have been modified with added soil material, mainly gravel. Below 42 cm a dense horizon with high content of gravel is developed, which likely originates from another parent material.

Soil Horizon Description



A_p 0-10 cm, smooth abrupt boundary; bright brown (7.5 YR 5/6) moist; loam; abundant medium angular to rounded weathered gravel; loose single grain; slightly sticky, non-plastic; few fine roots; non-calcareous.

A_h 10-23 cm, wavy clear boundary; brownish black (7.5 YR 3/2) moist; dull yellowish brown (10 YR 5/3) dry; clay loam; few sub-angular weathered fine and medium gravel; moderate platy; friable moist, hard dry; slightly sticky, slightly plastic; few fine roots; common ants and nests; non-calcareous.

AB 23-42 cm, wavy clear boundary; dark brown (7.5 YR 3/4) moist; clay loam; common sub-rounded weathered fine and medium gravel; weak to moderate fine sub-angular blocky breaking down to very fine sub-angular blocky; friable moist; slightly sticky, plastic; few fine roots; common ants and nests; non-calcareous.

$2B_t$ 42-100+ cm; bright brown (7.5 YR 5/8) moist; loamy sand; abundant sub-rounded weathered fine and medium gravel; very weak coarse sub-angular blocky breaking down to single grain; very friable moist; non-plastic, non-sticky; very few fine roots; non-calcareous.

Table 14. Chemical and textural data from soil profile at the field trial (* 76 % gravel has been removed from the soil sample "0-10 cm" before the analyses were made. ** 75 % gravel has been removed from the soil sample "42-100+ cm" before the analyses were made)

Soil depth (cm)	Particle size (%)		
	Clay (< 2 µm)	Silt (20-2 µm)	Sand (> 20 µm)
0-10*	33.5	36.7	29.8
10-23	35.2	34.4	30.4
23-42	34.4	33.6	32.1
42-100+**	41.8	34.4	23.9

Soil depth (cm)	Organic matter (%)	Organic C (%)	N (%)	C/N	P (mg/100 g)	pH_{KCl}	CEC (me/ 100 g soil)	CEC (me/ 100 g clay)
0-10*	5.2	3.0	0.22	13.6	1.86	4.8	11.4	34.1
10-23	5.0	2.9	0.14	20.7	0.51	3.8	10.0	28.5
23-42	2.7	1.6	0.10	15.8	0.36	3.8	7.0	20.4
42-100+**	1.1	0.7	0.07	9.4	0.31	3.8	5.9	14.2

Soil depth (cm)	Al^{3+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Apparent ECEC (me/100 g soil)	Al-saturation (Al^{3+}/ ECEC-soil) (%)	BS (%)
	(me/100 g)							
0-10*	0.10	7.60	0.62	0.07	0.31	8.7	1.2	75.3
10-23	3.24	0.50	0.07	0.03	0.10	3.9	82.2	7.0
23-42	2.72	0.32	0.04	0.02	0.05	3.5	87.8	6.1
42-100+**	1.13	0.48	0.07	0.02	0.08	2.8	76.5	10.9

Comments on the Classification

The A_p horizon seems to have been deposited by human activity at the site. This horizon is not present in the field trial. The field trial is situated next to the site. Due to this fact the Ah horizon is excluded from the classification of the profile.

According to World Reference Base (FAO, 1998) the Ah horizon is classified as an ochric horizon and the $2B_t$-horizon most likely as an argic horizon. This horizon is probably developed from another parent material than the overlying horizons. The $2B_t$-horizon is very dense with a high content (75 %) of gravel and roots seem to penetrate it with difficulty. The relatively higher content of clay in the fine earth fraction compared with the overlying horizons indicates clay illuviation. Thereby, the profile is classified as an Acrisol. In addition, it fulfils the criteria for the following lower level units: alumic, hyperdystric and endoskeletic. Finally, the profile is classified as a Hyperdystri-alumic Acrisol (endoskeletic).

According to Soil taxonomy (USDA, 1998) the Ah horizon is classified as an ochric epipedon and the $2B_t$-horizon as a Kandic horizon. The base saturation is thought to remain below 35 % to a depth of 157 cm from the surface and thus is classified as a Typic Kandiustult if the clay content is supposed to decrease less than 20 % at a depth of 150 cm from the mineral soil surface. If this were not the case it would be classified as a Typic Kanhaplustult.

APPENDIX 2. SOIL PROFILE DESCRIPTION, HOP SON 1A

General Information

Registration and location

Soil name: Hop Son 1a, 105°20 E and 21° 05 N
Soil profile description status: Routine soil profile description
Date of description: 2001-06-20
Authors: Joakim Andersson and Åsa Wisén
Location: Bavi community, Hop Son village, Bavi district, Hatay province, just north-west of Bavi National park, about 20 km west of Sontay, about 60 km west of Hanoi, Vietnam
Elevation: about 300 m above sea level
Map sheet number, grid reference, coordinates: 1:50 000, Ba Vi 6051 II, 1:50 000, 105° 20 E and 21° 05 N

Soil classification

Soil taxonomic classification:
According to Soil Taxonomy: Ustic haplohumult
According to World Reference Base: Chromi-humic Acrisol
Soil climate: Ustic, hyperthermic

Landform and topography

Topography: mountainous
Landform: mountain
Land element: slope
Position: crest
Slope: 35 %, steep (30-50 %), s-formed
Aspect: NNE, 20°
Micro-topography: human-made erosion control strips

Land use and vegetation

Land use: crop agriculture, rain fed arable cultivation, cassava
Human influence: vegetation disturbed, application of fertiliser, raised beds
Vegetation: cassava field, 40-80 % covering of wild grass

Parent material

Parent material: in situ weathered, saprolite, quartzitic sandstone
Effective soil depth: roots down to 60 cm, the soil layer continues deeper

Surface characteristics

Rock outcrops: very few (0-2 %), >50m apart
Surface coarse fragments: none
Erosion: main category: water erosion, rill erosion, area affected: >50 %, degree: moderate, activity: period of activity not known
Surface sealing: none

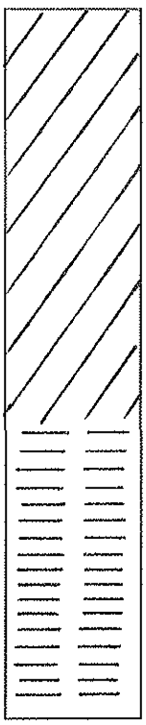
Surface cracks: width: <1 cm (1-2 mm), very closely spaced <0.2 m
Other surface characteristics: none

Soil-water relationships
Drainage class: somewhat excessively drained
Internal drainage: never saturated
External drainage: rapid runoff
Flooding: none
Groundwater: very deep >150 cm, fresh
Moisture conditions: Moist through out the profile (after heavy rains during the night)

Brief General Description of the Soil

This soil, developed in a mountainous monsoon region, is prone to erosion and presumably a result of strongly weathered quartzitic sandstone. The red colour indicates a high content of iron oxides and clay eluviation. The surface horizon is thin and low in organic matter as a result of erosion as well as absence of input from new organic matter.

Soil Horizon Description



A_h 0-7 cm, wavy clear boundary; dull reddish brown (5 YR 4/4) moist and orange (7.5 YR 6/6) dry; clay loam; very weak very fine angular blocky to single grain; very friable moist, slightly hard dry; slightly sticky, slightly plastic; common very fine roots; common insect activity; non-calcareous.

BA 7-17 cm, wavy clear boundary; bright reddish brown (5 YR 5/6) moist; clay loam; weak fine angular blocky; friable moist; sticky, slightly plastic; common very fine roots; common insect activity; non-calcareous.

B_t 17-67 cm, wavy diffuse boundary; bright reddish brown (5 YR 5/6) moist; clay loam; moderate coarse angular blocky breaking down to fine angular blocky; friable moist; sticky; slightly plastic; very few very fine roots; few insect activity; non-calcareous.

B_{t2} 67-110+ cm; bright reddish brown (5 YR 5/6) moist; clay loam; common medium gravel; moderate coarse angular blocky breaking down to fine angular blocky; friable moist; very few very fine roots; few insect activity; non-calcareous.

APPENDIX 3. SOIL PROFILE DESCRIPTION, HOP SON 1B

General Information

Registration and location

Soil name: Hop Son 1b, 105°20 E and 21° 05 N
Soil profile description status: Routine soil profile description
Date of description: 2001-06-22
Authors: Joakim Andersson and Åsa Wisén
Location: Bavi community, Hop Son village, Bavi district, Hatay province, just north-west of Bavi National park, about 20 km west of Sontay, about 60 km west of Hanoi, Vietnam
Elevation: about 250 m above sea level
Map sheet number, grid reference, coordinates: 1:50 000, Ba Vi 6051 II, 1:50 000, 105° 20 E and 21° 05 N

Soil classification

Soil taxonomic classification:
According to Soil taxonomy: Aeric epiaquept
According to World Reference Base: Gleyi-hydragric Anthrosol
Soil climate: Ustic, hyperthermic

Landform and topography

Topography: mountainous
Landform: mountain
Land element: valley floor
Position: bottom
Slope: level (0.2-0.5 %)
Micro-topography: no micro-relief

Land use and vegetation

Land use: crop agriculture, wet rice cultivation, rice (flooded)
Human influence: vegetation strongly disturbed, flood irrigation, application of fertilisers, burning, terracing
Vegetation: 15-40 % cover of grasses

Parent material

Parent material: in situ weathered, saprolite, sedimentary rock, sandstone
Effective soil depth: roots down to 85 cm, the soil layer continues deeper.

Surface characteristics

Rock outcrops: none
Surface coarse fragments: common stones
Erosion: main category: water erosion, deposition by water, area affected: 10-25 %, degree: slight, activity: period of activity not known
Surface sealing: none

Surface cracks: probably cracks during dry winter period
Other surface characteristics: none

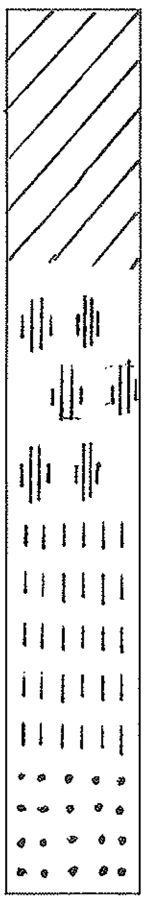
Soil-water relationships

Drainage class: poorly drained
Internal drainage: saturated for long periods every year
External drainage: ponded
Flooding: daily, 180-360 days, very shallow, irrigated
Groundwater: varies between very shallow to deep 0-100 cm, gleyic
Moisture conditions: wet throughout the profile

Brief General Description of the Soil

The profile situated low in the topography with a continuous water supply, during the wet season, is used for wet rice cultivation. Reddish and bluish mottles indicate altering reducing and oxidizing conditions due to dry and wet seasons in a monsoon climate.

Soil Horizon Description



A_p 0-13 cm, wavy gradual boundary; olive brown (2.5 Y 4/3) matrix moist, dull yellow (2.5 Y 6/3) matrix dry, many fine distinct mottles brown (7.5 YR 4/4) moist, common medium faint mottles bluish grey (10 BG 5/1) inside peds moist; light clay; weak medium angular blocky breaking down to fine angular blocky; friable moist, slightly hard to hard dry; slightly sticky, plastic; few fine roots; non-calcareous.

BA 13-27 cm, wavy gradual boundary; brown (10 YR 4/4) matrix moist, bright yellowish brown (10 YR 7/6) matrix dry; common medium faint mottles dull reddish brown (5 YR 4/3); clay loam; coarse angular blocky breaking down to medium angular blocky; friable moist, slightly hard to hard dry; slightly sticky, slightly plastic; very few very fine roots; non-calcareous.

B_w 27-85 cm, wavy clear boundary; brown (10 YR 4/4) matrix moist, bright yellowish brown (10 YR 7/6) matrix dry; clay loam; weak to moderate coarse angular blocky breaking down to medium angular blocky; friable moist, slightly hard dry; slightly sticky; slightly plastic; common medium soft mineral nodules black (5 YR 1,7/1); very few very fine roots; non-calcareous.

2C 85-100+ cm; yellowish brown (10 YR 5/6) moist, bright yellowish brown (10 YR 6/6) dry; loamy sand; abundant medium and coarse sub-rounded weathered gravel; no peds, single grain when wet; slightly hard to hard medium angular blocky when dry; no roots; non-calcareous.

Table 15. Textural and chemical data from the site 1b (*31 % gravel has been removed from the soil sample from depth 85-100+cm before the analyses were done)

Soil depth	Particle size (%)		
(cm)	Clay (< 2 μm)	Silt (20-2 μm)	Sand (> 20 μm)
0-13	10.5	69.5	20.0
13-27	2.0	81.5	16.5
27-85	2.5	89.1	8.4
85-100+*	2.2	65.2	32.6

Soil depth (cm)	Organic matter (%)	Organic C (%)	N (%)	C/N	P (mg/100 g)	pH_{KCl}	CEC (me/ 100 g soil)	CEC (me/ 100 g clay)
0-13	2.9	1.7	0.17	9.7	1.24	4.7	9.2	-
13-27	1.3	0.8	0.08	9.6	0.25	5.2	7.6	-
27-85	0.7	0.4	0.04	9.5	0.21	5.0	8.2	-
85-100+*	0.6	0.3	0.02	17.0	0.44	5.0	6.7	-

Soil depth	Al^{3+}	Ca^{2+}	Mg^{2+}	Na^+	K^+	Apparent ECEC	Al-saturation (Al^{3+}/ ECEC-soil)	BS
(cm)	(me/100 g)					(me/100 g soil)	(%)	(%)
0-13	0.12	3.17	1.91	0.05	0.10	5.4	2.2	56.7
13-27	0.06	3.37	2.62	0.03	0.05	6.1	1.0	79.6
27-85	0.06	3.55	3.53	0.05	0.10	7.3	0.8	88.0
85-100+*	0.06	2.82	2.82	0.03	0.08	6.1	1.0	90.4

Comments on the Classification

The soil has been used for wet rice cultivation for a long time and Fe-Mn mottles indicate that the A_p horizon could be classified as an Anthric horizon and the BA and B horizons as an hydragric horizon according to WRB (FAO, 1998). The soil keys out as an Anthrosol and fulfils the criteria for hydragric and gleyic lower level units. The classification of the profile is Gleyi-hydragric Anthrosol.

According to Soil taxonomy (USDA, 1998) the A_p horizon is classified as an Ochric epipedon and the BA- and B_w-horizons are classified as a Cambic horizon. The profile finally keys out as an Aeric epiaquept.

APPENDIX 4. SOIL PROFILE DESCRIPTION, HOP SON 2A

General Information

Registration and location

Soil name: Hop Son 2a, 105° 20 E and 21° 05 N
Soil profile description status: Routine soil profile description
Date of description: 2001-06-22
Authors: Joakim Andersson and Åsa Wisén
Location: Bavi community, Hop Son village, Bavi district, Hatay province, just north-west of Bavi National park, about 20 km west of Sontay, about 60 km west of Hanoi, Vietnam
Elevation: about 350 m above sea level
Map sheet number, grid reference, coordinates: 1:50 000, Ba Vi 6051 II, 1:50 000, 105° 20 E and 21° 05 N

Soil classification

Soil taxonomic classification:
According to Soil taxonomy: Ustic kanhaplohumult
According to World Reference Base: Veti-humic Acrisol (alumic)
Soil Climate: Ustic, hyperthermic

Landform and topography

Topography: mountainous
Landform: mountain
Land element: slope
Position: middle slope
Slope: 25 %, moderately steep (15-30 %), straight
Aspect: WNW, 320°
Micro-topography: no micro-relief

Land use and vegetation

Land use: plantation forestry, acacia, wild shrubs
Human influence: vegetation moderately disturbed
Vegetation: evergreen woodland, evergreen shrubs, grass cover 40-80 %

Parent material

Parent material: in situ weathered, saprolite, quartzitic sandstone.
Effective soil depth: roots down to 100+ cm

Surface characteristics

Rock outcrops: very few (0-2 %), >50 m apart
Surface coarse fragments: none
Erosion: main category: water erosion, sheet erosion, area affected: 0-5 %, degree: slight, activity: period of activity not known
Surface sealing: none

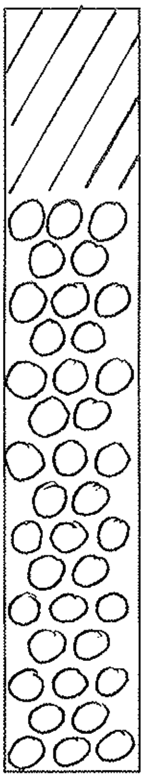
Surface cracks: none
Other surface characteristics: none

Soil-water relationships
Drainage class: somewhat excessively drained
Internal drainage: never saturated
External drainage: moderate to slow runoff
Flooding: none
Groundwater: very deep >150 cm, fresh
Moisture conditions: moist through out the profile

Brief General Description of the Soil

This soil, developed in a mountainous monsoon region, is prone to erosion and presumably a result of strongly weathered quartzitic sandstone. The red colour indicates a high content of iron oxides and clay eluviation. The surface horizon has a relatively high input of organic matter and the biological activity is fairly high down to 81 cm depth.

Soil Horizon Description



A_h 0-10 cm, wavy clear boundary; brown (7.5 YR 4/4) moist and bright brown (7,5 YR 5/6) dry; clay loam; weak medium sub-angular blocky; very friable moist, slightly hard dry; slightly sticky, slightly plastic; common fine roots; few insect activity; non-calcareous.

B_{t1} 10-51 cm, wavy gradual boundary; bright brown (7.5 YR 5/8) moist; clay loam; very few sub-rounded strongly weathered boulders; moderate coarse angular blocky breaking down to fine angular blocky; friable moist; slightly sticky, slightly plastic; few fine roots; few insect activity; non-calcareous.

B_{t2} 51-81 cm, wavy gradual boundary; bright brown (7.5 YR 5/8) moist; clay loam; common sub-rounded strongly weathered coarse gravel; weak to moderate coarse angular blocky breaking down to very fine angular blocky; very friable to friable moist; slightly sticky, plastic; few fine roots; few insect activity; non-calcareous.

C 81-100+ cm; brown (7.5 YR 4/4) moist; light clay; abundant sub-rounded strongly weathered stones; weak to moderate coarse angular blocky breaking down to very fine angular blocky; very friable to friable moist; very few fine roots; non-calcareous.

APPENDIX 5. SOIL PROFILE DESCRIPTION, HOP SON 2B

General Information

Registration and location

Soil name: Hop Son 2b, 105° 20 E and 21° 05 N
Soil profile description status: Routine soil profile description
Date of description: 2001-06-22
Authors: Joakim Andersson and Åsa Wisén
Location: Bavi community, Hop Son village, Bavi district, Hatay province, just north-west of Bavi National park, about 20 km west of Sontay, about 60 km west of Hanoi, Vietnam
Elevation: about 325 m above sea level
Map sheet number, grid reference, coordinates: 1:50 000, Ba Vi 6051 II, 1:50 000, 105° 20 E and 21° 05 N

Soil classification

Soil taxonomic classification:
According to Soil taxonomy: Humic haplustox
According to World Reference Base: Veti-alumic Ferralsol (hyperdystric)
Soil Climate: Ustic, hyperthermic

Landform and topography

Topography: mountainous
Landform: mountain
Land element: slope
Position: lower slope
Slope: 25 %, moderately steep (15-30 %), straight
Aspect: WNW, 340°
Micro-topography: terraces

Land use and vegetation

Land use: extensive grazing, wild shrubs
Human influence: terracing
Vegetation: evergreen shrub land, grass cover >80 %

Parent material

Parent material: in situ weathered, saprolite, quartzitic sandstone.
Effective soil depth: roots down to 100+ cm

Surface characteristics

Rock outcrops: very few (0-2 %), 20-50 m apart
Surface coarse fragments: very few boulders
Erosion: main category: water erosion, rill erosion, area affected: 10-25 %, degree: moderate, activity: period of activity not known
Surface sealing: none

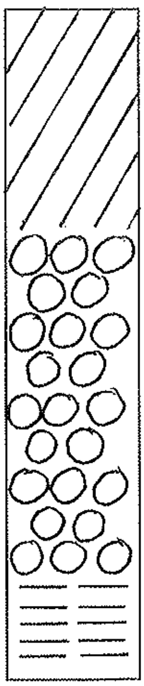
Surface cracks: none
Other surface characteristics: none

<u>Soil-water relationships</u>
Drainage Class: somewhat excessively drained
Internal drainage: never saturated
External drainage: rapid runoff
Flooding: none
Groundwater: very deep >150 cm, fresh
Moisture conditions: moist throughout the profile

Brief General Description of the Soil

This soil, developed in a mountainous monsoon region, is prone to erosion and presumably a result of strongly weathered quartzitic sandstone. The red colour indicates a high content of iron oxides and clay eluviation. The surface horizon seems to have been modified with additional soil material due to terracing at the site.

Soil Horizon Description



A_h 0-17 cm, smooth abrupt boundary; brown (7.5 YR 4/6) moist and orange (7,5 YR 6/6) dry; clay loam; weak to moderate medium sub-angular blocky breaking down to very fine and fine sub-angular blocky; friable moist, slightly hard dry; slightly sticky, slightly plastic; common fine roots; non-calcareous.

B_{w1} 17-45 cm, wavy clear boundary; dark brown (7.5 YR 3/4) moist; clay loam; weak to moderate medium sub-angular blocky breaking down to very fine and fine sub- angular blocky; friable moist; slightly sticky, slightly plastic; few fine roots; non-calcareous.

B_{w2} 45-71 cm, wavy gradual boundary; bright reddish brown (5 YR 5/8) moist; clay loam; moderate medium angular blocky breaking down to very fine and fine angular blocky; friable moist; slightly sticky, slightly plastic; few fine roots; non-calcareous.

C 71-100+ cm; light reddish brown (5 YR 5/8) moist; clay loam; many sub-rounded strongly weathered stones; weak very fine and fine angular blocky; friable moist; very few fine roots; non-calcareous.

Table 16. Textural and chemical data from the site 2b

Soil depth (cm)	Particle size (%) Clay (< 2 µm)	Silt (20-2 µm)	Sand (> 20 µm)
0-17	40.1	51.4	8.5
17-45	38.5	53.7	7.8
45-71	38.7	53.2	8.0
71-100+	32.6	50.9	16.5

Soil depth (cm)	Organic matter (%)	Organic C (%)	N (%)	C/N	P (mg/100 g)	pH_{KCl}	CEC (me/ 100 g soil)	CEC (me/ 100 g clay)
0-17	3.3	1.9	0.12	15.6	0.27	3.8	6.7	16.8
17-45	3.8	2.2	0.14	6.7	0.36	3.7	8.1	20.9
45-71	1.5	0.9	0.08	13.5	2.82	3.9	4.5	11.5
71-100+	1.1	0.7	0.60	9.6	0.25	4.2	3.5	10.6

Soil depth (cm)	Al^{3+} (me/100 g)	Ca^{2+}	Na^{+}	Mg^{2+}	K^{+}	Apparent ECEC (me/100 g soil)	Al-saturation (Al^{3+}/ECEC-soil) (%)	BS (%)
0-17	1.80	0.25	0.04	0.09	0.08	2.3	79.7	6.8
17-45	2.16	0.17	0.02	0.06	0.05	2.5	87.8	3.7
45-71	1.04	0.21	0.01	0.05	0.05	1.4	76.5	7.2
71-100+	0.52	0.26	0.01	0.07	0.05	0.9	57.1	11.3

Comments on the Classification

According to WRB (FAO, 1998) the A_h horizon is classified as an ochric horizon and the B_{w2}-horizon is probably classified as a ferralic horizon. The soil profile keys out as a Ferralsol. It fulfils the requirements for the following lower level units: vetic, alumic and hyperdystric. Finally, the soil profile keys out as a Veti-alumic Ferralsol (hyperdystric).

According to Soil Taxonomy (USDA, 1998) the A_h horizon is classified as an ochric epipdon and the B_{w2}-horizon most likely fulfil the requirements for an oxic horizon. If the oxic horizon is supposed to continue deeper than 125 cm from the mineral soil surface the soil profile keys out as a Humic haplustox.

It must be mentioned that the topsoil has been moved around this site due to former constructions of terraces and that a top layer of soil containing less clay could have been removed, indicating that clay eluviation have taken place at the site although not detectable today.

APPENDIX 6. ROOT DISTRIBUTION

Table 17. Root distribution in the field trial, no manure application

		Number of roots per 100 cm^2			
	Soil horizon & depth (cm)	Very fine	Fine	Medium	Coarse
Cassava	A_h 0-13	many	many	few	-
	AB 13-25	common	common	-	-
	$2B_t$ 25+	few	-	-	-
Cassava	A_h 0-13	many	many	many	-
	AB 13-25	common	-	-	-
	$2B_t$ 25+	few	-	-	-
Cassava	A_h 0-13	many	many	common	-
	AB 13-25	common	common	-	-
	$2B_t$ 25+	few	-	-	-
F. macrophylla	A_h 0-20	many	many	common	common
	AB 20-35	few	-	-	few
	$2B_t$ 35+	few	-	-	few
F. macrophylla	A_h 0-10	many	common	common	common
	AB 10-19	common	-	-	few
	$2B_t$ 19+	few	-	-	few
F. macrophylla	A_h 0-10	many	common	common	many
	AB 10-15	common	-	-	common
	$2B_t$ 15+	few	-	-	common
White mulberry	A_h 0-16	many	few	common	common
	AB 16-21	common	few	few	-
	$2B_t$ 21-	few	-	-	-
White mulberry	A_h 0-13	many	common	common	few
	AB 13-22	common	few	-	few
	$2B_t$ 22+	few	-	-	few
White mulberry	A_h 0-15	common	few	common	few
	AB 15-23	few	few	few	-
	$2B_t$ 23+	few	few	few	-
F. macrophylla & cassava	A_h 0-11	many/many	many/common	many/-	few/-
	AB 11-17	common/common	common/common	common/-	few/-
	$2B_t$ 17+	few/few	-/-	-/-	few/-
F. macrophylla & cassava	A_h 0-10	many/many	many/many	common/-	few/common
	AB 10-17	common/common	common/common	-/common	few/-
	$2B_t$ 17+	few/few	few/-	-/-	few/-
F. macrophylla & cassava	A_h 0-10	many/many	many/many	few/common	-/-
	AB 10-16	common/common	common/common	-/few	-/-
	$2B_t$ 16+	few/few	-/few	-/-	-/-
F. macrophylla & white mulberry	A_h 0-10	many/common	common/few	many/common	common/common

	AB 10-20	common/few	few/-	common/-	few/-
	$2B_t$ 20+	few/few	-/-	-/-	few/-
F. macrophylla & white mulberry	A_h 0-13	many/many	common/common	many/common	few/common
	AB 13-20	common/common	common/few	common/common	few/-
	$2B_t$ 20+	few/few	few/-	-/-	few/-
F. macrophylla & white mulberry	A_h 0-12	many/many	common/common	common/few	common/common
	AB 12-18	common/common	few/common	few/few	common/common
	$2B_t$ 18+	few/few	-/-	common/common	common/-

APPENDIX 7. SOIL STABILITY MEASUREMENT

Table 18. Results from water stability test of soil aggregates

Subplot	Weight soil g	Turbidimetervalue (20 ml suspension)	Weight clay g	Estimated clay content (20 ml suspension) (y=7E-06x+0.0125)	g clay /g soil
A.C.1.1	23.393	3086		0.0341	0.0091
A.C.1.2	20.809	2160		0.0276	0.0083
B.C.1.1	20.021	2456		0.0297	0.0093
B.C.1.2	18.335	2505		0.0300	0.0102
C.C.1.1	22.108	2306	0.0286	0.0286	0.0081
C.C.1.2	22.66	2584		0.0306	0.0084
A.C.2.1	28.457	4348	0.0439	0.0429	0.0094
A.C.2.2	29.408	3136		0.0345	0.0073
B.C.2.1	27.946	3450		0.0367	0.0082
B.C.2.2	23.088	3015		0.0336	0.0091
C.C.2.1	20.464	1435	0.0229	0.0225	0.0069
C.C.2.2	20.779	2535		0.0302	0.0091
A.C.3.1	26.793	3229		0.0351	0.0082
A.C.3.2	28.044	3548	0.0378	0.0373	0.0083
B.C.3.1	14.93	1232		0.0211	0.0088
B.C.3.2	13.956	974		0.0193	0.0087
C.C.3.1	121.115	2272		0.0284	0.0015
C.C.3.2	19.887	1710		0.0245	0.0077
A.C.4.1	26.935	5478		0.0508	0.0118
A.C.4.2	25.847	2836		0.0324	0.0078
B.C.4.1	27.656	3532		0.0372	0.0084
B.C.4.2	21.822	2464		0.0297	0.0085
C.C.4.1	19.319	3958		0.0402	0.0130
C.C.4.2	17.839	1481		0.0229	0.0080
A.FM.0.1	23.544	3665		0.0382	0.0101
A.FM.0.2	19.524	3539		0.0373	0.0119
B.FM.0.1	25.189	4731		0.0456	0.0113
B.FM.0.2	22.507	4099		0.0412	0.0114
C.FM.0.1	24.177	3629		0.0379	0.0098
C.FM.0.2	21.942	2513		0.0301	0.0086
A.CF.0.1	20.984	2949		0.0331	0.0099
A.CF.0.2	21.492	4781		0.0460	0.0134
B.CF.0.1	22.426	2702		0.0314	0.0088
B.CF.0.2	19.799	2746		0.0317	0.0100
C.CF.0.1	27.352	5057		0.0479	0.0109
C.CF.0.2	21.917	3589	0.0305	0.0376	0.0107
A.F.0.1	22.733	3720		0.0385	0.0106
A.F.0.2	24.814	2489		0.0299	0.0075
B.F.0.1	21.434	3196		0.0349	0.0102
B.F.0.2	19.064	2687		0.0313	0.0103
C.F.0.1	30.819	2430		0.0295	0.0060

C.F.0.2	25.907	1927		0.0260	0.0063
A.C.0.1	29.299	3217		0.0350	0.0075
A.C.0.2	19.719	4145		0.0415	0.0132
B.C.0.1	25.544	5378		0.0501	0.0123
B.C.0.2	21.823	4985		0.0474	0.0136
C.C.0.1	22.518	3243	0.0334	0.0352	0.0098
C.C.0.2	16.812	1404		0.0223	0.0083
A.M.0.1	25.358	5016		0.0476	0.0117
A.M.0.2	26.115	4377	0.0421	0.0431	0.0103
B.M.0.1	21.262	3033		0.0337	0.0099
B.M.0.2	17.776	1897		0.0258	0.0091
C.M.0.1	26.676	2564		0.0304	0.0071
C.M.0.2	21.689	1891		0.0257	0.0074
AB1	28.803	3250		0.0353	0.0076
AB2	26.059	3787	0.04	0.0390	0.0094
BC1	25.057	2538		0.0303	0.0075
BC2	20.337	4147		0.0415	0.0128

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Sveriges Lantbruksuniversitet
Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik
Box 7014
750 07 UPPSALA

Tel. 018-67 11 85, 67 11 86

Swedish University of Agricultural Sciences
Department of Soil Sciences
Division of Agricultural Hydrotechnics
P.O. Box 7014
S-750 07 UPPSALA, SWEDEN

Tel. +46-(18) 67 11 85, +46-(18) 67 11 86