Lecture Note 3

Soil and Water Conservation

Meine van Noordwijk and Bruno Verbist

INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

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Meine van Noordwijk and Bruno Verbist

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Lecture note 3

SOIL AND WATER CONSERVATION

By Meine van Noordwijk and Bruno Verbist

I. Objectives

- Illustrate the role of agroforestry in soil conservation at the landscape level

II. Lecture

1. What is soil conservation?

Soil conservation basically means ***a way of keeping everything in place***, literally as well as in a more abstract sense of maintaining the functions of the soil in sustaining plant growth. Soil conservation practices involve managing soil erosion and its counterpart process of sedimentation, reducing *its negative impacts* and exploiting the new opportunities it creates. Young (1989) defined soil conservation as a combination of ***controlling erosion*** and ***maintaining soil fertility***. In the past the focus has often been on trying to keep the soil at its place by plot-level activities only. Currently, the attention has switched to landscape level approaches where ***sedimentation*** is studied along with ***erosion***, and the role of '***channels***' (footpaths, roads and streams) is included as well as the '***filters***' that restrict the overland flow of water and/or suspended sediment.

2. Why bother?

Erosion concerns differ widely between ***human interest groups in the uplands*** and ***those who live downstream***. Erosion is part of the long-term geological cycles of mountain formation and decline, occurs in any vegetation and is an essential part of soil development. Efforts to reduce erosion to zero in humanly used landscapes are doomed to failure, but perceptions of the ***optimum degree of soil conservation*** differ between interest groups (stakeholders).

Concerns on soil conservation for agriculturally used lands, especially those recently converted from forest, are usually based on a combination of:

a. On-site loss of land productivity,
b. Off-site concerns on water quantity:
   - Annual water yield
   - Peak (storm) flow
   - Dry season base flow
c. Off-site concerns on water quality, as erosion leads to sedimentation on lowlands, siltation of lakes and reservoirs and/or the eutrophication of water.

Concerns b and c are mainly valued by lowland interest groups who will perceive changes when a natural (forest) vegetation is converted into agriculture, whereas aspect a is mainly an upland issue. The combination of those three concerns led to a widespread concept of erosion as the major contributor to loss of productivity of uplands as well as the cause of lowland problems with water quantity and quality.

Soil conservation measures will not address all concerns such as loss of land productivity (a), water quality (b) and water quantity (c) to the same degree. We have to differentiate between them in evaluating environmental impacts of land-use or land cover change and in considering options for maintenance of '***forest functions'*** in agricultural landscapes.

3. A reminder: some key principles for soil and water conservation (modified from FAO and IIRR, 1995)

- **The farm household** should be the focus of every soil conservation program, as they take the daily decisions that shape the landscape; communal action at local level can be an important entry point for outside 'soil conservation programs'.
- **Farmers can not ignore the short-term benefits of the land use decisions they make.** Only those production strategies have a chance to be adopted that will provide a reasonable return on the labour and other resources a farmer has to invest. Conservation strategies or technologies that do not meet this criterion are doomed to fail.
- **Lack of secure land tenure** maybe a major cause of low interest of farmer in environmental conservation**. Improving tenure security** may be the main intervention needed for farmers to adopt reasonable soil conserving technologies**.**
- Soil conservation programs have often led to **'pseudo-adoption'** if strong social pressure, subsidies or other government incentives (including tenure security) were used to support adoption of practices that required substantial labour and other resource investment.
- **Loss of soil productivity** is often much more **important** than the loss of the soil itself, as the soil on the move tends to be rich in organic matter and nutrients, relative to the remaining soil.
- **Loss of soil productivity is not easy to assess**, however, because impoverished zones of net erosion may be accompanied by enriched zones of net sedimentation and the farmer may decide to grow different crops in these two environments
- In upland systems, plant yields are reduced more by **a shortage** or **excess of soil moisture** (especially for tuber crops) or nutrients rather than by **soil losses** ***per se***. Therefore, there should be more emphasis on ***rainwater management***, particularly water conservation, and ***integrated nutrient management*** and less on soil conservation per se. Agronomic process such as tillage and mulching that maintain infiltration rates are more useful than mechanical measures blocking the path of water flowing at the soil surface in preventing erosion and runoff.
- **Erosion** is a consequence of how land and its vegetation are managed, and is not itself the cause of soil degradation. Therefore prevention of land degradation is more important than attempting to develop a cure afterwards.
- **Erosion is a top-down process**, because gravity determines the direction of water flow. Most past (and current ?) soil conservation programs focus(ed) more on land degradation than on the land user (the farm household), and used **a top-down approach in 'dissemina-tion' and 'extension' of 'best-bet' practices** that were considered to be applicable for a wide range of farm situations. Top down programs tend to focus primarily on the symptoms of erosion through subsidised terracing, promotion of hedgerow intercropping systems or other measures which have had mixed success when introduced by outside agencies.
- Soil conservation programs that aim to reduce land degradation problems through treatment of causes, require **a long term, bottom-up approach** supporting farmers who generally have detailed knowledge of their farm, know a wide range of potential interventions (although they can still learn new ideas from experiences elsewhere) and choose between these interventions on the basis of the resources and pressures on the farm household.

4. What soil conservation techniques are common practice?

A risk of accelerated erosion exists on cultivated land from the moment trees, bushes, grass and surface litter are removed. Erosion will be exacerbated by attempting to farm slopes that are too steep, cultivating up-and-down hill, continuous use of the land without any rotation of different crops, inadequate input of organic materials, compaction due to footpaths or heavy machinery used for tillage and removal of harvest products etc. Erosion control depends on good management, which implies establishing sufficient crop cover and selecting appropriate practices to maintain infiltration with or without soil tillage. Thus soil conservation relies strongly on agronomic methods in combination with a realistic soil management whilst mechanical measures play only a supporting role, see schematic strategies in Figure 1.

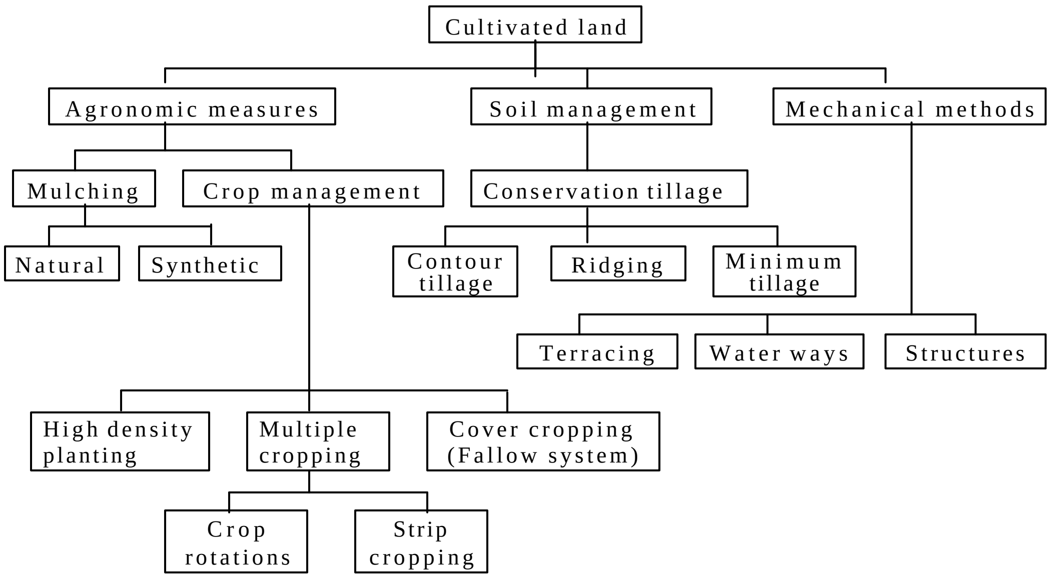


Figure 1. Soil conservation strategies for cultivated land (Adapted from Morgan, 1986)

Listing the full range of soil conservation techniques goes beyond the scope of this lecture note. A whole range of well-illustrated examples can be found in FAO-IIRR, 1995. We just would like to highlight examples of those three main groups of soil conservation strategies that involve agroforestry:

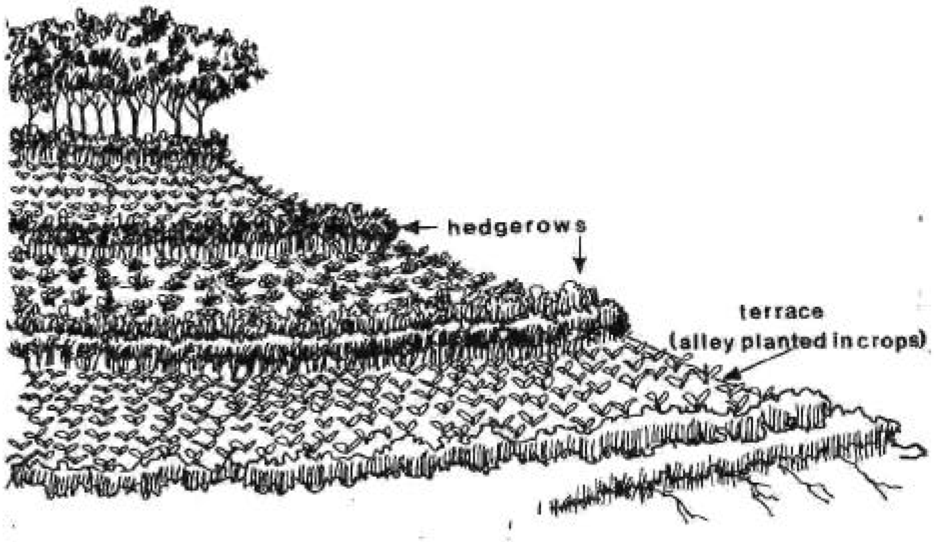
a. **Agronomic** or **biological measures** utilise the role of vegetation in helping to minimise the erosion by increasing soil surface cover, surface roughness, surface depression storage and soil infiltration. Some examples are:

- Strip cropping/alley cropping/hedgerow intercropping

Contour hedgerow systems using nitrogen fixing trees/shrubs have been widely promoted to minimise soil erosion, restore soil fertility, and improve crop productivity (Kang and Wilson 1987, Young 1997; Sanchez, 1995; Garrity, 1996, Friday KS, Drilling ME and Garrity DP. 1999). Hedgerows of trees or shrubs (usually double hedgerows) are grown at intervals of 4-6 m along the contours (see Figure 2). The strips or alleys between the hedgerows are planted with food crops. The hedgerow trees are regularly pruned to minimise shading of food crops, the pruned biomass can be used as green manure or as mulch *in situ,* or as fodder. Through time, natural terraces can form at the base of the hedgerow trees, and thereby minimise soil erosion and surface run-off. Terrace formation can be rapid if the soil is ploughed, but slower in no-till or manual tillage systems.

This technique has been recommended as a common feature of extension programs for sustainable agriculture in Asia. But this innovation has ***not been widely adopted*** outside of direct project intervention areas by upland farmers despite the positive results reported in a number of experimental and demonstration sites. The positive and negative ecological interactions between (hedgerow) trees and food crops are discussed more in detail in the Tree Crop Interaction lecture note (van Noordwijk and Hairiah, 2000). However, the major problem in practice is the large amount of labour needed to prune and maintain woody hedgerows. ICRAF (1996) estimated that the amount of labour required to prune leguminous-tree hedgerows was about 31 days per hectare, or 124 days annual labour for four prunings in the Philippines. There is a need for simpler, less labour intensive but effective contour hedgerow systems.

One can state that on flat land hedgerow intercropping is not interesting because of the high level of labour input needed. On sloping land, the improvement of soil fertility, stabilising crop production, may in principle pay off the labour inputs, but real farmer interest probably requires that the soil fertility accumulated in the hedgerows be used for profitable trees, crops or fodder.



Sloping Agricultural Land Technology (SALT) hedgerows are planted in dense double rows and trimmed frequently to produce large amounts of green manure for crops.

Figure 2. Contour hedgerows with pruned trees planted in dense double rows (Adapted from Friday KS, Drilling ME and Garrity DP. 1999); spontaneous adoption of these systems, outside of 'project' conditions, has been rare as the labour requirements for regularly pruning hedgerows of fast-growing trees are high

- Improved fallow systems (IFS)

In the uplands, arable areas are planted with food crops for some years and then the land is fallowed for some time to allow the soil to rejuvenate. To shorten the fallow period, the area can be seeded with leguminous trees. Once the soil has been rejuvenated, the trees are cleared for crops. This can be considered as an improved version of the traditional shifting cultivation practice. More information on fallow management, which was initiated, tested, proved and developed by farmers can be found in the lecture note on *Indigenous Fallow Management* (IFM) (Burgers, Hairiah and Cairns, 2000).

Example: the native *Leucaena* is used in a fallow system in Naalad, Naga, Cebu (the Philippines). The trees are cut and the branches are piled along the contours to form a barrier structure known locally as *balabag,* which traps the eroding soil. Through time, natural terraces are gradually formed, thus stabilising the steep slopes. Other advantage of this system is the reduction of the amount of nitrogen (N_2) needed as fertiliser because of N-fixation by *Leucaena.* The pruned leaves and branches can be used as fodder.

- Natural Vegetative Strips (NVS)

The use of natural vegetative strips (NVS) has proven to be an attractive alternative because they are so simple to establish and maintain. NVS are attractive as they mainly consist of 'no intervention'. When land is ploughed along contour lines, certain strips of 40-50 cm wide are left unploughed, across the field on the contour. These strips are spaced at desired intervals down the slope and can be marked beforehand. The recommended practice for spacing contour buffer strips has been to place them at every one meter drop in elevation, but a wider spacing may be acceptable. The contour lines can be determined using an *A-frame*. The natural vegetation of the strips filters the eroded soils, slows down the rate of water flow, and enhances water infiltration, making them very effective for soil and water conservation. Researchers found that these natural vegetative contour strips have many desirable qualities (Garrity, 1993). They hardly need pruning maintenance compared with fodder grasses or tree hedgerows, and compete little with adjacent annual crops. They are efficient in minimising soil loss and do not show a tendency to cause greater weed problems for the associated annual crops (Moody, 1992 as cited in Garrity, 1996), once plant succession favours the longer term survival of perennial species over the short-term production of typical 'weeds'. Especially in the Philippines, ICRAF has been working with a number of agencies to refine and expand the use of this conservation farming practice to much wider areas where it may be suitable.

b. **Soil management** is concerned with ways of preparing the soil to promote dense vegetative growth and improve the soil structure so that it is more resistant to erosion. Some techniques included in this group are: minimum tillage, crop rotation (food crops/ cover crops), manure, sub-soiling and drainage.

- **Minimum tillage/zero tillage.** In this system, simple farm equipment such as hoes and digging sticks are used to prepare land and plant food crops. Spraying herbicide kills weeds, and all plant residues (including weeds) are returned into the soil. Farmers in swidden systems traditionally are familiar with minimum tillage practices. While more intensive tillage generally increases porosity of the topsoil and reduced barriers to infiltration of the soil surface, it normally interrupts the continuity of the macro-pores in the soil and can reduce deep infiltration, especially if a 'plough-pan' is formed. No till systems that are implemented on soils that have never been ploughed or compacted by the use of heavy machinery generally maintain the high infiltration rates of forest soils. Transitions from ploughing to minimum tillage systems often involve a number of years of reduced infiltration, before new continuous macro-pore system is re-established by the activity of earthworms and other 'soil engineers'.

- **Crop rotation** is common practice for smallholder farmers in SE-Asia. It is a system with various crop species grown in sequence on the same plot. Example: maize grown at the first season and groundnuts in the second season. Groundnuts can replenish N (via N-fixation) which was extracted by maize. The different rooting pattern of different crop species planted may help on soil structure formation and improve water percolation. These cropping pattern can vary from year to year depending on market price or on soil/weather condition, but they are chosen for the same purposes: better soil physical and nutrient condition, interrupts life cycle of weed/pest/ plant disease.

c. **Mechanical** or **physical methods** can be viewed as an attempt **to control the energy available for erosion** (rain splash, runoff). These methods depend on manipulating the surface topography by installing terraces, ditches. Examples are:

Bench terraces consist of a series of alternating shelves and dykes and are used on sloping land up to 40 % with relatively deep soils to retain water and control erosion. The dykes are vulnerable to erosion and are protected by a vegetation cover (e.g. *Cajanus cajan*, *Sesbania grandiflora*, *Sesbania sesban*, *Gliricidia sepium* or fruit trees such as banana (*Musa*) and sometimes faced with stones or concrete. The plant spacing (6 x 6 m) of bigger fruit trees as mango (*Mangifera indica*), jack fruit (*Artocarpus sp.)* etc.) is generally too wide to be effective for dyke protection, but it increases economic revenue on those terraces. The terraces are normally constructed by cutting the soil to produce series of level steps or benches, which allow water to infiltrate slowly into the soil. Bench terraces are suitable mainly for irrigated rice-based cropping systems.

Soil traps (more commonly known as sediment traps) are structures constructed to harvest soil eroded from the upper slopes of the catchment. Common types of soil traps are **check dams and trenches.** They slow down the water flow and allow heavier soil particles to settle (see Figure 3). It prevents widening and deepening of gullies and promotes the deposition of nutrient-rich, highly fertile sediments. Afterwards this area can be used for growing crops. The accumulated soil can also be returned to the field, but that is quite laborious.

The size of the check dam depends on the size of the drainage or gully to be protected. Check dams can be built of stakes (e.g. from *Gliricidia*), bamboo, loose rocks, logs or other locally available materials. They should be permeable, as they are meant to slow down the speed of the water to increase sedimentation. They are not meant to stop or divert the flow of the water.

A combination between agronomic measures and good soil management can influence both the **detachment** and **transport phases** of the erosion process, whereas mechanical methods are effective in **controlling the transport** phase but do little to prevent soil detachment.

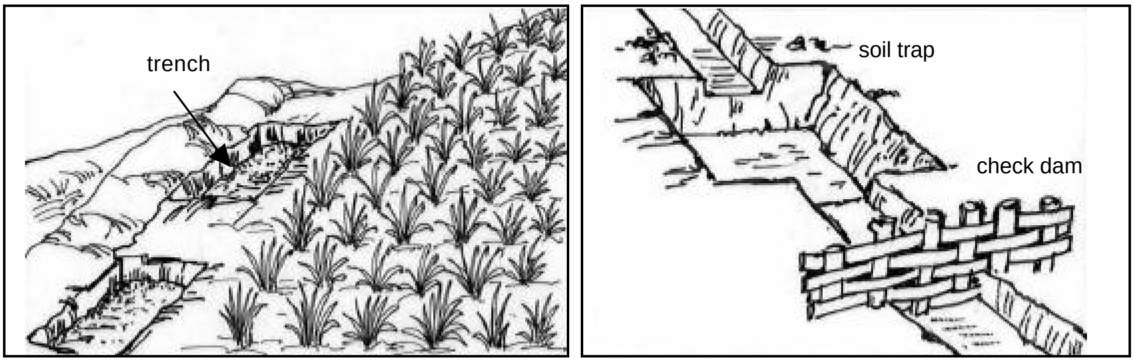


Figure 3. An example of trenches as soil trap and trenches + check dam combined. (Adapted from FAO and IIRR, 1995)

A case study from the Philippines:

Farmer-driven mechanisms toward widespread dissemination of conservation farming practices: The Landcare Approach

(quoted from Garrity D, Stark M and Mercado A, 1999. Natural Vegetative Strip technology: A "NO COST" paradigm that may help transform tropical smallholder conservation.).

An adoptable technology must have a **minimal cost** to the farmer, and **be easy to extend** to large numbers of farmers. Late 1995, ICRAF was approached by farmers for assistance in installing contour strips to prevent soil erosion. ICRAF scientists responded by combining their technical expertise with the extension skills of a technician from the Department of Agriculture, and the practical knowledge of a motivated farmer. This **Contour Hedgerow Extension Team (CHET)** was composed of three individuals. They initially worked with individual farmers who requested their assistance. Subsequently, group-training activities were conducted to reach more farmers: These involved 5-7 participants from each of the 7 villages in which the team was working. Before the end of the training the participants decided to organise themselves into a peoples "***self-help organisation for conservation farming***". Officers were elected and the organisation came to be known as '**the Claveria Land Care Association (CLCA)**'.

The Landcare Association evolved and **develops** and **shares** more effective ways of achieving sustainable agriculture through technology dissemination. The approach developed into a dynamic movement that now has 56 self-governing chapters (*similar to branches or sub-divisions*), over 2000 members and a municipal federation in Claveria. More than 600 farmers have installed NVS on their farms. The local government units were impressed with the energy of this movement, and started supporting the effort financially, with active involvement of the village leaders.
The Landcare approach has also been embedded in the natural resources management plan of a neighbouring municipality, Lantapan, Bukidnon. Currently about 125 Lantapan farmers have established NVS systems on their farms. Two types of key conservation farming practices were validated through farmer-participatory research in Lantapan: **Natural Vegetative Strip (NVS) systems and ridge-tillage systems**.

One of the key issues that emerged in various meetings was the establishment of cash perennials on the NVS. Although, farmers appreciated the role of NVS in **controlling soil erosion,** most want to **optimise the hedgerow space**. They are keen to establish **timber** and **fruit trees** on their NVS. *Gmelina arborea* has been widely planted, and farmers were looking for other species: ***Eucalyptus deglupta***, which has a **better market** potential for poles and timber. The CLCA put up a nursery. It was agreed that each chapter would contribute the labour required and the incurred costs for nursery establishment and maintenance. ICRAF provided improved seed. Nursery establishment and management training was conducted with the chapter chairmen, selected members, and 'barangay' or district councilors. The training included lectures and hands-on experience with the very different nursery practices required for *E. deglupta*.

More than 40 volunteer village nurseries have now been set up and are producing timber and fruit trees seedlings for the NVS. The seedlings raised are *Eucalyptus spp* such as: *E. deglupta, E. robusta, E. camaldulensis*, and *E. torelliana,* and a wide range of other fruit and timber species. Chapter members provided the nursery sheds, fencing, plastic bags, and potting material, and implemented all activities in the nurseries. The members on a rotational basis did tasks, such as watering and cleaning to maintain the nursery. The nursery activities did not compete with hedgerow establishment. NVS are established during the land preparation period, which is therefore a seasonal activity only. The NVS are proving to be a foundation for the evolution towards more productive timber or fruit tree-based agroforestry systems.

The Landcare approach is a method to **rapidly and inexpensively diffuse** agroforestry practices among **thousands of upland farmers**. It is based on the farmers' genuine interest in learning and sharing knowledge about new technologies that earn more money and conserve natural resources. Essential elements of the approach are:

- a flexible set of proven technologies for smallholder agroforestation and conservation farming;
- farmer exposure to these technologies through observation and spontaneous on-farm trials;
- a farmers organisation to widely diffuse knowledge about the technologies within the municipality; and (in the event that the prior steps are successful) financial support from local government (municipality and village) to enhance the sustainability of the movement.

Some outside resources, however, will be important to the success of the approach. The most critical of these is ensuring the presence of **sensitive, soundly trained**, and **highly motivated** persons to facilitate the process of conveying the technologies and developing a sound farmers' organisation. They will have to be capable to **identify** and **nurture** leadership qualities of farmers to become leaders in their organisations. The facilitators will need both technical skills and people skills. Beyond this, resources will be needed for fielding these people, and ensuring that the needs for transport, communications, and training materials are met. The specific activities of interest to the members of a Landcare Association will vary according to their interests, and their physical and economic environment.

Below are a few of the many activities that have been or are being developed as focal areas for the Landcare Association's work:

- establishment of natural vegetative strips (nvs) on the contour to reduce field or farm level soil erosion
- planting of cash perennials (either timber or high-quality fruit trees) on or just above the nvs strips to increase farm families cash income and enhance soil and water conservation
- adoption of minimum-tillage or ridge-tillage farming systems
- adoption of sound riparian buffer zone management along streams to enhance water quality and quantity

5. Issues of scale in a landscape approach

Most research on soil erosion by surface runoff is mainly focused on a comparison of **runoff** and **sediment loss** from plots with different land cover types (as treatments) with a bare fallow or farmer practice as a control. The experimental plots usually have standard dimensions and are normally protected from entering soil particle (runoff) from up-slope. The difficulties appear when it comes to scaling-up these results to what should be the target areas: **farmers' fields** or **catchment areas** and that makes 'scaling-up' erosion control experiences a far from trivial exercise.

Erosion and its counterpart process of sedimentation cannot be simply 'scaled-up' on an area basis from observation plots to farms and watershed. Although it is commonly done in the literature on the topic, one can not simply express erosion in **'ton per ha'** and multiply with the area to obtain erosion losses over a specified **period of time**. In larger areas much, if not most of those soil losses are deposited internally in sedimentation sites. (Just to bring the idea to the extreme: If one would have a plot with the size of the globe, there would be no erosion at all! It would just be a shift within the plot. Consequently the smaller your plot, the more erosion one would normally measure). A thorough analysis should take the following steps:

- How do soil and water movement at patch level combine to overall effects at landscape scale, and to what degree can '***filter***' strips or zones make up for incomplete soil and water conservation upstream? To what extent can '***forest functions'*** be ensured as filter to reduce soil loss, to maintain water quality and quantity.
- Which aspects of soil and water conservation at patch and landscape scale depend on land-use decisions?
- How do interventions aimed at off-site concerns b (water quantity) and c (water quality) influence on site productivity a?
- How can desirable land use decisions be influenced by a conducive policy environment (security of land tenure, financial incentives)?

Agroforestry research is gradually evolving from a focus on field level technologies and domesticated trees, to a more complete consideration of landscape-level processes and constraints to a farmer-led process technology development.

In a schematic form most agricultural landscape have undergone a gradual process of intensification (Figure 4) with a gradual loss of the '***forest functions***' in soil and water balance.

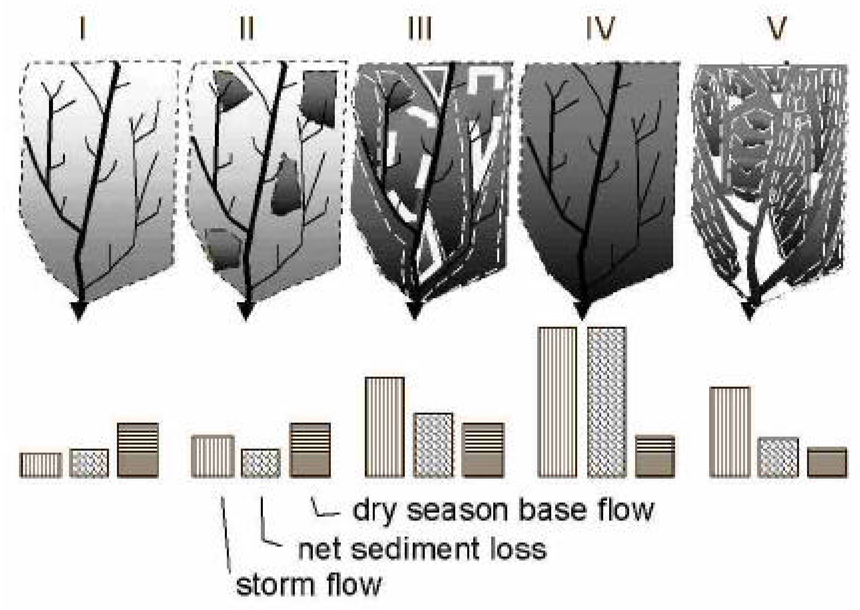


Figure 4. Schematic development of the landscape in a sub-watershed and its effects on storm flow, net sediment loss and dry-season base flow: I. original forest cover, II. patches of forest opened for shifting cultivation, III. intensification of land use has brought most land into cultivation, except for reverie borders and hedges along paths, IV. reclamation of all 'wastelands' has removed all filter strips causing a disproportional rise in net sediment loss, V. restored agroforestry landscape with permanently vegetated contour strips and riparian woodlands (Van Noordwijk *et al*., 1998).

Questions:

- Can forests lead to more water flow in streams in the dry season? Less storm flow? By what mechanism? Is it because of the **trees** or the **forest** (with its surface and soil properties)?
- What parts of the forest might be important?
- Where should the forest be located to reduce storm flow?

How could such functions be maintained in e.g. a mosaic landscape with coffee agroforestry system on the slopes and irrigated rice field in the valleys?

6. Erosion and sedimentation in a mosaic landscape with some trees

A model simulation described by Van Noordwijk *et al.*, (1998) demonstrated that tree position (location) on sloping land is more important than the number of trees in reducing sediment loss or storm flow (Figure 5). Tree cover varied from 0 – 100% with different positions of the trees.

Different tree positions lead to a wide range (or '*envelope*') of possible results for the same total tree density. The model showed that a tree cover of 50 % with the most favourable spacing had the same effect as a full forest, while a tree cover of 25% could reduce the negative impacts of crops to 20% for sediment loss and 30% for storm flow. This type of model can be used in the future to explore how the widths of the 'envelope' for sediment loss and storm flow vary with climate, soil type and topography. ***The strongest reduction in net sediment loss was obtained when trees were located at the bottom of the slope*** (to intercept downward moving sediment) and in well-spaced contours (to prevent gully formation and breakthroughs in the riparian strips and other filters).

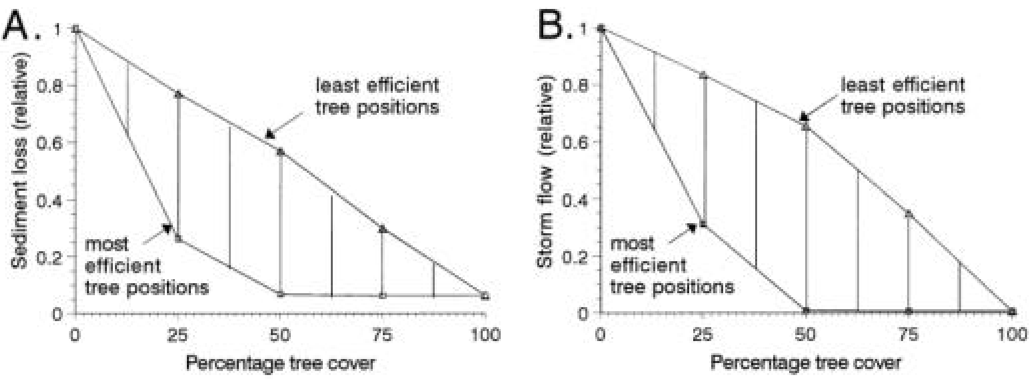


Figure 5. Model calculations of the effect of tree cover on sediment loss (A) and storm flow (B) for a range of tree densities and spatial patterns. The width of the envelope indicates different spatial patterns at equal percentage tree cover at a given scale of measurement (Van Noordwijk *et al*., 1998)

Questions:

- Do you know other techniques that can act as a filter? How can filter effects be measured?
- Imagine: You have 1 ha of land located on a steep slope and you have only 20 tree seedlings.

Where will you plant those trees in your land to obtain a maximal reduction in soil erosion?

7. Before a soil conservation project starts …. A word of caution.

To conclude a word of caution: Most soil conservation measures require a lot of labour investment, while it is not always obvious who will benefit from it. Before an attempt is made to introduce soil conservation measures, some time should be spent to *'read the landscape'*. This means that some time should be spent on trying to answer the following questions, before any activity is undertaken:

- Is soil erosion a real problem? Who perceives soil erosion as a problem: the 'uplanders', the people downstream or other stakeholders?
- Are there any elements in the landscape, which are currently reducing soil erosion? Include neighbouring plots in your assessment.
- If the different stakeholders see lack of soil conservation as a problem, how and to what extent will the person executing the soil conservation measures also benefit from his/her work? If the one, who is supposed to carry out the job, will not benefit in the short and long term, chances of failure are large.
- If soil erosion is seen as a downstream problem, then a discussion should be held between downstream and upstream stakeholders to find a reasonable solution, which could e.g. include compensation paid to farmers upstream to carry out soil conservation measures. Are sedimentation zones effectively used for productive purposes? Making more profitable use of them can increase incentives to capture sediment in such zones.
- If it is clear that those who will do the soil conservation also benefit from it, only then one can start thinking about different technical measures.

Questions:

Imagine you are an extensionist responsible to promote soil and water conservation in an area of about 100.000 ha, which you know very well and which covers about 30 villages. About 100.000 people live in this mostly rural upland area.

- How would you go about it?
- What are most likely the bottlenecks and problems you will encounter?
- What steps would you undertake to solve those problems?
- What opportunities do you see?

III. Reading Materials

Scientific Journal:

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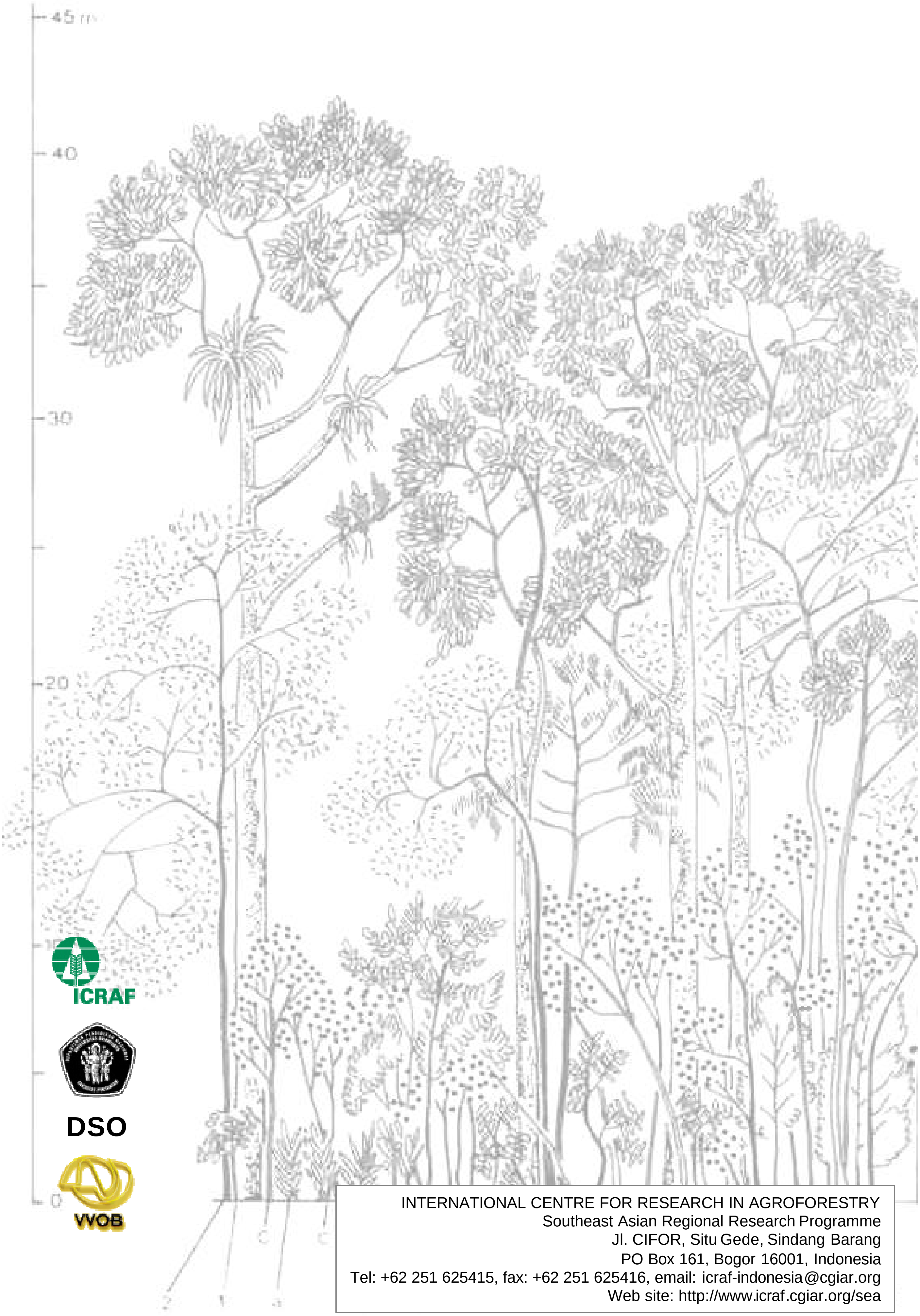

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INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY
Southeast Asian Regional Research Programme
Jl. CIFOR, Situ Gede, Sindang Barang
PO Box 161, Bogor 16001, Indonesia
Tel: +62 251 625415, fax: +62 251 625416, email: icraf-indonesia@cgiar.org
Web site: http://www.icraf.cgiar.org/sea