Minor Field Studies No 326

WaNuLCAS modelling of runoff and soil loss for different agroforestry scenarios in a catchment in Northern Vietnam

Lina Nolin

MSc thesis at the Division of Environmental Physics, Department of Soil Sciences

Swedish University of Agricultural Sciences
SLU External Relations
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Abstract

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A large part of the world arable land is affected by degradation and a global population pressure drives people to unsustainable cultivation methods to meet food demands. Water is the most common cause of erosion and soil erosion tends to be especially severe in steep lands in areas with monsoon rains. Agroforestry, meaning plantation of trees in combination with crops, is considered to be a promising approach to sustainable land use because it can meet the demands of food at the same time as of the need of soil and water conservation.

This study was carried out as a Minor Field Study within the LUSLOF project (Sustainable Land Use Practices for the Uplands of Vietnam and Laos: Science and Local Knowledge for Food Security). In a Participatory Landscape Analysis made in 2002 in the project field site, the Dong Cao catchment in Hoa Binh province in Northern Vietnam, it was found that the main issue in the area was declining crop yields due to depleted soil.

In this study, the model *Water, Nutrient and Light Capture in Agroforestry Systems* (WaNuLCAS) was used to evaluate three different cropping systems at plot level in terms of water runoff and soil loss amounts for a 5-year period. The cropping systems were (1) monocropping cassava, (2) cropping cassava with hedgerows of *Tephrosia candida* and (3) cropping cassava with hedgerows of *Bambusa Blumeana*. The study compares model results of runoff and soil loss in the cropping systems and compares also up-scaled model results at plot level with measurements at catchment level. Before simulations were performed, sensitivity analysis and calibration were made with input and validation data from experimental runoff plots at a nearby site.

During calibration of the model, it was shown that runoff and soil loss simulated by the model agreed well with observed total sums of the 5-year period and on yearly basis, but not on event basis. One of the reasons seems to be overestimation of soil loss by the model in time of the year when soil was uncovered. In simulations of different cropping systems, hedgerows of *Bambusa Blumeana* gave overall the minimum soil loss, while hedgerows of *Tephrosia candida* gave the minimum runoff. All scenarios with hedgerows showed to prevent runoff better than the monocropping system, whereas generally only hedgerows of *Bambusa Blumeana* showed to prevent soil loss better than the monocropping system. The up-scaled model outputs showed that simulated runoff was considerably lower than measured runoff, while simulated soil loss varied greatly compared to measured soil loss, depending on which land use that was considered.

Keywords: Agroforestry, erosion, filter, modelling, runoff, soil conservation, soil loss, Vietnam, WaNuLCAS.

Sammanfattning

Modellering med WaNuLCAS av avrinning och jordförluster för olika agroforestryscenarier i ett avrinningsområde i norra Vietnam

Lina Nolin

För en stor del av världens odlingsbara mark utarmas och försämras jorden och en global befolkningsökning tvingar människor att använda icke-uthålliga jordbruksmetoder för att tillgodose matbehoven. Jorderosion orsakat av vatten är den vanligaste erosionstypen och särskild svår erosion kan uppkomma på branta sluttningar i områden med monsunregn. *Agroforestry*, som innebär plantering av träd i kombination med grödor, anses vara en lovande metod för uthållig markanvändning eftersom den tillgodoser behovet av mat samtidigt som den bevarar vatten- och jordresurserna.

Detta arbete gjordes som en *Minor Field Study* inom projektet LUSLOF (*Sustainable Land Use Practices for the Uplands of Vietnam and Laos: Science and Local Knowledge for Food Security*). I en undersökning av Dong Cao avrinningsområde i Hoa Binh-provinsen i norra Vietnam, fann man i samarbete med lokalbefolkningen år 2002 att den viktigaste frågan i området var minskad skörd på grund av utarmad jord. I denna studie användes modellen *Water, Nutrient and Light Capture in Agroforestry Systems* (WaNuLCAS) för att utvärdera tre olika odlingssystem på fältnivå utifrån mängden simulerad vattenavrinning och jordförluster för en 5-årsperiod. De tre odlingssystemen var (1) kassavaodling, (2) kassavaodling med rader av *Tephrosia candida* och (3) kassavaodling med rader av *Bambusa Blumeana*. De simulerade värdena för avrinning och jordförluster för de olika odlingssystemen på fältnivå jämfördes och skalades upp till hela avrinningsområdets storlek för att även jämföras med uppmätta värden för avrinningsområdet. Innan simuleringarna utfördes, gjordes en känslighetsanalys och kalibrering av modellen med indata och valideringsdata från experimentella erosionsplotter på en närliggande plats.

Under kalibreringen visade det sig att simulerad avrinning och jordförluster stämde väl överens med totala uppmätta mängder över 5-årsperioden och med årliga värden, men inte med individuella värden. En av orsakerna verkar vara att modellen överskattade jordförlusterna under den del av året då marken saknade växttäcke. Simuleringarna av de olika odlingssystemen visade att systemet med rader av *Bambusa Blumeana* gav den minsta jordförlusten medan systemet med rader av *Tephrosia candida* gav den minsta avrinningen. Systemen med rader av *Tephrosia candida* eller *Bambusa Blumeana* visade sig vara bättre på att förhindra avrinning än kassavaodling utan trädrader, medan huvudsakligen bara systemet med *Bambusa Blumeana* kunde förhindra jordförluster bättre. De uppskalade simulerade värdena visade att simulerad avrinning var betydligt lägre än uppmätt avrinning, samtidigt som simulerad jordförlust varierade stort jämfört med uppmätt jordförlust, beroende på vilket odlingssystem som simulerades.

Nyckelord: Agroforestry, erosion, filter, jordbevarande, jordförlust, modellering, Vietnam, WaNuLCAS, ytavrinning.

Foreword

This master thesis is one of the outputs of a Minor Field Study (MFS). Thanks to two persons, Prof. Ingmar Messing and Dr. Minh Ha Hoang Fagerström at the Department of Soil Sciences at the Swedish University of Agricultural Sciences, an opportunity to carry out a MFS was opened in the fall 2003. They were my main supervisors in this study and besides the guidance in the start, I would like to thank Minh Ha for her presence and involvement in the fieldwork in both Vietnam and Indonesia and Ingmar for giving fast response and scientific advice throughout the whole work.

The first half of the study included a lot of contact with different people. I value greatly these contacts and collaborations and would like to thank my supervisors in Vietnam and Indonesia for enabling these meetings and experiences; Dr. Tran Duc Toan at National Institute for Soils and Fertilizers (NISF) in Hanoi, Vietnam, Dr. Meine van Noordwijk and Dr. Betha Lusiana at World Agroforestry Centre (ICRAF) in Bogor, Indonesia. Also, many thanks to Dr. Didier Orange and Dr. Pascal Podwojewski at International Water Management Institute (IWMI) in Hanoi for guidance in the data collection work. Thank you La Nguyen, Mr Phoung, Ms Ni'matul Khasanah and everyone else at NISF and ICRAF that gave a helping hand in the study or in some way made my time in Vietnam and Indonesia to a pleasant memory. I would also like to thank the village leader Mr Tuoi and farmers in Dong Cao for hospitality and willingness to help. My travel friend and work partner, Carina Ortiz, deserves especially acknowledgement. We lived and worked close during the months abroad and I would like to thank you for your company and support, both when times were joyful and difficult.

Sometimes the work was challenging and not always easy. However, I have learned a lot about research work and myself. Without my closest friends and family, the thesis process would have been much more hard and unwieldy. I cannot express how grateful I am to my family for all support, both financial and mental. You never doubted in me, which was probably the basic condition making me carry out this study in the first place and manage to finish it. My partner Christian is the one I owe the most thanks to for daily encouragement and debating work troubles.

Thank you

Terima kasih

Com on

Tack

Lina Nolin
Uppsala, December 2005

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1 INTRODUCTION

1.1 A global problem

An increased global population has lead to increased food demands. The lack of arable land in areas with high population density drives people to cultivate on non-suitable land (Lal, 1994). Intensified cultivation on sloping land, for example, may increase the risk of erosion and soil degradation, which in turn contributes to a declined crop yield and food shortage (FAO, 2004, internet). More than one third of the world arable land is affected by some form of degradation (Lal, 1994). Figure 1.1 presents the geographic spreading of degraded soil.

Most soil erosion occurring in the world is caused by water (56%) and wind (28%) (Lal, 1994). Erosion processes tend to be more important in areas with monsoon rains, i.e. rainstorms with high intensities, which may cause high runoff rates (FAO, 2004, internet). Water erosion is especially severe in steep lands, and in the effort to control soil erosion, runoff management plays an important role (Lal, 1994).

Reforestation is the most important action for soil conservation and decreases the risk of soil degradation. Agroforestry, meaning plantation of trees in combination with crops, is today considered to be a promising approach to sustainable land use, especially in developing countries of the tropics and subtropics (Nair, 1994). This practice means that demands of food and other products could be met simultaneous with soil and water conservation.

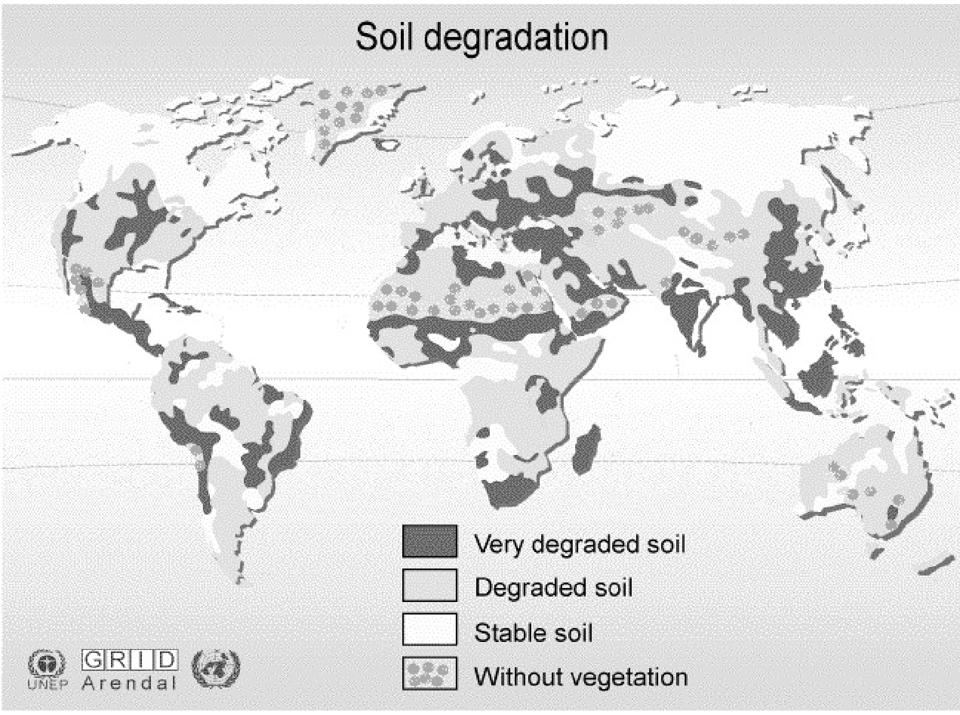

Figure 1.1. World map of the spreading of degraded soil (adapted from UNDP, 2004, internet).

1.2 A study within the LUSLOF project

This study was carried out as a Minor Field Study (MFS) within the LUSLOF project. The project LUSLOF, *Sustainable Land Use Practices for the Uplands of Vietnam and Laos: Science and Local Knowledge for Food Security,* was funded by the Rockefeller Foundation and the SAREC/Sida for a duration of three years, 2002-2004. The project aims at understanding the interplay between technical land use options at landscape scale and farmer knowledge and decision-making processes in selected study sites in Vietnam and Laos. The LUSLOF project is carried out by an international team from the Swedish University of Agricultural Sciences (SLU), the International Centre for Research in Agroforestry (ICRAF) in Southeast Asia and the National Institute for Soils and Fertilizers (NISF) in Vietnam (ICRAF-NISF-SLU, 2002a).

The LUSLOF-project, with the ambition to integrate the local knowledge into the research process, makes use of participatory methods; Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA) (ICRAF-NISF-SLU, 2002a). The RRA and PRA methods were developed during the 1980s and are research tools for identifying problems and potential solutions, based mainly on the perceptions of the local people involved. Examples of RRA and PRA methods to collect data and local knowledge are participatory group meetings, drawing maps and using semi-structured interviews (Catacutan *et al.*, 2001). The common principle of RRA and PRA is that researchers make an explicit effort to treat the local people as partners in the land use planning procedure (Gill, 1994).

The LUSLOF project activities have resulted in wide problem definitions, analysis and issue formulations. After the first steps taken in a survey named Participatory Landscape Analysis (PaLA) with RRA and PRA methods, computer modelling with the agroforestry model WaNuLCAS, *Water, Nutrient and Light Capture in Agroforestry Systems*, has been an important part of the project work. The objective of the PaLA survey was to understand farmer management options and farmers' perception on lateral flows and internal filter functions in the landscape. From the findings in the survey, different land use scenarios have been simulated by the model to evaluate erosion control.

This study was carried out one month in Vietnam at NISF to collect field data and two months in Indonesia at ICRAF to get introduced to the modelling work with WaNuLCAS. Besides comparing different agroforestry settings, the purpose of the modelling work in this study was to calibrate the model in terms of surface water runoff and soil loss before performing the predictions and to test the feasibility of up-scaling the model result at plot level to catchment level, which has not earlier been made in the project.

2 BACKGROUND

The largest areas affected by water and wind erosion are found in Asia (Lal, 1994). The possibilities for agricultural production in the Asia Pacific region are limited, by e.g. steep slopes and adverse soil texture, in 86% of the total land area (FAO, 2004, internet). In Vietnam, nearly three-quarters of the country are mountainous, while the population density is the second highest in Southeast Asia (235 inhabitants per km^2 in 1997) (IDRC, 2004, internet). As a result of the population pressure, most upland farmers in Vietnam practicing shifting cultivation have intensified the land use by reducing the fallow period. In additional, the cultivations often take place on sloping land with a land management that often leads to soil erosion (Hoang Fagerström, 2000).

2.1 Erosion processes

Geological erosion is a process that changes the earth surface naturally by water, wind ice and gravity. *Accelerated erosion* occurs when people disturb the soil. Accelerated erosion is often 10-1000 times as destructive as geological erosion, especially on sloping lands in regions of high rainfall. In Africa, Asia and the South America the average rate of erosion by water and wind on agricultural land is estimated to 30-40 Mg (tonnes) ha^{-1} annually, comparing to for example 12-17 Mg ha^{-1} annually in USA (Brady and Weil, 2002).

Soil erosion by water is a three-step process; (1) detachment of soil particles from the soil, (2) transportation of the particles downhill and (3) deposition of sediment. There are different types of water erosion, classified as sheet, rill and gully erosion. Sheet erosion means that the splashed soil is removed more or less uniformly. Rill erosion occurs when water concentrates in small channels, rills, usually on bare land. If the water is further concentrated it cuts deeper into the soil, creating larger channels called gullies (Brady and Weil, 2002).

Most erosion is initiated by the impact of raindrops rather than the flow of water itself (Podwojewski, 2003, pers. comm.; Brady and Weil, 2002). As raindrops hit the ground, they transfer their kinetic energy to the soil particles and the force exerted by raindrops may be so great that they do not only loosen and detach soil granules, but also beat granules to pieces. Soil surface runoff water, on the other hand, plays the major role in the transportation step of the soil erosion. When water flows slowly and smoothly it has little power to detach soil particles, but as the runoff increase in velocity and turbulence and rills and channels are created, particles may be detached and transported downslope (Brady and Weil, 2002).

2.1.1 Soil conservation and runoff management

The aim of soil conservation is to minimize the losses of soil caused by accelerated erosion by water or other erosive agents, but also to enhance the soil quality and productivity. In terms of soil erosion by water, runoff management is important for erosion control. Such runoff management include strategies for decreasing runoff amount and reducing runoff velocity, involving e.g. slope management by terraces, contour farming or contour barriers by vegetative hedges. Properly managed vegetative hedges decrease runoff velocity, promote sedimentation and reduce runoff and soil erosion (Lal, 1994).

2.2 The concept of Agroforestry

Agroforestry practices have been used throughout the world for a long time, but attained prominence as a land use practice in the scientific world first in the 1970's (Nair, 1994). Agroforestry is widely promoted in Southeast Asia as a solution for developing sustainable land use. Most agroforestry systems have been developed by farmers and they are usually perceived as 'traditional', while systems developed by scientists are referred to as 'modern'. By cultivating different crops and trees simultaneously or sequentially in time, the farmer combines economic profitability (for example timber, fruit and vegetable) and long-term conservation of both soil fertility and biodiversity (de Foresta *et al.*, 2000). In simultaneous agroforestry systems, various interactions take part between soil, crops and trees, e.g. through shading, litter decomposition and root competition. The interactions can be either *positive* (complementarity between the components) or *negative* (competition between the components) (Hairiah and van Noordvijk, 2000). The challenge of agroforestry is to design systems that maximize beneficial effects of trees on soil and minimize the negative effects (Nair, 1994).

Three main groups of soil conservation strategies for cultivated land that involve agroforestry are (a) agronomic methods, (b) soil management and (c) mechanical methods (Table 2.1). The most important techniques to minimize erosion are soil management (i.e. the way of preparing the soil) combined with agronomic methods (i.e. to utilize the role of vegetation). Trees support soil conservation structures e.g. through the stabilizing effect of the tree root system, increased soil cover and maintenance of organic matter (Nair, 1994). Hedgerow systems using nitrogen-fixating trees are considered to minimize soil erosion, restore soil fertility and improve crop productivity (van Noordwijk and Verbist, 2000).

Table 2.1. Three major groups of soil conservation strategies that involve agroforestry (adapted from van Noordwijk and Verbist, 2000)

Soil conservation strategy	Example	Aim
(a) Agronomic methods	Hedgerow intercropping, improved fallow	Increase soil surface cover, surface roughness and soil infiltration
(b) Soil management	Minimum tillage, crop rotation	Promote dense vegetative growth and improve soil structure
(c) Mechanical methods	Bench terraces, soil traps	Control the energy available for erosion (by manipulating the surface topography)

2.3 The use of models and different scales

Models are common tools in research work. Generally, they are constructed by assumptions and simplified descriptions of reality and the purpose of using models is to gain further understanding and to predict results of different alternatives of action (e.g. EOG, 2005, internet; RM, 2005, internet). The output of models represents an estimated image of reality and may contain errors, which is of importance to keep in mind when utilizing models. It is therefore preferable to combine model predictions with other research tools, for example field measurements and observations or interviews, in decision-making processes. To develop economically and ecologically sustainable agroforestry systems there is a need of building models that can quantify the systems' impact on production, soil loss etc. Performing scenarios with agroforestry models is a relatively cheap and fast method to evaluate the influence of different land use alternatives. The study of model application could contribute to the development of models as valuable tools in decision support.

A model often represents the reality at a certain scale. In terms of erosion, the study of sediment amount is likely to differ in result depending on what scale has been considered. Soil loss research at plot level gives usually more soil loss yield than research at catchment level, because the sediment amount leaving a watershed is usually less than the sediment amount produced within the watershed. The difference in sediment amount is due to deposition, occurring for instance at field boundaries and on toes of concave slopes (Foster, 1988). These elements that restrict the overland flow of water and/or suspended sediment are also called *filter functions* (van Noordwijk and Verbist, 2000).

2.4 Objectives and hypothesis

The general objectives in this study were to compile data for model simulation and to make simulations with the WaNuLCAS model for a better understanding in agroforestry systems and to possible contribute to model development. The specific objectives were to:

I. Gain knowledge of agroforestry systems in field and how to simulate them in the WaNuLCAS model.

II. Calibrate WaNuLCAS for the uplands of Northern Vietnam, in terms of surface water runoff and soil loss for one monocropping system and one system with tree hedgerows.

III. Perform predictions with WaNuLCAS in terms of surface water runoff and soil loss for a site in the uplands of Northern Vietnam, in order to compare systems with different hedgerow species and spacing on fields with different land use history, slope and soil properties.

IV. Test the feasibility of up-scaling the results from predictions at plot level to catchment level.

The hypothesis for the model simulations was:

> Simulations by WaNuLCAS of fields with a combination of crop cultivation and tree hedgerows will give less runoff and soil loss than of fields with crop cultivation only. In addition, up-scaling the results from WaNuLCAS at plot level to catchment level will show greater runoff and soil loss than measured runoff and soil loss at catchment level.

3 MATERIALS AND METHODS

3.1 List of abbreviations

SAREC	Sida's Department for Research Co-operation
SIDA	Swedish International Development Cooperation Agency
LUSLOF	Sustainable Land Use Practices for the Uplands of Vietnam and Laos: Science and Local Knowledge for Food Security
PaLA	Participatory Landscape Analysis
SLU	Swedish University of Agricultural Sciences
ICRAF	World Agroforestry Centre (before: International Centre for Research in Agroforestry
NISF	National Institute for Soils and Fertilizers, Vietnam
MSEC	Managing Soil Erosion Consortium
WaNuLCAS	Water, Nutrients and Light Capture in Agroforestry Systems
IWMI	International Water Management Institute
IRD	L'institut de Recherche pour le Developpement

3.2 Concepts and definitions

Agroforestry — a land-use system in which woody perennials (trees, shrubs etc.) are purposely grown on the same land unit as agricultural crops and/or animal breeding, in spatial arrangement or temporal sequence, meaning both ecological and economic interactions between the different components (World Agroforestry Centre, 2005, internet).

Catchment — the area that contribute all the water that passes through a given cross section of a stream (here used analogous to watershed) (Dingman, 1994).

Fallow — land resting from cropping (Nair, 1994).

Hedgerow — a barrier of bushes, shrubs or trees growing close together in a line (AFAE, 2004, internet).

Infiltration — the movement of water from the soil surface into the soil (Dingman, 1994).

Monocropping — highly simplified cropping system, which involves the planting of only one crop in a season (Altieri, 1994).

Runoff — the overland water flow caused by excessive precipitation (Lal, 1994).

Saturated hydraulic conductivity — the rate at which water moves through a water saturated porous medium under a unit potential-energy gradient (Dingman, 1994).

Shifting cultivation — old agricultural system in which land under natural vegetation is cleared (usually by slashing and burning), used for crops for a few years and then left unattended while natural vegetation regenerates (Nair, 1994).

Soil loss — the amount of soil lost in a specified time period over an area of land which has experienced net soil loss (Nearing *et al.*, 1994).

3.3 Study sites

The two sites *Lam Son* and *Dong Cao* that provided the model with input data are both situated in Luong Son district, Hoa Binh province (21° N, 105° E), in Northern Vietnam (Figure 3.1). Lam Son is situated 5 km south of Dong Cao. The people living in these areas belong mostly to Muong and Kinh ethnic groups (Hoang Fagerström, 2000). In this area, the climate is temperate (Cw), meaning warm to hot summers and cool, dry winters (Köppen classification; UWSP, 2004, internet). The rainy season reaches from May to October and the mean annual rainfall is around 1500 mm (Toan *et al.*, 2002).

The *Lam Son* site is situated close to the Rong Can village, in the Lam Son commune 45 km southwest of Hanoi (Hoang Fagerström, 2000). The site is approximately 100 m above sea level and the average slope is 22-24 degrees. The soil is silty to clay, reddish brown and moderately acidic and classified as Haplic Ferralsol. Dominant geological formations are Gneiss, Paleozoic sandstone and Permian limestone (Hoang Fagerström, 2000). *Dong Cao* belongs to Tien Xuan commune and is located 80 km southwest of Hanoi. The altitude of the site varies between 110 to 470 m above sea level and the average slope of the hills is 45% (i.e. 24 degrees). The soils show clay-silty texture and are classified as Ferralsols and Acrisols (Chaplot *et al.* 2002). The parent rock is volcano-sedimentary schist of Permian-Triassic age (Toan *et al.*, 2003a).

The Dong Cao catchment is the field site of the LUSLOF-project and is well investigated regarding e.g. farmer land use intention, land use history and soil properties. Moreover, MSEC (Managing Soil Erosion Consortium), IWMI (International Water Management Institute) and NISF carry out measurements of both runoff and soil loss at catchment level in the area (Toan *et al.*, 2003a). The access to the background material makes the Dong Cao catchment suitable to model simulations of land use and land use effects. However, the WaNuLCAS model operates at plot level (van Noordwijk and Lusiana, 2000). The reason to why also the Lam Son site was included in this study, is that before making the model predictions for the Dong Cao catchment, the model was desired to be somewhat calibrated to the existing conditions. Therefore, adjustments of some model parameters were made on the basis of data at plot level from experimental plots in Lam Son. Next, the runoff and soil loss predictions of different land use options were made with input data from the Dong Cao catchment. Dong Cao and Lam Son could be regarded as comparable considering climate and soil properties (Toan and La Nguyen, 2003, pers. comm.). In this study, they are regarded as similar enough to justify the application of data from one site to the other.

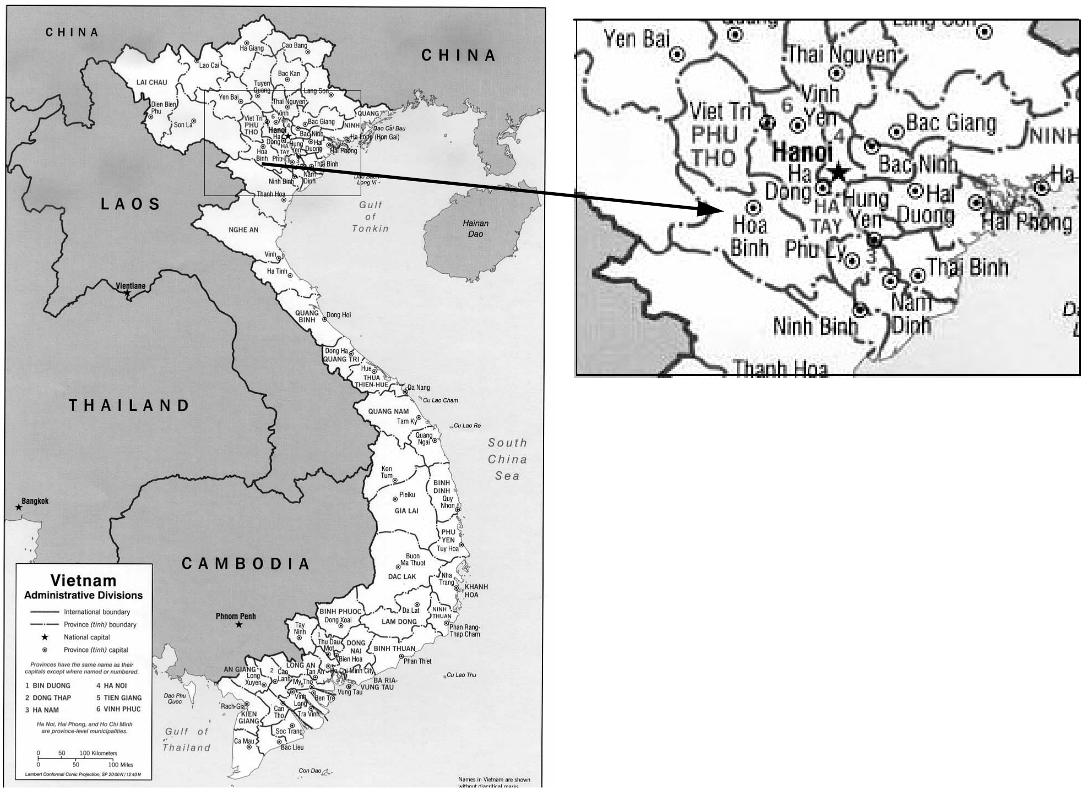

Figure 3.1. Map of Vietnam and the locations of Hoa Binh province (adapted from UTL, 2004, internet).

3.4 Sources of information

3.4.1 Literature review

Previous field works and investigations in both the Lam Son site and in the Dong Cao catchment supplied this study with model input data as well as background information. Site-specific data from the Lam Son site and the Dong Cao site were used when available, for simulations of respectively site. Regarding field conditions of the Lam Son site, the findings of Hoang Fagerström (2000) were the main source of data. For the Dong Cao catchment on the other hand, which is a research site of MSEC, NISF and the LUSLOF project, several reports about work and findings in the catchment area were reviewed. The field survey report within the LUSLOF project from 2002 was especially important in setting the direction of this work since the suggestions of simulation scenarios (in Table 3.1 and 4.1 in ICRAF-NISF-SLU, 2002b), based on the findings from the survey, inspired to the simulation set-ups in this study. Further, the extensive field investigations reported in Olsson and Schwan (2003) (e.g. of soil texture, surface infiltration and slope) were very useful as input data, and the catchment properties of Dong Cao (e.g. runoff and soil loss) were found in material provided by IWMI/MSEC, e.g. in Toan *et al.,* (2003a).

3.4.2 Other sources of information

The size of the Dong Cao catchment and the sub-catchments were not very fixed and different sources gave different area estimations. By using the GIS (*Geographic Information Systems*) software ArcView and a digital map of the watershed created and provided by the MSEC project, model operations could present areas of the catchment. The result was crosschecked by specific field area data, gathered by the LUSLOF project, added up to sub-catchments. The estimations of the sub-catchment area from the GIS were used in this study (Appendix A).

In Dong Cao, field activities such as studying soil profiles (FAO, 1990), erosion spots, river flow and springs and vegetative field borders, were made together with the local farmers and personnel from the NISF, IWMI/IRD and LUSLOF project. The intention was to familiarize with field environment, earn understanding of the soil properties in field and of the historical, present and coming living conditions of the farmers. In discussion with the farmers, PRA methods were practiced, such as semi-structured interviews and transect walks. These methods were experienced as useful tools and functioned as guidance in the study for choice of e.g. plant specie in the predictions. These activities will not be further considered in this report, but are described in Ortiz (2004).

3.5 WaNuLCAS model and modelling process

3.5.1 General description of model

In this work, the model WaNuLCAS version 2.2 was used. WaNuLCAS (*Water, Nutrient and Light Capture in Agroforestry Systems*) was developed at ICRAF and was designed to represent interactions between trees, soil and crop at plot level in simultaneous and/or sequential systems. This enables explorations of interactions for different combinations of trees, crops, soil, climate and management (van Noordwijk and Lusiana, 2000).

The model is based on soil science, tree and crop physiology and above and below ground architecture of crops and trees. WaNuLCAS is created in the Stella software environment and linked to Excel sheets for input and output data (van Noordwijk and Lusiana, 2000). The Stella version 7.0.2. was used in this study. The Stella shell allows the users to modify parameters and also add model structure. Simulations require a defined soil profile (physical and chemical properties per layer), degree of slope and climate conditions, but values can be set for a large range of input parameters considering, for example, soil management, nutrients and profitability. The field plot is visualized as four horizontal zones with four vertical layers of soil (Figure 3.2). The output parameters give information on a daily time step about the interaction in the soil 'boxes' (van Noordwijk and Lusiana, 2000).

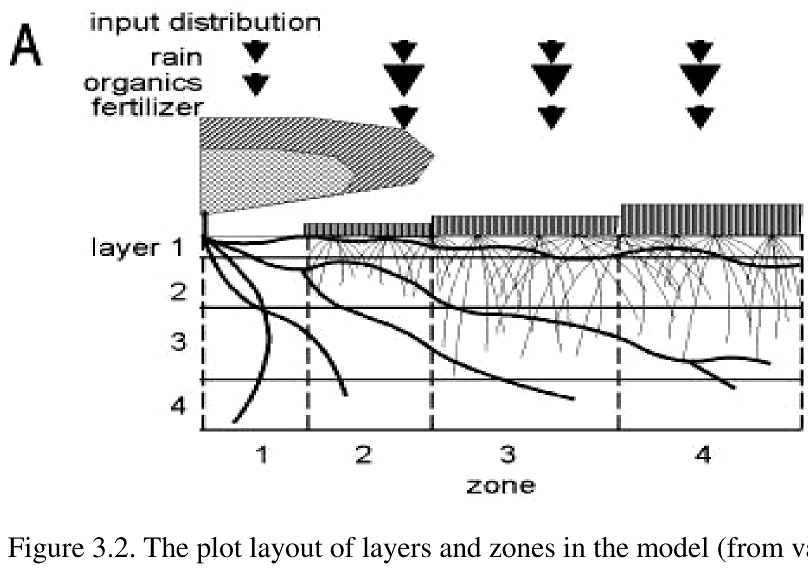

Figure 3.2. The plot layout of layers and zones in the model (from van Noordwijk and Lusiana, 2000).

3.5.2 General assumptions in the modelling

The output parameters observed in the modelling work in this study were *BW_RunOffCum*, the amount of surface runoff water (l m^{-2}), and *E_Soilloss*, the amount of soil loss (kg m^{-2})[1].

The option for simulating a dynamic soil, represented by the name *S_SoilStrucDyn?*, which means that the soil structure is open for changes during the simulation time, was applied through all modelling in this study. When simulating a dynamic soil, the value of saturated hydraulic conductivity, K_{sat}, defined by the user is used as initial value but tend to return to the default value estimated by the model[2]. In a similar way, the value of surface infiltration changes in a simulation of a dynamic soil. The user defines two infiltration rates (1) *S_SurfInfiltrInit*, the infiltration rate of the soil surface at the start of the simulation and (2) *S_SurfInfiltrDef*, infiltration rate of the soil surface in the absence of soil biological activity. During the simulation, the former value can tend to take the value of the latter, depending on whether macropores are rebuilt or decayed.

Also, there are different alternatives to simulate a sloping land. The two parameters *AF_SlopeInit*, the slope of the soil surface at the start of the simulation, and *AF_SlopeSoilHoriz*, the slope of the soil horizons below the surface, can be set to different values. However, in this work the slope value did never differ between the two.

3.5.3 Steps in the modelling work

After field data were gathered, for input to the model and for evaluation of the model output, and agroforestry scenarios to be simulated in the model were defined, the following modelling process consisted of different steps (Figure 3.3).

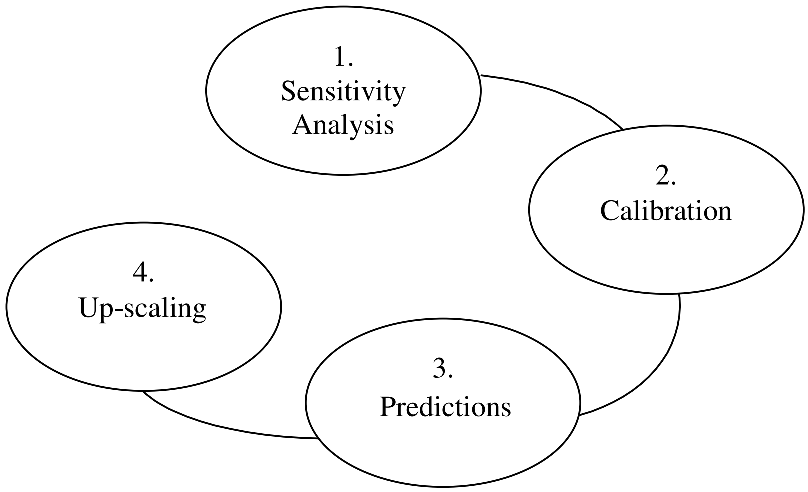

Figure 3.3. The steps in the modelling process.

[1] Two options exist for simulating soil loss in WaNuLCAS, the Rose equation and the Universal Soil Loss Equation, USLE. Here, the Rose equation was used in the modelling after recommendation by ICRAF (Kasahana, 2003, pers. comm.)

[2] The default K_{sat}-value is derived by the Van Genuchten equation via a "pedotransfer" function, using input data of soil properties, e.g. content of silt, clay and organic matter (van Noordwijk and Lusiana, 2000).

3.6 Sensitivity analysis

Computer models typically contain a number of parameters, which will influence the output of the models. The degree of influence on the result differs from one parameter to another. Sensitivity analysis refers to establish the grade of impact on the output of interest when varying the values of input data (DEQ, 2005a, internet). Thus sensitivity analysis determines the sensitivity in one parameter, the sensitivity relative to other parameters and gives an indication on how to interpret the simulation result.

3.6.1 Selecting parameters

The WaNuLCAS model contains a large number of parameters but sensitivity analysis was only made for parameters that were assumed to in one way or other affect the runoff and/or soil loss (see Appendix B). A water balance equation (e.g. Grip and Rodhe, 1994), Eq. 1, and the Rose equation (Rose, 1988), Eq. 2, were used as base when selecting parameters.

$$P \quad = \quad E + R + \Delta S \qquad \rightarrow \qquad R \quad = \quad P - (E + \Delta S) \qquad (1.)$$

where P = precipitation, E = evaporation, R = runoff, ΔS = change in storage (all in mm)

$$m_a \quad = \quad 2700 \times S \times C_r \times \eta \left(\frac{1.0 - \Omega_0}{\Omega_{mean}} \right) \times \int_0^{t_r} Q dt \qquad (2.)$$

where m_a = soil loss per unit land area (kg m^{-2}), S = land slope (sine of inclination angle), C_r = fraction of soil surface unprotected from entrainment by overland flow (C_r = 1 means bare soil), η = efficiency of net entrainment of overland flow ($0 < \eta > 1$), Ω_0 = stream power to entrain sediment (W m^{-2}), Ω_{mean} = mean stream power (W m^{-2}), Q = event runoff (mm h^{-1}), t_r = end time of erosion event (min).

Further, the controlling factors of soil erosion in the WaNuLCAS model shown in Khasanah *et al.*, (2002) were used (the boxes with unbroken frames) (Figure 3.4). To complete the figure so as to include controlling factors of both runoff and soil loss, more issues were added (boxes with broken frames). The parameters determining these factors were found in the manual and in the list of input parameters of the model. By advice from ICRAF (Khasanah, 2004, pers. comm.) a number of parameters were chosen as relevant for sensitivity analysis. The names, units, input sections, default values and definitions of the parameters included in the sensitivity analysis are given in Appendix B.

3.6.2 Model set-up

In the sensitivity analysis, a cropping system that easily could be exposed to erosion was preferred, in order to easily detect the degree of influence of the parameters. The cultivation system was therefore wanted to consist of crops but no trees. Input data, that later was used in the calibration work for the monocropping situation (i.e. the *Mono*-treatment, see Table 3.1) was applied, including the daily rain, temperature and evaporation data for five consecutive years, the soil layer depth and content of clay, silt and organic matter along with the management of crop (growing upland rice in all zones of the plot), as described in section 3.7.3-3.7.5. The slope was set to 50%. The input data used are showed in Appendix C:I.

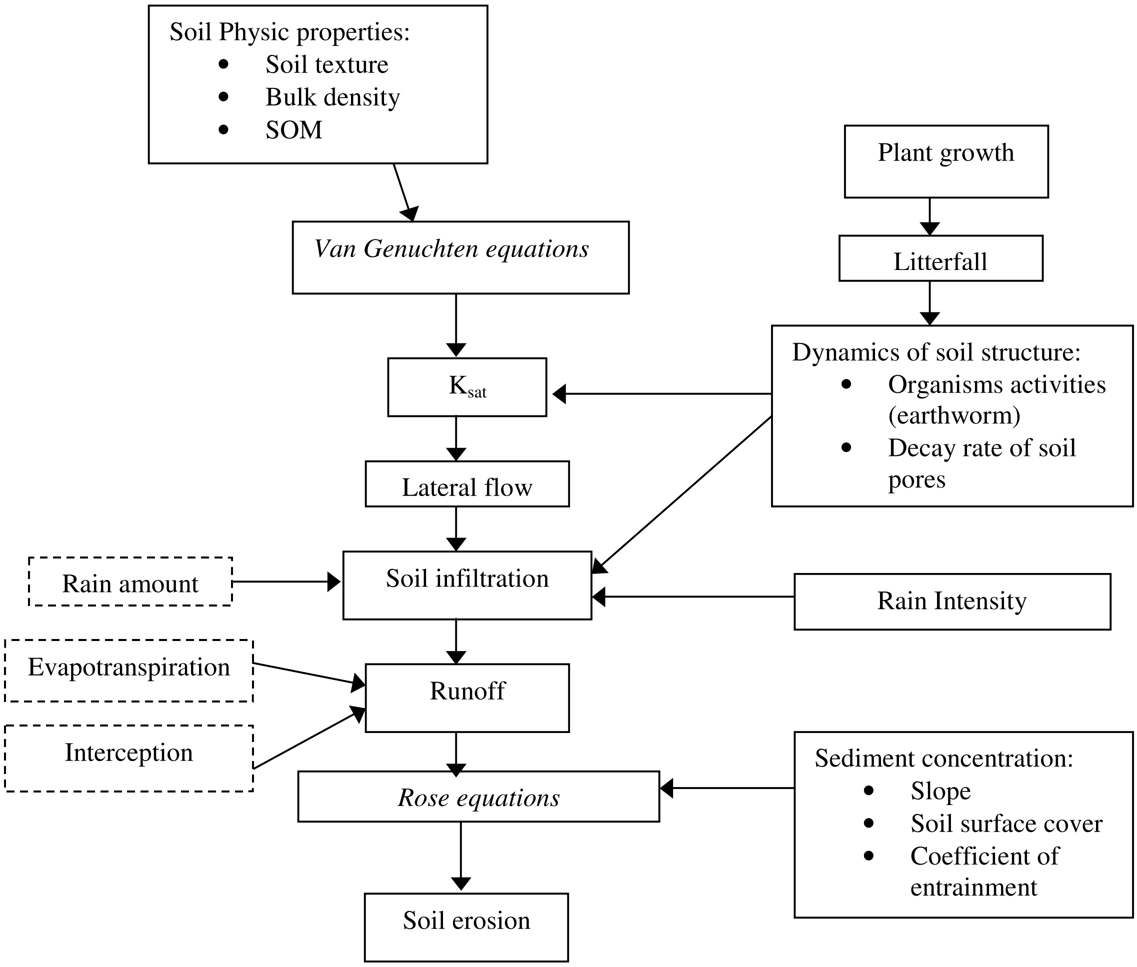

Figure 3.4. Assumed controlling factors of runoff and soil erosion in the WaNuLCAS model (boxes with unbroken frames from Khasanah *et al.,* 2002).

3.6.3 Sensitivity analysis procedure

The option in the Stella environment for performing sensitivity analysis was used. The user specifies what parameter to consider, what values the parameter will take and the time length of the sensitivity analysis. If the range of value of the parameter was available in the model input list, the sensitivity analysis was performed within this interval. If the range of value was missing, the default value was used as point of view to set a range. In some cases the site-specific value was known and then this value was used as point of view.

Every sensitivity analysis was performed for a time period of five years, varying the parameter value in five steps. For some of the parameters the sensitivity analysis showed a sharp fall or rise of runoff and/or soil loss in the given range. In that case a second sensitivity analysis was performed with a narrower range to detect, if possible, in what interval the parameter was most sensitive. The sums of runoff and soil loss for the total time length of simulation, i.e. five years, were considered when analyzing the result. The runoff and soil loss was considered as sensitive to changes in a parameter if the total sums varied by approximately 25 % (i.e. 500-600 l m^{-2} and/or 0.8-1 kg m^{-2}, respectively) or more from the initial values (i.e. 3018 l m^{-2} and 4.41 kg m^{-2}, respectively) with the current model set-up.

3.7 Calibration of the Lam Son site

Calibration of a model means adjusting the parameter values until the output from the model matches field observations. The input data need to correspond to the characteristics of the field, else the calibrated model will not represent the actual field conditions (DEQ, 2005b, internet). The intention of the calibration in this study was not to achieve perfect parameter optimization, rather to adjust a few parameter values in order to obtain model output of the same approximate size as observed values. A summary of the input parameters used is shown in Appendix C:II, while a description of the data is given in this chapter.

3.7.1 Experimental set-up

A field experiment was established on a hillside in the Lam Son site in 1996 in order to compare different cropping systems with respect to soil erosion and concomitant nutrient losses. All cropping systems were upland rice (*Oryza sativa*)-based and in treatments where trees were planted, the specie was *Tephrosia candida* (*T. candida*). Upland rice was chosen as crop because of its traditional importance and *T. candida* as tree, for its nitrogen-fixing ability and acceptance in the region (Hoang Fagerström, 2000). The experimental plots were especially designed to measure surface runoff and soil loss through erosion. The methods to measure runoff and soil loss from the plots are described in Hoang Fagerström (2000). Further description of the experimental set-up and design of the plots are found in Appendix D.

3.7.2 Choice of calibration set-up

Based on the findings of the PaLA-survey in the Dong Cao catchment, where it was revealed that one main future vision of the farmers was to establish trees on the fields, (ICRAF-NISF-SLU, 2000a), different agroforestry scenarios for runoff and soil loss model prediction were identified (see section 3.8.4). In the Lam Son experimental plots, the treatment that resembled the prediction scenarios was the *TepAl*-treatment, i.e. hedgerows of *T. candida* in the crop field. The model was therefore calibrated to the *TepAl*-treatment and the *Mono*-treatment, as a control alternative (Table 3.1). For general species description of upland rice (*Oryza sativa*) and *Tephrosia candida,* see Appendix E.

Table 3.1. The chosen treatments in the Lam Son experimental site for the calibration

Abbreviation	Treatment
Mono	Monocropping upland rice (*Oryza sativa*) for five years
TepAl	Cropping upland rice with hedgerows of *T. candida* for five years, including mulching of biomass, pruned from the hedgerows

3.7.3 Species arrangement and management

To resemble the experimental plots in field, the total plot lengths simulated was 22 m. In the *Mono*-treatment each zone was set to 5.5 m (Figure 3.5a). In field, the *TepAl*-treatment consisted of 3 hedgerows with a length of 1.5 m each, giving a total hedgerow length of 4.5 m. The design of the model plot allows tree application only in two places, the outer zones 1 and 4. To simplify the model set-up, only 2 rows of trees were simulated, with the same total length as in field, 4.5 m, but instead 2.25 m each (Figure 3.5b).

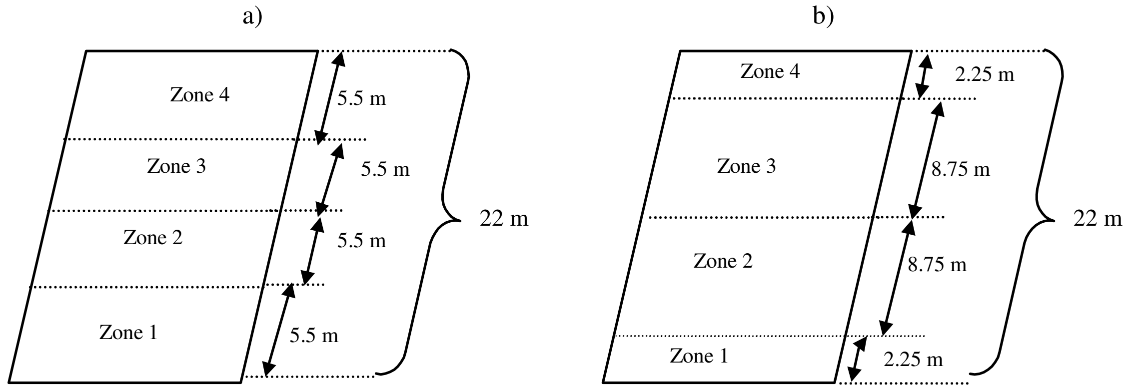

Figure 3.5. Model zone length of the *Mono*-treatment plot (a) and the *TepAl*-treatment plot (b).

The management of crop and tree (dates of sowing, pruning and slash-and-burn, etc) were based on field experimental information given by Hoang Fagerström (2003, pers. comm.), in Hoang Fagerström (2000) and in Hoang Fagerström *et al*., (2002). The slash-and-burn management was set to slash the vegetation the 91st day every year and burn it 1-3 days after slashing, according to information found by Iwald (2001). In the *TepAl*-treatment, with hedgerows of trees, the slash-and-burn management was modified in the *Slash and burn input*-module in Stella by removing zone 1 and 4 from these functions, so trees would not be included in this management.

The default values of crop specific parameters provided in the model for rice were used, with some modifications of the days for the vegetative and generative stage (changed from 70 to 90 and from 50 to 60 days respectively) to agree with the description of the experimental set-up. Tree specific parameters for *T. candida* were available from the data preparation by Iwald (2001). The weed growth function was set to simulate weed whenever crop was absent. Both the parameters of the bush *Chromolaena odorata* (local name 'Cho de') and a weed ('Co chi') were gathered form earlier WaNuLCAS modelling (LUSLOF, 2002, sim.) and used as weed options. 'Cho de' was one of the most common weeds in Lam Son (Hoang Fagerström, 2000) and 'Co chi' was frequently appearing in Dong Cao (Olsson and Schwan, 2003).

In the field experiment, each hedgerow consisted of 3 rows of trees and occupied an area of 1.5 m × 5 m = 7.5 m^2. In Hanum and van der Maesen (1997), tree planting density for *T. candida* is reported to be about 40-90 cm × 10 cm for intercropping. In this study, the trees were assumed to be planted with 1 m space in every row, which make a total of 15 trees in each hedgerow. That means a planting density of 2 trees m^{-2} (20 000 trees ha^{-1}). The simulations of the *TepAl*-treatment were set to include pruning (1-2 times per year) and mulching of the tree biomass (distributed evenly between the zones).

3.7.4 Climate input data

For some years or for some parameters, mainly concerning climate and soil properties, data was not available for the Lam Son site. Then data was used from the Dong Cao catchment or, regarding climate data, from the Hoa Binh weather station, the latter situated 20-30 km from the Lam Son site (La Nguyen, 2003, pers. comm.). The climate data recorded at the Hoa Binh station could be assumed to be similar to the actual conditions at the Lam Son site (Toan, 2003, pers. comm.).

Data of daily rainfall amount for the Lam Son site existed only for parts of the simulated period, why complemented data were used from the Hoa Binh station (Table 3.2). In addition, data of evaporation and temperature from the Hoa Binh station were used. Daily rainfall amount, potential evaporation and temperature data for 32 years (1968-2000) were available in digital form, since the data preparation and collection work made by the LUSLOF team (Olsson and Schwan, 2003). In this study, data for the years 1996-2000 was used in the calibration process. In WaNuLCAS, rainfall, evaporation and temperature data can be entered in different ways, for example as constants and monthly averages (van Noordwijk and Lusiana, 2000). Here, the option for reading the data from daily values tabulated in an Excel-sheet was used.

Average values of rain intensity, *Rain_IntensMean*, and the coefficient of variance of the rain intensity, *Rain_IntensCoefVar*, are data needed for the model. The rainfall intensity data recorded at an automatic weather station in Dong Cao in 2002 was provided by IWMI/MSEC (Appendix F). From this, the rain intensity parameters could be estimated and were used in the model set-up for both the Lam Son and Dong Cao site (Table 3.3). In WaNuLCAS, the rain intensity mean is estimated from the daily mean of rain intensities for each separate rainfall event in one day (Lusiana, 2004, pers. comm.). The available rain intensity data from Dong Cao did only contain one value of rain intensity, i.e. event average (IWMI/MSEC, 2002).

Table 3.2. Source of rainfall data as input for Lam Son site

Year	Source of rainfall amount data	
	Lam Son	Hoa Binh
1996	1 Jan – 31 Dec	-
1997	-	1 Jan – 31 Dec
1998	-	1 Jan – 31 Dec
1999	1 April – 31 Oct	1 Jan-31 March, 1 Nov-31 Dec
2000	1 April – 31 Oct	1 Jan-31 March, 1 Nov-31 Dec

Table 3.3. Input data of the rain intensity (adapted from IWMI/MSEC, 2002)

Rain intensity mean (*Rain_IntensMean*) (mm h^{-1})	29
Coefficient of variance (*Rain_IntensCoefVar*)	1.2

3.7.5 Slope and soil properties

The average slope for Lam Son site is 22-24° (Hoang Fagerström, 2000). In terms of percentage slope, as expressed in the model, a number of 40 % was used[3].

Original data of clay, silt and carbon (C) content (all three together hereafter called soil texture), surface infiltration and saturated hydraulic conductivity (K_{sat}) were modified to obtain data suitable for the calibration. Input data of soil texture was based on a soil profile of six layers, located in the centre of the experimental site in Lam Son in 1996. The soil texture of the soil profile layer 1 and 6 were set as input for the WaNuLCAS layer 1 and 4, respectively. Weighted averages for the original soil layers 2-3 and 4-5 were used as input for the WaNuLCAS layer 2 and 3, respectively (see input data in Table 3.4 and original data and calculations in Appendix G:I).

Values of surface infiltration and saturated hydraulic conductivity rate were not available for Lam Son site. Instead, field measurements in Dong Cao in 2002 (Olsson and Schwan, 2003) were used to

[3] Slope in degrees was converted to percentage slope by trigonometric function; slope in percentage = tan a × 100 (tan a $= \frac{VD}{HD}$, where a = angle in radians, VD = Vertical Distance and HD = Horizontal Distance in a hypothetical triangle (Rodhe and Sigstam, 1998)).

achieve input data. Average values of original infiltration rates together with average values of K_{sat} from both measured and estimated[4] K_{sat} values for every soil layer were used (see original data and calculations in Appendix G:II and III). The obtained values of the two parameters of surface infiltration, 9120 and 23400 mm day^{-1} (Table 3.5), were regarded as very high, compared to infiltration rates into bare and grassed loam measured with rain simulator in laboratory studies, 240 - 5000 mm day^{-1}, with slope variations 0-32 % (Dingman, 1994). The soil in Dong Cao is typically known to have high porosity and macroporosity, excellent internal drainage (Messing, 2004, pers. comm.) and to never be saturated (Podwojewski, 2003, pers. comm.; Olsson and Schwan, 2003), why a high infiltration rate could be expected. But, since the average values were widely outside the range of rates in Dingman (1994), only 50 % of the calculated average infiltration rates were used in the model calibration set-up (Table 3.5). Similar to the infiltration rates, the calculated K_{sat} averages were considered as very large compared to other typical values, determined from data of a large number of soils (Dingman, 1994). The calculated K_{sat} from Dong Cao varied between 2400 - 4400 cm day^{-1}, while a range of 11 - 1520 cm day^{-1} (the K_{sat} of clay loam to clay in the lower part of the range) were given by the typical values. Like the infiltration rate, 50 % of the Dong Cao K_{sat} rates were used as input data (Table 3.6).

In addition to the soil input data mentioned above, soil type (chosen from an existed database in WaNuLCAS) and data of initial phosphorus was considered, see Appendix G:IV.

Table 3.4. Modified data of layer depth and texture as input in the calibration of the Lam Son site (adapted from Hoang Fagerström, 2000)

WaNuLCAS layer	Depth (cm)	cm layer^{-1}	Clay (%)	Silt (%)	Total C (%)
1	0 - 12	11	49.0	47.0	1.7
2	12 - 42	30	49.3	42.7	1.0
3	42 - 84	42	33.5	55.6	0.2
4	84 - 102	18	52.0	39.0	0.5

Table 3.5. Calculated infiltration rates as input for WaNuLCAS (adapted from Olsson and Schwan, 2003)

Parameter	Average (mm day^{-1})	Input values (mm day^{-1}) (Average $\times$ 0.5)
S_SurfInfiltrDef	9120	4560
S_SurfInfiltrInit	23400	11700

Table 3.6. Calculated K_{sat} as input for WaNuLCAS (adapted from Olsson and Schwan, 2003)

Layer	Average (cm day^{-1})	Input values (cm day^{-1}) (Average $\times$ 0.5)
1	2407	1203
2	4480	2240
3	5735	2868
4	4356	2178

[4] Estimations of K_{sat} were based on a correlation between the measured K_{sat} and the total pore diameter, the latter estimated from soil profile descriptions of macropores, since performing field measurements involved difficulties (Olsson and Schwan, 2003)

3.7.6 Calibration data

Observed data of runoff and soil loss were available for every year during the experimental period 1996-2000 in the Lam Son site (Brodd and Osanius, 2002). In the early years, 1996-1997, only yearly data existed whereas event data were available for year 1998-2000 (Table 3.7). In field, the runoff and soil loss were observed whenever there was a heavy rainfall, i.e. generally in the rainy season between May and October (Hoang Fagerström, 2000). Data of observed event runoff and soil loss, together with event rainfall data for Lam Son in 1998-2000, were compiled in Brodd and Osanius (2002). Before using the data, modifications were made in both the original rainfall data and the data of measurements, see Appendix H. In WaNuLCAS one year has 365 days so for the leap years, 1996 and 2000, the data of the 29th of February was excluded.

Table 3.7. Number of observed runoff and soil loss events and measurement periods in 1998-2000 (adapted from Brodd and Osanius (2002))

	Number of events				Measurement period (date of first and last measurement)
	Runoff		Soil loss		
Year	Mono	TepAl	Mono	TepAl	
1998	13	13	3	0	31 May – 12 Oct
1999	10	10	3	0	27 May – 20 Sep
2000	14	14	6	0	22 April – 29 Sep
Sum of events	37	37	12	0	

Measurement period in 1996 and 1997 were assumed to be between 1st of April – 31st of October

3.8 Predictions for the Dong Cao catchment

3.8.1 Land use history

Today, farmers in Dong Cao observe erosion and depleted soil at their fields on steep land (ICRAF-NISF-SLU, 2002a). The most common erosion type in Dong Cao is rill erosion (Toan *et al.*, 2003b). In the 70s, the original forest covering the whole catchment was cut down, giving place to annual crops. In the 90s, cassava became the most common crop since the soil fertility had reduced to a level where other crops could not produce reasonable yield. At this time 'taungya' systems, where crops grow along with forest species during the early stage of establishing tree plantation (Nair, 1996), were introduced in the catchment with financial support from the Government program and MSEC (Toan *et al.*, 2003a). *Acacia Mangium* and *Aleurites Montana* (in Figure 3.7 called *Vemicia Montana*) were the most common trees in the intercropping systems while other species, as *Bamboo*, were used in hedgerow systems (Johansson, 2003).

3.8.2 Field measurements

The Dong Cao catchment has been equipped since 1999 to collect meteorological and hydrological data and to measure soil loss. The catchment was divided in four sub-catchments and a weir was built at the outlet of every sub-catchment (W1-W4) and at the main outlet (MW) (Figure 3.6). The water level was recorded every 6th minute at the 5 outlets. If it was raining, bed load sediment from each weir was weighed twice a month. In addition, in year 2001 and 2002 the suspended load was measured at the main weir (Toan *et al.*, 2003a)[5].

3.8.3 Introduction to field 8 and 9

In the PaLa-survey made in year 2001, two focus places were identified by the local farmers. One of the focus places was regarded as more degraded and eroded than other parts in the catchment, due to more intensified cultivation, whereas the other area was considered as the least eroded part and also as water supplier for the whole catchment (ICRAF-NISF-SLU, 2002a). A thoroughly investigation of a representative transect in each focus place was made by the PaLA team. Transect 1 is positioned in the "weak" part, the most eroded fields, and Transect 2 in the "strong" part, the least eroded fields (Figure 3.6).

Transect 2[6], extending through field 7, 8, 9 and 10 (Figure 3.7, field division from map of Olsson and Schwan, 2003) was described as a strong part with filter effects, i.e. hindering runoff and soil loss in their way through the landscape (ICRAF-NISF-SLU, 2002a). The upper field, field 10, is still occupied by forest, field 8 and 9 had been under crop production but now in fallow for varying time lengths and field 7 was the most cultivated field. For this present study, field 8 and 9 were considered as representative for Transect 2 and suitable for a comparable model survey of the effect on runoff and soil loss of different land use options in a filter place, in order to protect the filter from soil degradation. Field 8 and 9 are located in the middle of Transect 2 (in the middle of the larger ellipse according to Figure 3.6) and parts of the fields (the east sides) belong to the sub-catchments 3 and 4 (sub-catchment division by MSEC). Model simulations of different land use scenarios have also been made for Transect 1 (in the middle of the smaller ellipse according to Figure 3.6), partly situated in sub-catchment 1, by La Nguyen (2004).

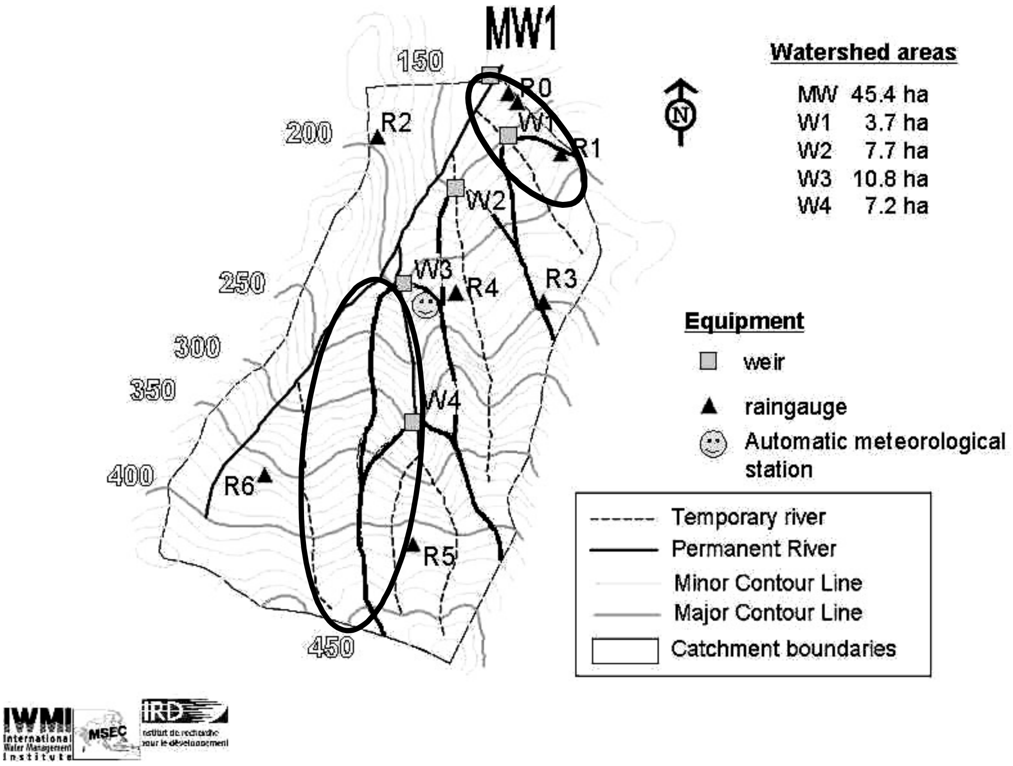

Figure 3.6. Map of the sub-catchment division in Dong Cao (adapted from Toan *et al.*, 2002). The smaller ellipse surrounds the area of Transect 1 and the larger ellipse the area of Transect 2.

[5] Further description of methodology and equipment is described in Toan *et al.* (2001).
[6] In earlier LUSLOF-reports called upper and lower field 3.

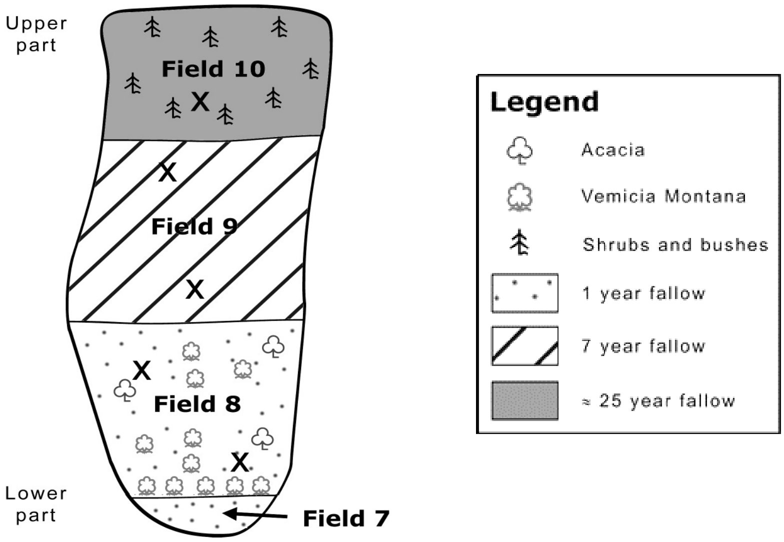

Figure 3.7. Map of the fields in Transect 2, as they appeared in 2002 (from Olsson and Schwan, 2003).

Some characteristics of field 8 and 9 are compiled in Table 3.8. Field 8 is situated downhill field 9. Both field 8 and 9 have been in fallow, but field 9 was laid in fallow earlier. Field measurements show that field 8 is steeper than field 9 and has both lower surface infiltration and lower saturated hydraulic conductivity. More biological activity (earthworms and termites) occurred in field 9 and the percentage of clay and organic matter in the soil in field 9 was greater than in field 8 (Olsson and Schwan, 2003). According to farmers living in the Dong Cao village, runoff and soil loss occur in field 8 but not in field 9 (ICRAF-NISF-SLU, 2002a). A summary of the input parameter values used for field 8 and 9 are shown in Appendix C:III, while a description of the data is given in the rest of this chapter.

Table 3.8. Characteristics of field 8 and 9 ([1]ICRAF-NISF-SLU, 2002a, [2]own GIS estimations, [3]Olsson and Schwan, 2003)

	Field 8	Field 9
Size	Length[1]: 176 m Area[2]: 1.26 ha	Length[1]: 205 m Area[2]: 2.15 ha
Historical land use[1]	Cassava 1985-2001, fallow from 2001	Fallow from 1995
Location on hill and topography[1]	In the middle of transect but downhill field 9, convex topography	In the middle of transect but uphill field 8, concave topography
Slope[3] [%]	53 (upper part of field)	35 (lower part of field)
Infiltration[3] [cm day^{-1}]	1 699 (upper part of field)	10 022 (lower part of field)
Runoff[1]	Yes	No
Soil loss[1]	Yes	No

3.8.4 Choice of species

In the Dong Cao catchment, one of the hedgerow species chosen for the simulations could be regarded as traditional and the other as modern. The *Bamboo* species stands here for the traditional species. The most common *Bamboo* species in the Dong Cao catchment is the *Bambusa Blumeana* (local name "Tre gai"), planted as borders in the fields because of its, according to the farmers, ability to decrease erosion. Other advantages are the easy handling and the Bamboo shots that are important as vegetable (La Nguyen, 2004). The second species used as hedgerow in the predictions was *Tephrosia Candida (T. candida)* and is here regarded as modern species. It was found in the research experiment by Hoang Fagerström (2000) that cropping systems with *T. candida* could increase the crop yield and more effectively prevent soil loss than continuous monocropping systems. In the model set-up, furthermore, cassava was chosen as crop species because of its common use in the catchment. General species descriptions of *Bamboo*, *Tephrosia Candida* and cassava are found in Appendix E.

3.8.5 Species arrangement and management

The real field length of field 8 and 9 each were close to 200 m but the range of length for simulations is 1-100 m (van Noordwijk and Lusiana, 2000). The total plot lengths in the simulations were therefore kept less than 100 m, more exactly close to 80-90 m. Since the design of the model plot allows tree application only in the outer zones, 1 and 4, simulations of uphill plots is needed to obtain a field with hedgerows also within the outer zones (Figure 3.8). Simulating uphill plots means that the defined plot is being reproduced uphill. Depending on the hedgerow spacing, the total simulated plot length will vary (Table 3.9). The hedgerow zone lengths, i.e. zone 1 and 4, were set to 1 m each.

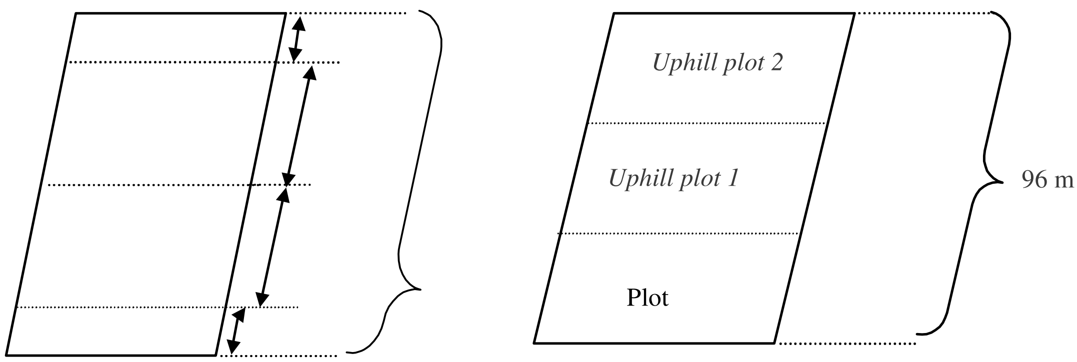

Figure 3.8. A layout example of the total simulated plot in the model, when simulating two uphill plots (the *Bamboo* system with 30 m between hedgerows).

Bamboo and cassava specific parameters were gathered from La Nguyen (2003, sim.). The tree management in the same source; planting in day 91 and pruning in day 182, was applied for both *Bamboo* and *T. candida*. Other management activities; slash-and-burn in day 60 and planting cassava in day 66, was gathered from LUSLOF (2002, sim.). In the simulations, trees were wanted to grow in hedgerows rather than forest-like, why the planting was assumed to be closer than in a forest. Based on the tree planting density found for *T. candida* (see section 3.7.3) and for *Bamboo*, approximately 5 $\times$ 5 m for forest plantation (BFRI, 2000), the tree planting density was set to 1 tree m^{-2}, i.e. 10000 trees ha^{-1}.

3.8.6 Climate input data

The Hoa Binh weather station was the main source of weather data. The weather station is situated 5-10 km from Dong Cao but according to MSEC personnel, the climate in the catchment is similar. In earlier WaNuLCAS simulations with Dong Cao data, climate data from year 2000 was used, since it was considered as a representative year out of 32 years (1968-2000) with respect to rainfall (Olsson and Schwan, 2003). In the model predictions of this study, daily rainfall amount, potential evaporation and temperature data from year 2000 were used and repeated five times, so to be applied for five years.

The values of the rain intensity parameters *Rain_IntensMean* and *Rain_IntensCoefVar* as estimated in section 3.7.4 for the calibration, were used also in the prediction set-ups.

3.8.7 Simulation set-ups

Simulations were made for three different cropping systems; (1) monocropping cassava, (2) cropping cassava with hedgerows of *Tephrosia candida* and (3) cropping cassava with hedgerows of *Bambusa Blumeana,* later referred to as only *Bamboo*. In the hedgerows systems (2) and (3), predictions were made with different distances between hedgerows, in order to test if the length of the spacing between the tree rows would affect the runoff and soil loss. The set-up in the Bamboo system included spacings of 20, 30 and 40 m while the *T. candida* system consisted of spacings of 6, 20 and 30 m (Table 3.9). La Nguyen (2004) found by measurements that the roots of *Bamboo* species in Dong Cao could reach at least 15 m why 20 m was considered as the starting distance. In the *T. candida* system, the 6 m length as used in the Lam Son site was considered as the minimum space, since the farmers that participated in the experiment would prefer longer distance between hedgerows (Hoang Fagerström, 2000).

The cropping systems were simulated with data to resemble the conditions in field 8 and 9, respectively. The data used for separating the fields were soil texture (content of clay, silt and organic C), slope, infiltration and K_{sat}. But, besides changing the distance between hedgerows, the slope and infiltration rate were also varied in every cropping system, to reflect other conditions in the catchment as well (Table 3.10). In addition, by varying the slope and infiltration by the same values in simulation set-ups with soil texture and K_{sat} according to field 8 and field 9 respectively, the effect on runoff and soil loss due to the change in texture and K_{sat} (from field 8 to field 9), while keeping the slope and infiltration constant, could be seen. Besides the output of runoff and soil loss, the agronomic yield for cassava (kg m^{-2}), *C_AgronYields*, were also looked upon to see if there were any differences in crop production between the scenarios.

Table 3.9. Simulation plot set-up for the agroforestry systems (2) and (3), spacings in [m]

	Tephrosia candida			*Bamboo*		
Distance between hedgerows	6	20	30	20	30	40
Length of zone 2 and 3	3	10	15	10	15	20
Length of zone 1 and 4	1	1	1	1	1	1
Number of uphill plot/-s	11	3	2	3	2	1
Total length of each single plot	8	22	32	22	32	42
Sum crop zone	72	80	90	80	90	80
Sum total	96	88	96	88	96	84

3.8.8 Slope and soil properties

Slope values from field measurements were found in Olsson and Schwan (2003). The maximum slope measured was about 70%. Both the slope of field 8 and field 9, approximated to 50% and 30% respectively, were common in the catchment. For every cropping system simulated, the slope was varied between 30, 50 and 70%.

Soil texture data of field 8 and 9 were obtained from field specific soil descriptions in Olsson and Schwan (2003). The input data of *S_SurfInfiltrDef* as calculated in section 3.7.5 and used in the calibration was kept unchanged. Regarding *S_SurfInfiltrInit* and K_{sat}, field-specific input data were used, based on data in Olsson and Schwan (2003) as mentioned in section 3.7.5. The infiltration values of field 8 and 9 were – similar to the average value calculated in section 3.7.5 – regarded as unusual high. In the model predictions, the surface infiltration rate (*S_SurfInfiltrInit*) were therefore varied between the measured values in field 8 (which was below average) and 9 (which was above average) and a third, lower alternative that was 50 % of the value of field 8. The combinations of varied parameters in the predictions are illustrated in Table 3.10.

Table 3.10. The combinations of varied values of slope and infiltration in the predictions with soil texture and K_{sat} according to field 8 and 9

	Hedgerow spacing								
	x			y			z		
Infiltration (mm day^{-1})	Slope [%]			Slope [%]			Slope [%]		
	30	50	70	30	50	70	30	50	70
8500									
16990									
100220									

3.8.9 Validation data for up-scaling

Both measured values at catchment level, from the main weir MW, and measured values from W4, the sub-catchment 4, which was regarded as the weir most likely to reflect the runoff and soil loss from field 8 and 9, were compared to up-scaled simulation results.

The data of measured discharge (l s^{-1} and l month^{-1}), soil loss and suspended load (ton ha^{-1}) were provided by IWMI/MSEC in paper and digital form. For year 2000-2001 monthly discharge data were available for the main weir. In addition, discharge data were provided for every weir in the sub-catchments for year 2002. The measurements in the weirs include all water in the streams, originating from the total sub-catchment areas as both surface runoff and baseflow. The surface runoff was obtained by subtracting 10 % of the discharge, given that surface runoff generate approximately 90 % of the water recorded in the stream – the other 10 % reflecting the base flow (Didier, 2003, pers. comm.). However, the rainfall data used in simulations originated from year 2000, why it was preferable to estimate the runoff in 2000. The yearly runoff ratio of the MW and the W4 obtained from the year 2002 was therefore applied to the runoff of MW in year 2000 to achieve runoff data of W4 (Table 3.11).

Regarding soil loss, measurements of yearly bed load were available for year 1999-2002 for all weirs, besides measurements of suspended load in 2001-2002. From the measurements it was found that suspended load is an important factor for the soil loss process in Dong Cao (Toan *et al.*, 2003a). Therefore, an average of suspended load from 2001-2002 was added to the bed load in each weir to estimate total soil loss in 2000 (Table 3.12). The original data and calculations of runoff and soil loss are found in Appendix I:I and I:II.

Table 3.11. Runoff in year 2002 for MW and W4 and runoff in year 2000 for MW based on measurements, and the runoff for W4 in 2000 based on ratio of runoff of MW and W4 in 2002 (adapted from IWMI/MSEC, 2003, Appendix I:I)

	MW	W4
Runoff (m^3) in 2002	330 599	61 802
Runoff (m^3) in 2000	264 791	49 500
Runoff (m^3 ha^{-1}) in 2000	5 328	5 893

Table 3.12. Soil loss (tonnes ha^{-1}) and total soil loss (tonnes) for MW and W4 year 2000 (adapted from IWMI/MSEC, Appendix I:II)

Yearly bed load (tonnes ha^{-1})		Suspended load (tonnes ha^{-1})	Total soil loss (tonnes)	
MW	W4	MW	MW	W4
0.64	0.49	2.95	178.4	28.9

3.9 Limitations

Due to time and work limitation, the following restrictions were made in this study:

I. Only two experimental treatments, monocropping rice and hedgerow intercropping, were included in the calibration work, although other treatments could have been of interest as well. Besides, only one type of agroforestry land use, i.e. hedgerow intercropping, was used in the model predictions, although other possibilities exist both in the model and for the farmers in the study area.

II. The time length of the model predictions was set to five years, which may be regarded as a short time for model predictions. Instead, priority was given to perform a larger number of simulations.

III. This study did not aim to go into details concerning model equations, “cause and effect”, but rather compare the simulation results with observed data and give general explanations.

4 RESULTS AND DISCUSSION

4.1 Sensitivity analysis

Runoff showed to be sensitive to changes in 10 parameters and soil loss in 9 of the totally 22 parameters (Table 4.1). Despite the fact that many parameters proved to have impact on runoff and/or soil loss, some of them were yet not changed from the default value in the simulations. The reason was the difficulty in estimating the specific value of the parameter for the actual site. In cases where a parameter was considered as not likely to be correct estimated by the author of this work, for example P10, rate of ponding surface water flowing to neighbouring zone or plot, or P18, activity of soil fauna per unit organic input in litter metabolic pool, the default value in the model was used in the simulations. When a parameter showed to be insensitive within the range used in the sensitivity analysis and the site-specific value was unknown, it was assumed that the real value at the site would not differ more than inside this range. Then again the default value was kept unchanged.

Figures showing results of the sensitivity analysis of each parameter are shown in Appendix J. The figure numbers have the same number as the parameter they represent, why references to figure numbers seemed unnecessary and were left out in section 4.1.1-4.1.3.

4.1.1 Parameters showing no affect on runoff or soil loss

A number of 10 parameters showed to be not important for the output of runoff and soil loss. P1, P2, P11, P12, P14, P15, P20, P21 and P22 did not prove any or only a slightly impact on runoff and soil loss in the sensitivity analyses (Table 4.1). These parameters were therefore not considered in the following modelling, so they stayed unchanged from the default value (see Appendix B for default values). Neither did changes in P5 show big impact on runoff and soil loss. But since P5 was calculated from recorded rain intensity and belongs to P6, the calculated value (1.2) was set as a starting point.

4.1.2 Parameters showing affect on both runoff and soil loss

Both runoff and soil loss showed to be sensitive in changes of P6, P10, P13, P16, P17, P18 and P19 (Table 4.1). Regarding P6, the greatest sensitiveness took place in the range 0 - 50 mm h^{-1}. Between 25 and 35 mm h^{-1}, i.e. in the region of the rain intensity mean estimated for the site of calibration (29 mm h^{-1}), the runoff and soil loss differed with 600 l m^{-2} and 0.8 kg m^{-2}, respectively, over the five-year period. 29 mm h^{-1} was used as input value. Both P16 and P17 showed great influence on runoff and soil loss up to 2500 mm day^{-1} and the most sensitive interval was 500 – 1000 mm day^{-1}. The input data of estimated infiltration rates to be used in simulations of the Lam Son and Dong Cao sites were broadly outside this interval.

Table 4.1. Result from sensitivity analysis, showing whether parameters had influence on runoff, R, and/or soil loss, S (see Appendix B for full description of parameters)

No	Parameter name in WaNuLCAS	Unit	Range of Sensitivity Analysis	Affecting R	Affecting S
P 1	AF_DeepSubSoil	m	0 – 10	-	-
P 2	AF_DepthGroundWaterTable	m	0 – 10	-	-
P 3	AF_SlopeInit / AF_SlopeSoilHoriz	% / %	15 – 80 / 15 – 80	-	X
P 4	E_EntrailmentCoeffBarePlot	$m^2\ kg^{-1}$ (soil) mm^{-1}	**a)** 0 – 0.5 **b)** 0 – 0.01	-	X
P 5	Rain_IntensCoefVar	dimensionless	0 – 5	-	-
P 6	Rain_IntensMean	mm h^{-1}	0 – 100	X	X
P 7	Rain_IntercDripRt	mm hr^{-1}	**a)** 1 – 50 **b)** 1 – 20	X	-
P 8	Rain_IntMult	dimensionless	0 – 10	X	-
P 9	Rain_MaxIntDripDur	mm hr^{-1}	0 – 2	X	-
P 10	Rain_PondFlwRt	mm hr^{-1} per m of zone width	**a)** 0 – 50 **b)** 0 – 12.5	X	X
P 11	Rain_PondStoreCp	mm	0 – 10	-	-
P 12	S_KSatVDeepSub	cm day^{-1}	1 – 1000	-	-
P 13	S_KStrucDecay	day^{-1}	**a)** 0 – 0.1 **b)** 0 – 0.02	X	X
P 14	S_RelWormLit*i*	dimensionless	0 – 1	-	-
P 15	S_RelWormSurf	dimensionless	0 – 1	-	-
P 16	S_SurfInfiltrDef[Zone]	mm day^{-1}	**a)** 25 – 10000 **b)** 25 – 2500	X	X
P 17	S_SurfInfiltrInit[Zone]	mm day^{-1}	**a)** 1 – 10000 **b)** 1 – 2500	X	X
P 18	S_WormLikeLitMetab	$m^2\ kg^{-1}$	**a)** 0.00001 – 0.1 **b)** 0.00001 – 0.0015	X	X
P 19	S_WormLikeLitStruc	$m^2\ kg^{-1}$	**a)** 0.0000005 – 0.1 **b)** 0.0000005 – 0.006	X	X
P 20	S_WormLikeSOMMetab	$m^2\ kg^{-1}$	0.000001 – 0.1	-	-
P 21	S_WormLikeSOMStruc	$m^2\ kg^{-1}$	0.0000005 – 0.1	-	-
P 22	W_ThetaInit*i*]Zone]	ml cm^{-3}	0 – 1	-	-

a) The range of parameter value in the first run of two
b) The range of parameter value in the second run of two

P10 greatly affected runoff and soil loss in the lower values, but the impact was small from at least 0.75 mm h^{-1}. The default value, 10 mm h^{-1} per m of zone width, was outside the sensitivity interval. Also changes in the lower values of P13, 0 - 0.01 day^{-1}, resulted in great changes of runoff and soil loss. The default value, 0.001 day^{-1}, seemed to be in the sensitive range. P18 and P19 showed the most influence in the interval of 0 - 0.025 m^2 kg^{-1}. P18 was most sensitive between 0 - 0.0015 m^2 kg^{-1} whereas P19 was most sensitive at 0 - 0.006 m^2 kg^{-1}. Site-specific values of P10, P13, P18 and P19 were not known why the default values were used in the modelling work.

4.1.3 Parameters showing affect on runoff or soil loss only

P7, P8 and P9 showed a little impact on runoff and unnoticeably on soil loss. The impact, showing a difference in runoff of approximately 500 l m^{-2} was mainly in the lower part of the parameter range; in 0 - 10 mm hr^{-1} for P7, in 0 - 5 (dimensionless) for P8 and 0 - 0.5 mm hr^{-1} for P9. Given that the impacts were not of major size, there was no effort in finding a possible better value of these parameters in the calibration work than the default value.

The parameters P3 and P4 proved to be crucial in the generation of soil loss, but not of runoff (Table 4.1). From the graph of P3 it is shown that the soil loss increased approximately 1 kg per 10 units percent increase of the slope. For P4, the most dramatic changes of soil loss occurred in the range 0 - 0.250 m^2 kg^{-1} (soil) mm^{-1}. Also in the region of the default value 0.002, an increase or decrease of P4 caused large changes in soil loss. Adjusting the parameter by a step of 0.001 units changed the soil loss by approximately 3 kg m^{-2}.

4.2 Calibration of Mono-treatment

4.2.1 Results before calibration

Before adjusting parameters, the model was run for five years with the input data according to Appendix C:I, i.e. with model set-up used in the sensitivity analysis. As mentioned in section 3.7.6, the measurements of runoff and soil loss took place during a limited time period, varying from year to year but approximately reaching from April to October. The model output during this specific measuring period, (m.p.) was compared to the measured values. It showed that the total simulated amounts of runoff in the measuring periods for the five-year time length, 2294 l m^{-2}, were much larger than the total measured runoff, 478 l m^{-2}. The simulated runoff differed with 300-700 l m^{-2} each year from the measured values, except in year 1997 where the difference was about 100 l m^{-2} (Figure 4.1a). In contrast, the total simulated soil loss, 1.63 kg m^{-2}, was less than the measured soil losses, 9.33 kg m^{-2}. The greatest difference occurred the two first years, i.e. a difference of about 5 kg m^{-2} in 1996 and 1.5 kg m^{-2} in 1997 (Figure 4.1b). The three last years, the simulated soil loss values were close to the measured values.

The sums of simulated runoff and soil loss in the measuring period were compared to total yearly sums (y) to see the degree of the generated output obtained in the measuring period (Figure 4.1a and b). For the five-year period, the total sum of runoff and soil loss was 3018 l m^{-2} and 4.41 kg m^{-2}, respectively. Compared to the values of runoff and soil loss obtained in the measuring period, it was shown that 76% of the total runoff and 37% of the total soil loss for the five-year period were simulated in the same time of year as measurements took place in field. Apparently, the greatest part of the soil loss in the simulations was registered in the time of the year when no measurements were made, i.e. November to March, in the following text called the non-measuring period.

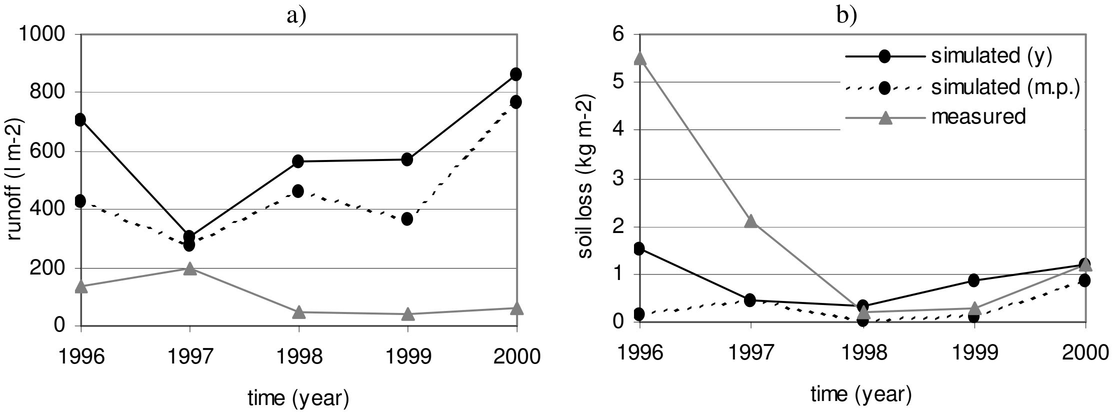

Figure 4.1. Measured and simulated runoff (a) and soil loss (b) for years in total (y) and for the measuring period (m.p.) before calibration.

4.2.2 Results after calibration

The set-up of parameters found in the calibration is given in Appendix C:II. The results, as in Figure 4.2, was considered as realistic for the purpose of this study; still a lot could have been done to obtain optimal model output. The results are discussed in this and the following section, while the calibration procedure, from the beginning to final result, is described in sections 4.2.4 – 4.2.5.

The results of simulated runoff and soil loss sums in the measuring periods were closer to the observed values than the model output generated before calibration (Figure 4.2 and 4.1). The simulated runoff in the measuring periods (m.p.) did not differ much from the simulated runoff, only about 10-20 l m^{-2} every year, except in 1997 where the simulated value showed 80 l m^{-2} more than the measured value (Figure 4.2a). Regarding the simulated soil loss, the sums from the measuring periods agreed well with measured values, except the first year of simulation, in 1996 (Figure 4.2b). Then the simulated value was underestimated by a difference of about 4 kg m^{-2}.

Compared to total yearly sums (y), the yearly simulated runoff did not differ much from the runoff simulated in the measuring periods (Figure 4.2a). 83% of the total simulated runoff occurred in the measuring periods. The total sum of simulated runoff (552 l m^{-2}) was only 15% larger compared to total sum of measured runoff (478 l m^{-2}). The yearly simulated soil loss on the other hand, showed that a large part of the total soil loss became simulated in the non-measuring period (Figure 4.2b). Merely 50% of the total simulated soil loss occurred in the measuring period. In 1998 for example, there was a difference of almost 3 kg m^{-2}. But in year 1997 and 2000, almost all amount of both runoff and soil loss were simulated in the measuring period. The total sum of simulated soil loss (4.83 kg m^{-2}) was app. 30% larger compared to total sum of measured soil loss (3.7 kg m^{-2}).

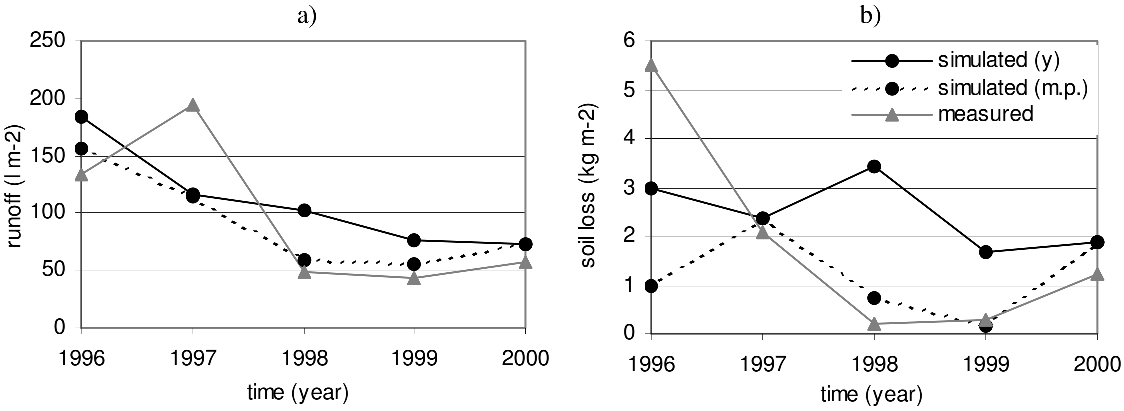

Figure 4.2. Measured and simulated runoff (a) and soil loss (b) for the years in total (y) and for the measuring periods (m.p.) for the *Mono*-treatment.

4.2.3 Correlation for individual runoff and soil loss events

Runoff and soil loss data from each individual measurement event were available in 3 of the 5 years considered, 1998-2000, and correlations could be made of simulated runoff/soil loss events and measured runoff/soil loss events. The correlations in Figure 4.3 showed no good fit. Only a few occasions of the simulated runoff and soil loss peaks (events of maximum runoff or soil loss) coincided with measured events. Generally, when these peaks were simulated they showed greater amounts than the measured peaks.

The measurements indicated a runoff manner of many occasions but small quantities, while the number of simulated runoff events on the other hand was fewer but of larger quantities (Figure 4.4a). Most of the measured runoff values were in the interval 0-10 l m^{-2} and the highest was about 17 l m^{-2}, but some of the simulated values even showed amounts of 20-55 l m^{-2} (Figure 4.3a). Regarding the soil loss, the number of simulated occasions was greater than the number of measured events, and in addition many of the simulated sums were larger (Figure 4.3b). The majority of the measured soil loss values were lower than 0.2 kg m^{-2} and the highest value reached 0.4 kg m^{-2}, while the highest simulated value reached 1.3 kg m^{-2} and about half of the simulated occasions were higher than 0.2 kg m^{-2} (Figure 4.4b).

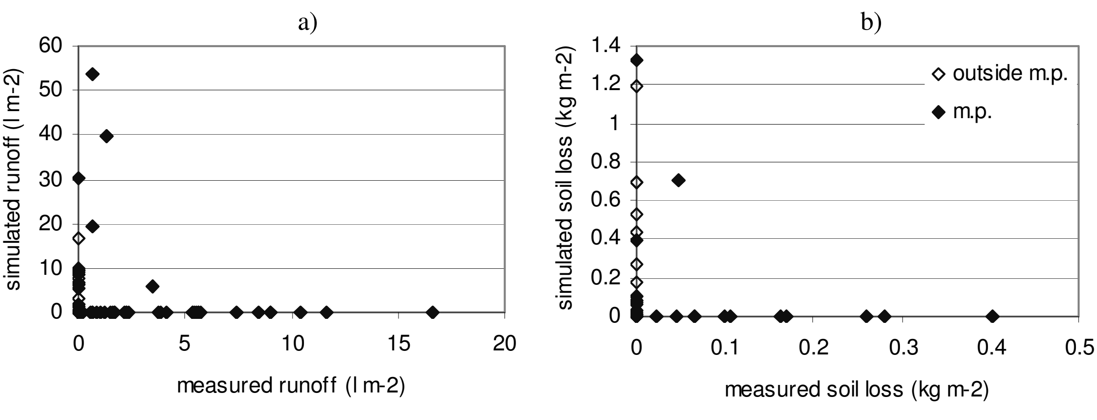

Figure 4.3. Measured runoff vs simulated runoff (a) and measured soil loss vs simulated soil loss (b), year 1998-2000.

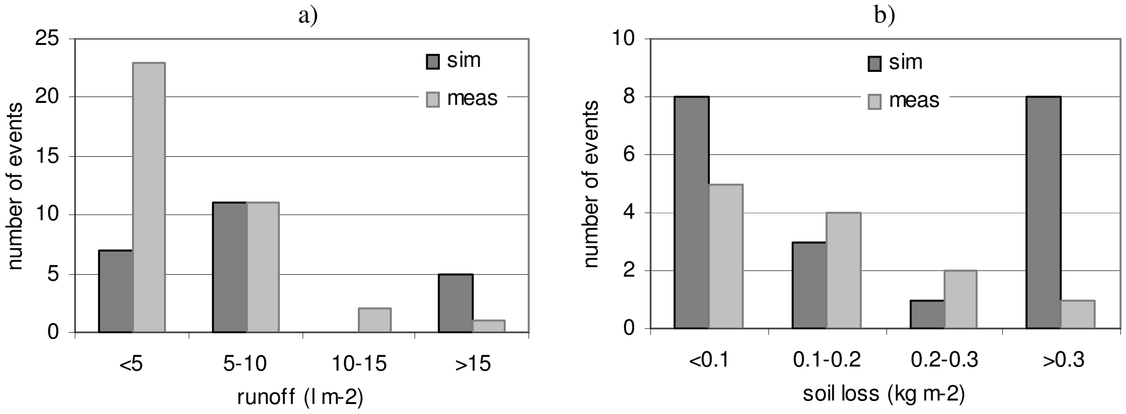

Figure 4.4. Number of simulated and measured runoff events (a) and soil loss events (b) year 1998-2000.

4.2.4 The calibration process

Finding proper parameter values with few site-specific data and testing the reliability of the site-specific parameter values was a dynamic process. The parameters for slope (P3), rain intensity (coefficient of variance and mean - P5 and P6), surface infiltration (default and initial - P16 and P17) where changed according to estimated site-specific values (Appendix C:II). The coefficient for sediment movement (P4) on the other hand, was changed step-wise until it achieved a value that resulted in reasonable yield of soil loss. The default value was 0.002 kg^{-1} (soil) mm^{-1} m^2, but a value of 0.03 seemed to fit better. The default weed parameters were switched to those of the local bush *Chromolaena odorata* ('Cho de'). The total soil loss then increased (from 6.52 to 8.32 kg m^{-2}). However, the soil loss in the measuring period only was too small, about 4 kg m^{-2} compared to measured soil loss, 9.33 kg m^{-2}. Switching the weed specie again to the second local weed species 'Co chi', caused an increase in soil loss to a total of 12.35 kg m^{-2} and 6.12 kg m^{-2} in the measuring period. This weed option was maintained in the rest of the modelling work.

During the calibration it was revealed that there were no difficulties in simulating similar sums of runoff and soil loss for the total measuring time period (five years) as the total sums of the observed values. Rather, the dilemma seemed to be to obtain a proper balance between the total simulated amount of soil loss and the soil loss amount simulated in the measuring period. The greatest part of the simulated soil loss was assumed to occur in the same time of the year as soil loss was measured in field. But the model results showed that in 3 of the 5 years considered, most of the soil loss amounts were simulated outside the measuring period (Figure 4.2).

During the calibration process, different means were tried in an attempt to correct the problem with overestimated soil loss in the non-measuring periods. The values of rain intensity (coefficient of variance and mean - P5 and P6), surface infiltration (P16 and P17) and K_{sat} were reduced since they were believed to be overestimated, see Appendix K for results. However, the new results of sums and correlations did not motivate a change in these parameter values to achieve a more suitable output than with origin input values. Moreover, some crop parameters were varied, which suggested a change in the input values and the parameters regarded are described in the next section, 4.2.5.

4.2.5 Varying crop parameters

According to input data, upland rice was usually planted in May, i.e. when the rainfall period usually began. The measurements of runoff and soil loss are assumed to have begun as the rainfall period began. Some of the default values of crop specific parameters for rice were modified, with the intention to decrease the fraction of simulated soil loss during the non-measuring period and increase the fraction of soil loss given in the measuring period.

Changing the crop cover efficiently factor (*Cq_CovEff[Cr]*) for rice from 0.5 to 0.25 did not affect runoff, but increased the result of soil loss in the measuring period (from 3.74 to 6.12 kg m^{-2}), why this adjustment was applied in the calibration. Also, the effect on soil loss of the specific leaf area[7] (SLA) (*Cq_SLA[Cr]*) of rice and weed ('Co chi') was tested. The hypothesis was, that the default values of rice SLA were overestimated, leading to overestimated interception of rain on rice leaves (growing in the rainy season, i.e. the measuring period), alternative the weed SLA were underestimated leading to underestimated interception of rain on weed leaves (growing whenever rice is absent, i.e. in the dry season). The parameters of SLA of rice were therefore reduced by 50%. It made the simulated soil loss increase some in the measuring period. The values of SLA of 'Co chi' were also changed, by raising the values by double in order to minimize the soil loss in the non-measuring period (Table 4.2). The soil loss produced outside the measuring period then decreased, but so did the soil loss in the measuring period as well. The option of reduced rice SLA and default weed SLA was applied in the calibration.

The crop cover efficiently factor (*Cq_CovEff[Cr]*) of cassava, the crop species used in the prediction scenarios (see section 3.8.4), was close to the value applied for rice (0.2 compared to 0.25). On the other hand, the parameters of SLA applied in the modelling, were overall greater for cassava than for rice (25 compared to 10-15 m^2 kg^{-1}).

Table 4.2. Simulated values in the measuring period with changed SLA (def. = default, red. = reduced, incr. = increased) compared to measured values

	Measured values	Simulated values			
		Def. rice SLA and def. weed SLA	Red. rice SLA and def. weed SLA	Red. rice SLA and incr. weed SLA	Def. rice SLA and incr. weed SLA
Runoff (l m^{-2})	478	359 *(453)*	457 *(552)*	439 *(527)*	340 *(428)*
Soil loss (kg m^{-2})	9.33	4.47 *(10.49)*	6.12 *(12.35)*	4.94 *(9.97)*	3.54 *(8.35)*

Numbers in brackets show total simulated values

4.3 Calibration of TepAl-treatment

4.3.1 Results after calibration

The parameter values found in the calibration of *Mono*-treatment (section 4.2.4 – 4.2.5) were also used in the set-up for *TepAl* since the same site was used. Only the management was modified to simulate trees as hedgerows in the field of rice, see Appendix C:II for the parameter set-up.

Almost all amounts of simulated runoff and soil loss, 88% and 99% respectively, for the *TepAl*-treatment were obtained in the measuring periods (m.p.) (Figure 4.5). The simulated runoff each year showed the same trend as the measured runoff, but the total sum of simulated runoff (315 l m^{-2}) was almost the double compared to the total sum of measured runoff (163 l m^{-2}). The simulated soil loss on the other hand, did not show the same trend over the 5-year period as the measured values. Similar to the *Mono*-treatment, the simulated soil loss the first year was greatly underestimated compared to measured values. Instead, most of the simulated soil loss was produced in 1997 and 2000. From 1997,

[7] Green surface area (one-sided) per unit leaf dry weight as a function of crop growth stage (m^2 g^{-1}) according to Appendix 7 in van Noordwijk and Lusiana (2000).

the measured values stayed at almost 0 kg m^{-2}. The total sum of simulated soil loss was 30% larger (4.83 kg m^{-2}) compared to total sum of measured soil loss (3.7 kg m^{-2}).

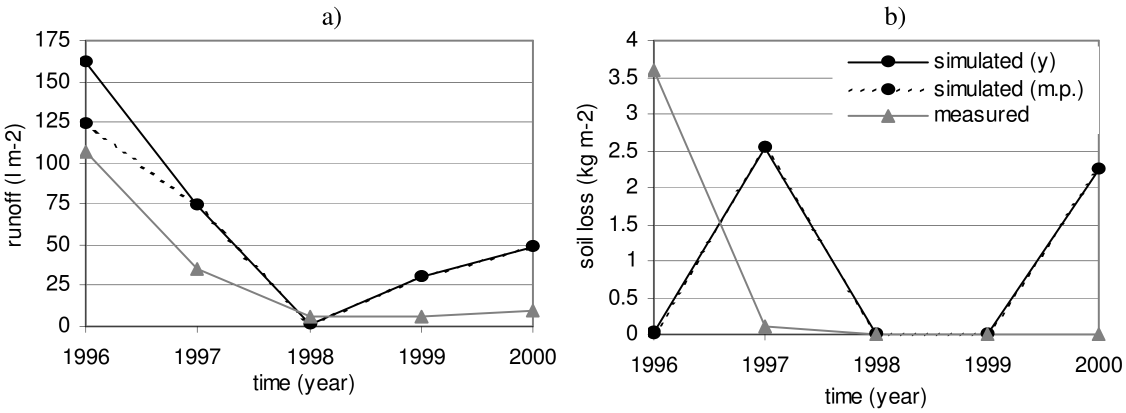

Figure 4.5. Measured and simulated runoff (a) and soil loss (b) for the years in total (y) and in the measuring periods (m.p.) for the *TepAl*-treatment.

4.3.2 Correlation for individual runoff events

There were runoff and soil loss data available from each individual measurement event in year 1998-2000. In the *TepAl*-treatment, there was no soil loss measured in these years, why correlation was made only for runoff events. Similar to the *Mono*-treatment, the correlation showed no good fit (Figure 4.6a). Most of the measured runoff sums were in the interval 0-1 l m^{-2}, while most of the simulated runoff sums showed values greater than 1 l m^{-2} (Figure 4.6b).

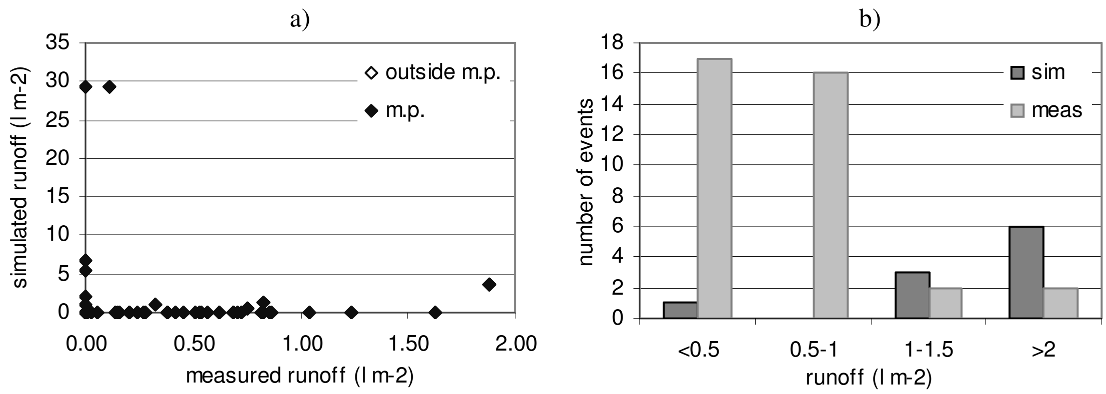

Figure 4.6. Measured runoff vs simulated runoff (a) and number of simulated runoff events (b) for the *TepAl*-treatment year 1998-2000.

4.3.3 Varying fraction of pruned canopy

According to the management description of the *TepAl*-treatment, pruning of the tree canopy and mulching evenly between the plot zones were simulated. The parameter for giving the fraction of pruned tree canopy (*T_PrunFracD*) was varied. Unexpectedly, the minimum sum of soil loss was obtained with no pruning at all. Setting the pruning fraction to 1, 0.5 and 0 caused approximately 50, 13 and 3 kg m^{-2} of soil loss, respectively. The runoff showed the same pattern, but with very small differences. In addition, Dethlefsen *et al.* (2003) found during simulations with WaNulCAS of different pruning regimes that the maximum yield of upland rice was achieved in the scenarios with no pruning. This trend was a little surprisingly, since the pruning and mulching activities were expected to improve the condition of crop growth, for example through returned organic matter to the soil, and preventing runoff and soil loss by mulch protection. Obviously, the negative effects of pruning were overriding the positive effects. For example, the loss of leaf interception of rain may be part of the explanation to the increased soil loss from increased fraction of pruned canopy. Finally, the fraction of pruned tree canopy was set to 0.1.

4.4 Importance of crop cover and temporal distribution of rain

The result from the calibration of the *Mono*-treatment showed that sometimes runoff, but mainly soil loss, were simulated in the time of the year where there were no measurements made in field. There could be a number of reasons to why not most of the simulated soil loss occurred within the time period of the measuring activities. Basically, one explanation could be that runoff and/or soil loss peaks did occur in field in the time of the year as the model stated and that the measuring periods were too short to include all erosion events. Another explanation could be found in the precipitation data. All rainfall data used in the calibration for 1997 and 1998 was recorded outside the study site (at the Hoa Binh weather station, see section 3.7.4), which means that the real rain falling in the Lam Son study site could differ from input data. That would mean that the effect of rain in field could differ from the effect in the model. Looking at the simulated part of runoff and soil loss generated in the measuring period of the *Mono*-treatment (Figure 4.2), the source of rainfall itself is not sufficient as explanation. More or less all of the simulated runoff and soil loss in 1997 occurred simultaneously as the field measurements.

The ground cover is an important factor influencing erosion (Didier, 2004, pers. comm.; Rose, 1988). The actual temporal distribution of rain together with the extent of the measuring period (m.p.) for each year were analysed to see the reason to the model distribution of soil loss and the role of vegetation type during the rainfalls. In the *Mono*-treatment, runoff peaks were to some extent simulated according to rainfall peaks in year 1996-1998 (Figure 4.7). In 1999 and 2000 the greatest runoff peaks did not fit with the greatest rainfall peaks. It is also seen that runoff was tended to occur in the time between the 'slash-and-burn'-management and the start of the cropping season, even when rainfall events in this time period were small. In 1996, 1997 and 1999 runoff was caused also in the end of the cropping season or after the crop had been harvested.

Soil loss did not coincide with rain peaks in the cropping season at all (Figure 4.8). Instead, almost all soil loss produced was related to the runoff events taking place before or after the crop had been on field, i.e. when weed was set to grow. Large runoff events within the cropping season, like in 1997 and 1999, did only cause soil loss of minor amount. Regarding the field measurements of runoff and soil loss (measuring periods, m.p.), they seemed to have begun too late in year 1998 and 1999 according to model result. Nevertheless, the rainfalls occurring before the start of the measuring period in 1998 were small, and still the model generated runoff and great amounts of soil loss. In this time of the year, after the 'slash-and-burn'-management and prior to the cropping season, the soil is dryer, not very covered by vegetation and could be assumed to be more sensitive to runoff and soil loss than the rest of the year. But looking at the magnitude of the soil loss generated in this time compared to the magnitude of the soil loss generated by rain peaks, the model seem to overestimate soil loss in the weed-covered period.

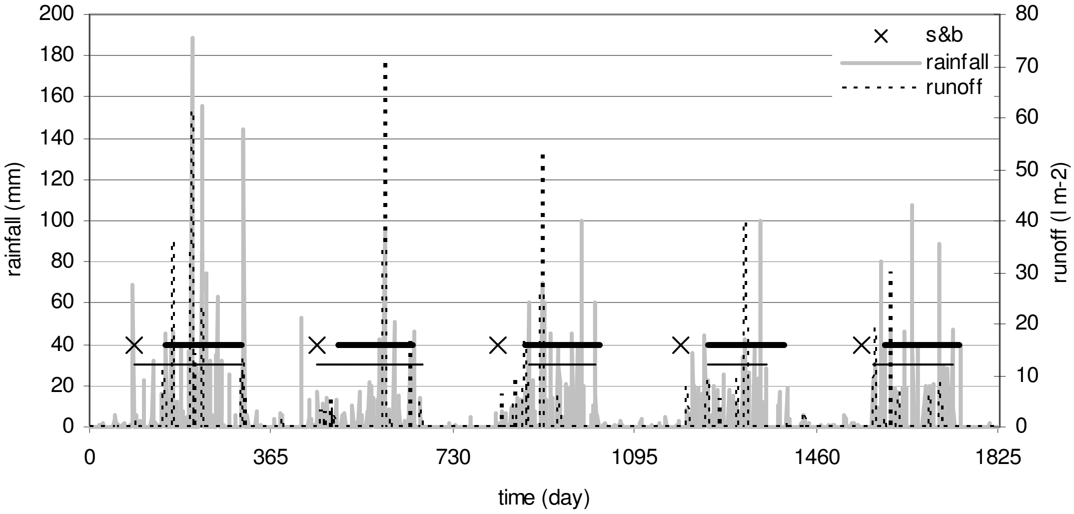

Figure 4.7. Distribution of rainfall and simulated runoff for the *Mono*-treatment during the time period 1996-2000. Black, thick line = extent of cropping season; black, thin line = extent of m.p.; s&b = slash and burn – management.

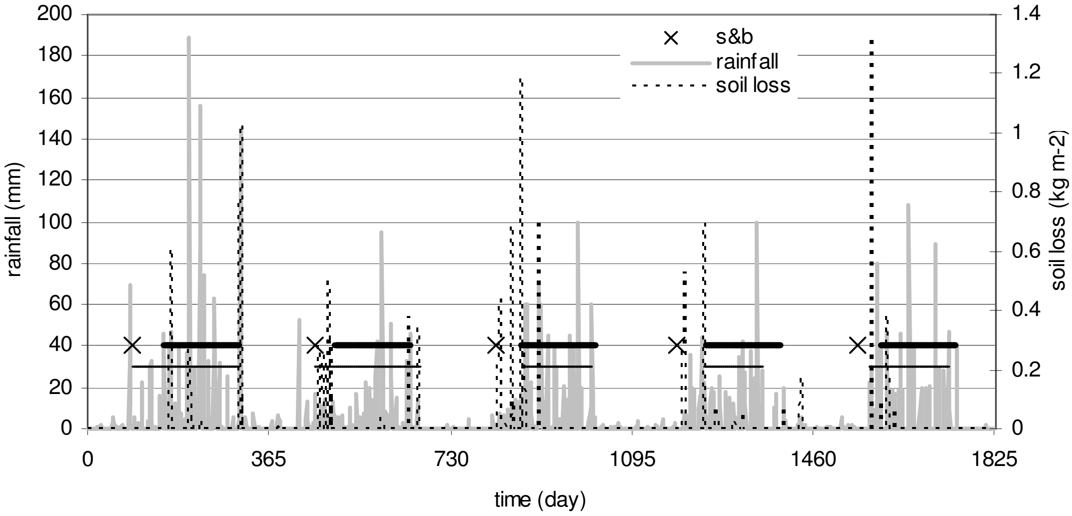

Figure 4.8. Distribution of rainfall and simulated soil loss for the *Mono*-treatment during the time period 1996-2000. Black, thick line = extent of cropping season; black, thin line = extent of m.p.; s&b = slash and burn – management.

The runoff and soil loss pattern for the *TepAl*-treatment looked different. The runoff events were not as many but in the same magnitude as the runoff obtained in the *Mono*-treatment (Figure 4.9). However, in 1998, no runoff at all occurred. Half of the runoff simulated for the total time period was obtained in the first year of simulation, in 1996. On the other hand, only a negligible sum of soil loss was produced in 1996 (Figure 4.10). In 1997, the generation of soil loss responded to the runoff event right after a tree pruning activity was performed. In 1999, a runoff event happened just prior to a pruning management, and then a soil loss occasion was lacking. Unlike the runoff and soil loss generated in the *Mono*-treatment, neither runoff nor soil loss events took place in the time before or after the cropping season (except in the end of 1996). The reason could be that in the *TepAl*-treatment, not all vegetation on the ground was cut down in the slash-and-burn management. The trees were left unslashed, meaning that the soil was not completely exposed to the processes leading to soil loss.

It was unexpected that the first year of the simulation period did not show larger amount of simulated soil loss. At this early stage of the tree establishment, where trees were planted in day 103 (the same date as the first slash-and-burn management in Figure 4.10), the trees are assumed to be too small to have some effect on the runoff and soil loss. One explanation could be that in the *TepAl*-treatment, the area occupied by crop and weed (growing when crop was absent) in the *Mono*-treatment was reduced since trees replaced part of the area. Weed showed a tendency to cause more soil loss than crop and as the crop/weed area was reduced, the soil loss might have been reduced as well.

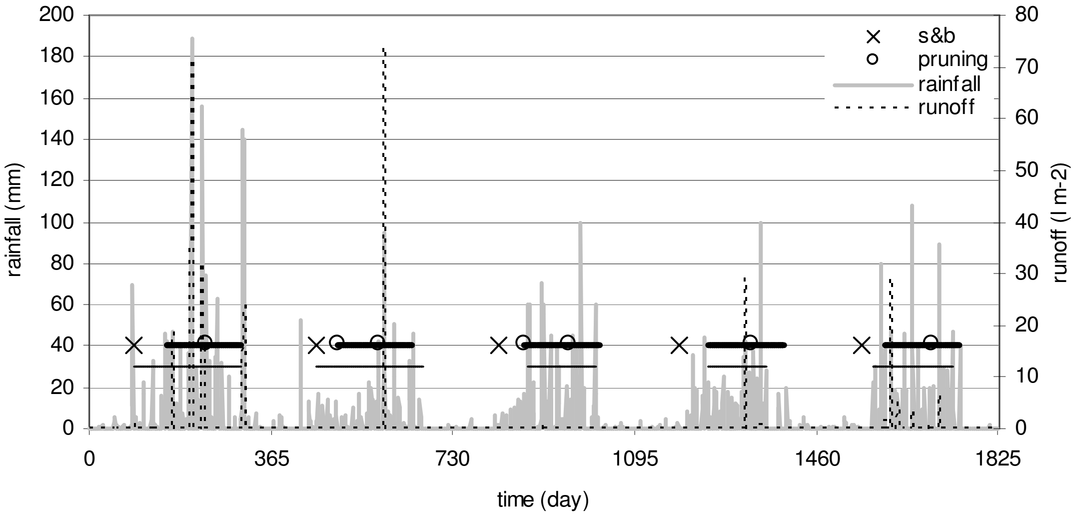

Figure 4.9. Distribution of rainfall and simulated runoff for the *TepAl*-treatment during the time period 1996-2000. Black, thick line = extent of cropping season; black, thin line = extent of m.p.; s&b = slash and burn – management.

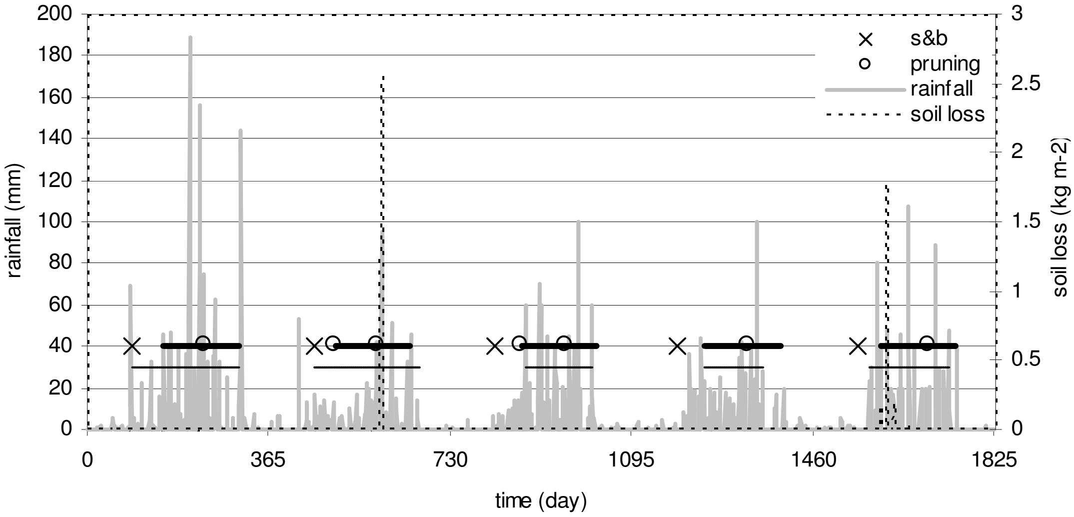

Figure 4.10. Distribution of rainfall and simulated soil loss for the *TepAl*-treatment during the time period 1996-2000. Black, thick line = extent of cropping season; black, thin line = extent of m.p.; s&b = slash and burn – management.

4.5 Predictions

4.5.1 Differences in result of field 8 and 9

The simulated runoff and soil loss showed great differences between field 8 and 9 (Figures 4.11 and 4.12). Generally, the sums of runoff and soil loss in field 8 were about the double of the sums in field 9. Concerning the yield of cassava, there were no major differences between the yield produced in field 8 and field 9, but field 9 gave in general slightly more yield (Figure 4.13).

The distinction in simulation results of field 8 and 9 could be explained by the difference in land use history. The larger K_{sat}, infiltration capacity and fraction of organic matter in field 9 may be due to the effect of the fallow period in the 90s. The fallow period may be assumed to have improved the soil quality or at least prevented the soil degradation. In this time, field 8 was still cultivated with cassava and thus more exposed to fertility depletion. Based on the results of the sensitivity analysis (section 4.1), the steeper slope in field 8 could explain part of the greater soil loss but not the greater runoff. The differences in runoff, crop yield and to some extent in soil loss are thus ascribed the difference in soil quality, and then primarily the infiltration rate, as seen in the result of all simulated scenarios, Appendix L:I and L:II.

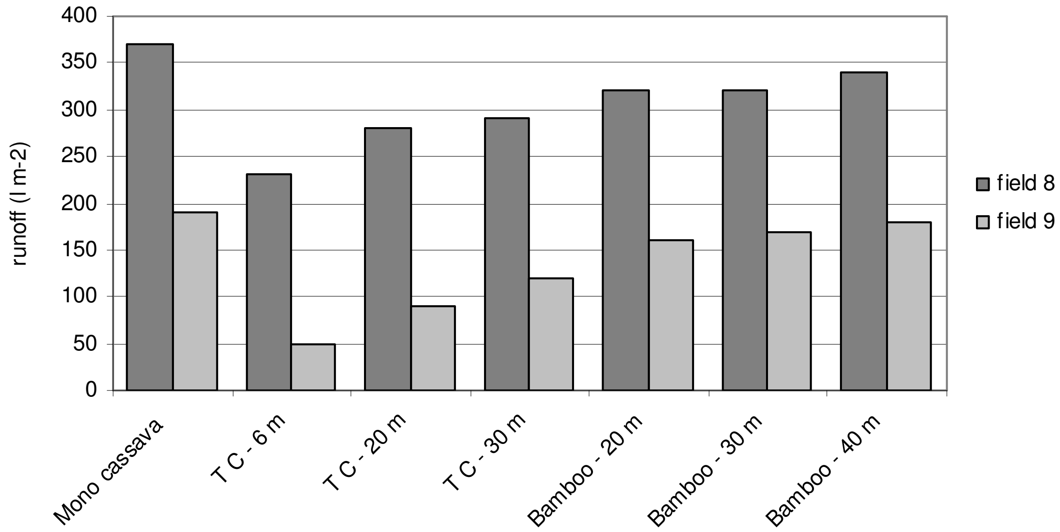

Figure 4.11. Runoff differences between monocropping cassava, hedgerows of *T. candida* (6, 20 and 30 m) and hedgerows of *Bamboo* (20, 30 and 40 m) in field 8 and 9.

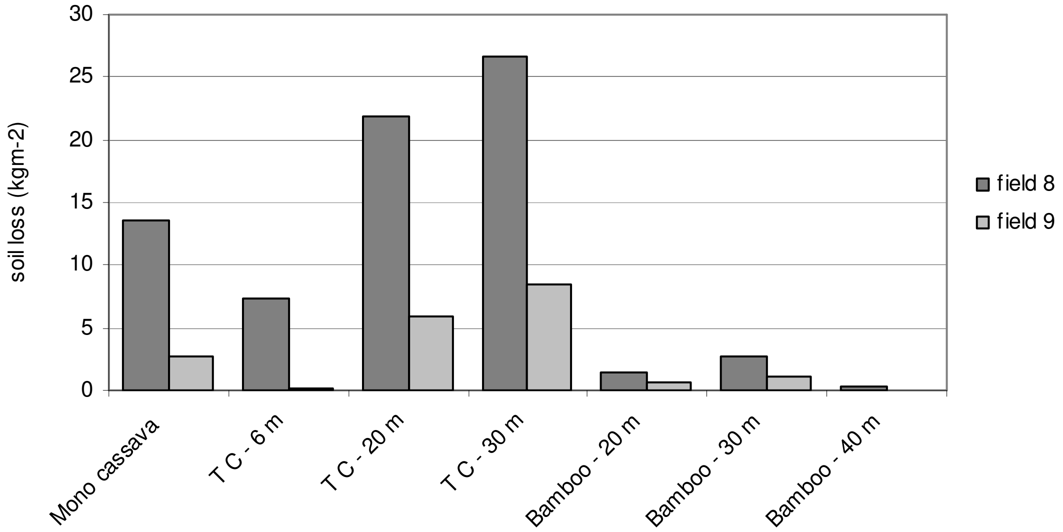

Figure 4.12. Soil loss differences between monocropping cassava, hedgerows of *T. candida* (6, 20 and 30 m) and hedgerows of *Bamboo* (20, 30 and 40 m) in field 8 and 9.

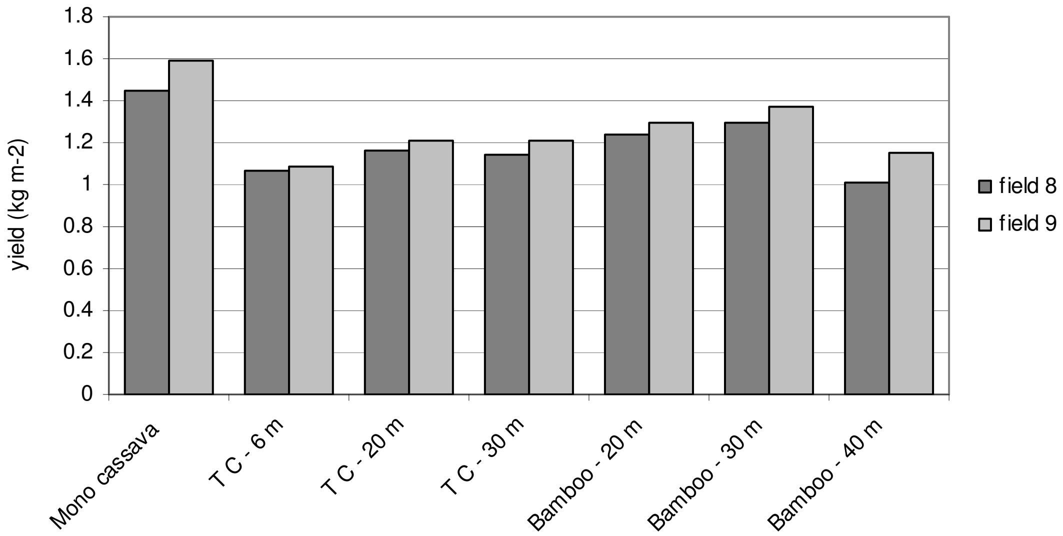

Figure 4.13. Cassava yield differences between monocropping cassava, hedgerows of *T. candida* (6, 20 and 30 m) and hedgerows of *Bamboo* (20, 30 and 40 m) in field 8 and 9.

4.5.2 Differences in land use system

Scenarios with tree hedgerows were assumed to improve soil structure and physically prevent overland flow and soil loss, and hence likely to cause clearly less runoff and soil loss and more crop yield than the monocropping system. But, the result was a little surprising. As expected, scenarios with tree hedgerows gave less runoff than the monocropping scenario, especially the *T. candida* system in field 9, while the *Bamboo* system showed only small differences (Figure 4.11). Furthermore, the cassava yield became lower in scenarios with tree hedgerows (Figure 4.13). The outcome of the cassava yield in the simulations, approximately 2.4 tonnes ha^{-1} per year (1.2 kg m^{-2} in 5 years, Figure 4.13) is below the average yield of the world cassava production in year 2000; 10.2 tonnes ha^{-1} per year (IITA, 2004, internet).

Most unexpected was the result of soil loss. Generation of soil loss in the *T. candida* system showed about the double of the soil loss amount in the monocropping scenario (except for the soil loss in the 6 m spacing) (Figure 4.12). In contrast, generation of soil loss in the *Bamboo* system showed considerable lower values than the monocropping system. Actually, the soil loss produced in the *Bamboo* system, 0 - 600 kg ha^{-1} per year (0 - 0.3 kg m^{-2} in 5 years, Figure 4.12), is comparable to soil loss observed under undisturbed forest, i.e. 500 kg ha^{-1} per year (Stocking, 1994).

There exist complex interactions among vegetation, slope, soil type and erosion, why erosion processes in even known field conditions are difficult to forecast. Indeed, there are examples of tree plantations made in order to prevent soil erosion, appearing to show the opposite; the planted trees accelerated the erosion (Stocking, 1994). That is precisely what seemed to have occurred in the simulations of *T. candida* hedgerows (e.g. Figure 4.12). Generally, vegetation protects the soil from erosion by intercepting raindrops and absorbing their kinetic energy. Some water evaporates from the leaves but most reaches the ground either by stemflow or by reforming into droplets. The height of the vegetation cover above the ground surface is important. Droplets can be larger in mass than raindrops in the origin rainfall and they could have energy enough, though less than the original raindrops, to impact the soil surface and initiate erosion (Stocking, 1994). To explain the difference in result of simulations with hedgerows of *Bamboo* and hedgerows of *T. candida*, tree specific parameters that could be assumed to affect the runoff or soil loss in the model were compared. The *Specific Leaf Area* (SLA) was almost twice as big for *T. candida* as for *Bamboo*. The parameter *Rainfall water stored at leaf surface* was also larger for *T. candida*. *T. candida* should then be able to intercept more rain than *Bamboo*, leading to evaporation of a greater fraction of the rainfall. That would mean less rainfall water turning into runoff, which was also the case in the simulations. However, the *Maximum canopy height above bare stem* and the *Maximum canopy radius* were each almost five times greater for *Bamboo*, which in turn should indicate large interception of the *Bamboo* canopy. But obviously the water amount becoming runoff was greater in the *Bamboo* system. The high amount of soil loss in the *T. candida* system could be explained by water dripping from the leaves, splashing the soil hard enough to cause soil loss. The soil loss results of *Bamboo* on the other hand, having higher stem and larger canopy radius but smaller leaves, could be explained by the assumption of rainfall reaching the ground direct or by running on the stem rather than being intercepted and forming droplets on leaves. Then the splashing effect would not be as prominent as for *T. candida* and could explain the cause of less soil loss.

Model simulations of runoff for the area in the Dong Cao catchment that was regarded as the weak part, Transect 1, (see Figure 3.7) differed in results compared to the results described above. The plot set-ups of the *Bamboo* and *T. candida* hedgerow systems in Transect 1 were similar to the set-up used in this report[8]. For Transect 1, the simulated runoff reached higher values than the values obtained for

[8] For Transect 1, the *Bamboo* hedgerow system consisted of 66 m between hedgerows and the *T. candida* hedgerow system consisted of 6 m between hedgerows and the *T. candida* was harvested and replanted the 5th year of a total simulation period of 7 years (La Nguyen, 2004). No calibration process, with the exception of *Bamboo* parameters, was made before simulations of Transect 1.

Transect 2, which was expected. However, the difference in runoff was very large; about 20 times larger for Transect 2 (6000 l m^{-2} compared to 50-250 l m^{-2} for the *T. candida* system and 5000 l m^{-2} compared to 150-350 l m^{-2} for the *Bamboo* system in 5 years). Unexpected was the difference in result of the hedgerow systems. In Transect 1, hedgerows of *Bamboo* showed to prevent runoff better than hedgerows of *T. candida*, while the opposite was true in Transect 2. For other agroforestry scenarios and model outputs explored for Transect 1, see La Nguyen (2004).

4.5.3 Impact of hedgerow spacing

The pattern seemed to be increased runoff with increased spaces between hedgerows (Figure 4.11). Soil loss in the *T. candida* system showed the same trend, while the *Bamboo* system showed the minimum amount of soil loss in the scenarios with greatest space (30 and 40 m) between hedgerows (Figure 4.12). There were no large dissimilarities in yield production between the spacing scenarios, except for the 20m spacing in the *Bamboo* system, which showed somewhat greater amount than the other (Figure 4.13). The space between hedgerows showed to be most important in the *T. candida* system in terms of runoff and soil loss. Especially the shortest spacing, the 6 m space between hedgerows, showed lower values than the 20 and 30 m spaces.

4.5.4 Impact of varying input parameters for slope and infiltration

Overall, runoff and soil loss increased with increasing slope and decreased with increasing infiltration, while cassava yield decreased with increasing slope and increased with increasing infiltration, irrespective of cropping scenario (Appendix L:I and L:II). The changes in runoff due to the changes in slope from 30 to 70 % were not large. The difference was only 10-20 l m^{-2} at the most, as slope changed from the lowest to the highest value. Neither did the yield of cassava differ much between different slopes, only 0.01 - 0.02 kg m^{-2}. Soil loss raised clearly when increasing the slope, sometimes as much as the double from the lowest to the steepest slope, for instance from 14 to 30 kg m^{-2} (with soil properties according to field 8, in the scenario with 20 m spacing of *T. candida*, with the lowest infiltration rate).

Changing the infiltration rate from 8500 to 100220 mm h^{-1} did affect the outcome of runoff, by about 200 l m^{-2}. The largest change occurred between the middle and highest infiltration value. Also the soil loss varied in some cases with varying infiltration rate, especially in the monocropping system and in the *T. candida* system with 6 m between hedgerows. The yield of cassava did not change much due to changed infiltration rate, but tended to increase slightly with increasing infiltration. There were some exceptions for the trends described above, for example in simulation with soil texture and K_{sat} of field 9, in the 20 m spacing of the *Bamboo* system, where the soil losses with the highest infiltration rate were greater than the soil losses with the middle infiltration rate (with 50 and 70 % slope).

Runoff and soil loss differences due to slope and infiltration for the hedgerow scenarios showing the best result of soil loss (the 6 m scenario in the *T. candida* system and the 30 m scenario in the *Bamboo* system) were compared with the result of the monocropping system (see figures in Appendix M). In the scenario with soil texture and K_{sat} according to field 8 and with the lowest infiltration (8500 mm h^{-1}) there was no big difference in runoff between the monocropping system and the *Bamboo* scenario, while the runoff in the *T. candida* scenario was considerably lower. The same pattern was shown for the middle and highest infiltration rate (16990 and 100220 mm h^{-1}). In simulations with soil texture and K_{sat} according to field 9, the runoff result was similar to the result for field 8. This means that in both fields and for all three infiltration rates, the hedgerow scenario of *T. candida* in 6 m space would be to prefer in terms of runoff prevention, prior to the monocropping system and all other hedgerow scenarios. Regarding the soil loss in simulations with soil texture and K_{sat} according to field 8, the *T. candida* scenario was a better choice than the monocropping system, but the *Bamboo* scenario showed to be the best option in all infiltration alternatives. However, with the highest infiltration rate, the soil loss in the *T. candida* scenario was almost of the same low quantity as the *Bamboo* scenario. In simulations with soil texture and K_{sat} according to field 9, the soil loss in the *T. candida* scenario was lower than the same scenario in field 8. Still, the best choice to obtain minimum soil loss would be the hedgerow scenario of *Bamboo* in 30 m space, at least with the lowest and middle infiltration rate, prior to the monocropping system and all other hedgerow scenarios.

4.5.5 Impact of varying input parameters for soil texture and K_{sat}

As illustrated in Appendix M, changing the soil texture and K_{sat} alone, from data according to field 8 to data according to field 9, while the infiltration and slope values stayed constant, did in most scenarios not show great affect on runoff or soil loss. Mostly, runoff and soil loss values were slightly lower and cassava yield higher in simulations with soil texture and K_{sat} of field 9 (Appendix L:I and L:II). Nevertheless, there were exceptions from these features, like the runoff values in the 20 m spacing of *Bamboo* which was actually a little higher in simulations with soil texture and K_{sat} of field 9 than of field 8.

Only the *T. candida* system showed a clear difference when switching the soil texture and K_{sat} from field 8 to field 9, as seen in figure M.2 in Appendix M. The soil losses were reduced by almost half the sums in the 20 and 30 m spacings (Appendix L). Changing the soil texture and K_{sat} in combination with the change of the infiltration rate to the field-specific value, caused changes in the runoff and soil loss also in the other cropping scenarios. The yield of cassava, however, seemed to be more sensitive to changes in the texture and K_{sat} than to the changes in slope or infiltration rate.

4.5.6 Up-scaling model result to catchment level

The simulation result with data of the fields 8 and 9 in the Dong Cao catchment was up-scaled to the total area of the catchment and to the area of W4, the sub-catchment 4. The scenario in each cropping system with the minimum and maximum of runoff and soil loss (see Figure 4.11 and 4.12) were compared to the measured values. The average values of runoff and soil loss for the 5-year-period were compared to measured values of year 2000. Since the measured values (per hectare) of the main weir, MW, and W4 did not differ noticeably (see section 3.8.9); neither did the up-scaling to the total catchment level and to the sub-catchment level differ in result. The following comparison will refer to the values of MW only.

Compared to measured catchment runoff, the simulated values of runoff were in general clearly lower (Figure 4.14a). The model outputs were only 2 – 13% of the measured value. Given that the model operates at plot level, and does not show the features of a catchment, the opposite result was to be expected. At a catchment scale, valleys, varying slope and other elements downhill are likely to capture parts of the runoff and soil loss from uphill areas. Looking at the result of the soil loss, this aspect seemed to be true for some of the scenarios (Figure 4.14b). The model outputs were in some cases (the monocropping system and one situation in the *T. candida* system) hundreds and even thousand times greater than the measured value. Nevertheless, some scenarios did also show the same relationship to the measured value as the runoff values, i.e. one simulated scenario each with hedgerows of *Bamboo* and *T. candida* gave only 0 – 10% of the measured soil loss.

The fields 8 and 9, which provided the model with input data in the predictions, were areas located in a part of the Dong Cao catchment that was considered as a filter area. This area had not been as intensively cultivated as other parts in the catchment and showed larger capacity to prevent erosion (high infiltration rates, moderate slopes, etc.). This fact could explain why runoff and soil loss predicted by the model turned out to be lower than expected, since the whole catchment then was assumed to have as good filter effects as the filter area. The reason to why the up-scaled runoff was lower than the measured runoff at the same time as the up-scaled soil loss generally was higher than the measured soil loss, could again be due to the differences in what was simulated in the model compared to what was actually happening in field. In the catchment, the specific fields that could be assumed to give the most runoff are intensively used and some parts of the soil excessively compacted by human and cattle traffic, why the water may run off without much ability to entrain soil particles. The areas with soil compaction were not reflected in the model simulations and that could explain the differences in model result and field measurements (low simulated runoff versus high measured runoff and high simulated soil loss versus low measured soil loss).

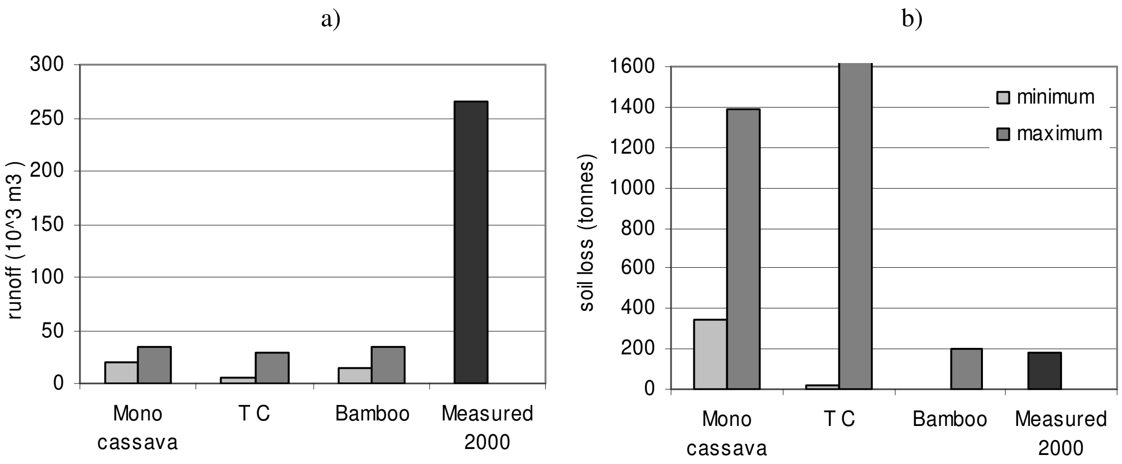

Figure 4.14. Up-scaled simulated runoff and soil loss (average of five years) for the minimum and maximum value of each different cropping systems, compared to the measured value in MW in year 2000 (adapted from IWMI/MSEC, 2003). (The maximum soil loss in the *T. candida* system reached 2500 tonnes.)

4.5.7 Optimal agroforestry scenarios

The yield of cassava stayed at a relatively constant level through the simulations, why most attention was paid to the results of runoff and soil loss when selecting the most promising land use at field 8 and 9 from the model results. The 6 m spacing of *T. candida* showed low values of both runoff and soil loss in field 9. However, scenarios of *Bamboo* hedgerows in field 8 generated lower soil loss than the *T. candida* hedgerows. Both the 30 and 40 m spacing gave low soil loss in both field 8 and 9, although runoff amounts were large (and the cassava yield somewhat lower). Thus, the 6 m space of *T. candida* turned out to be the best alternative in field 9 but a *Bamboo* based system in field 8.

At fields with similar soil properties as field 8 or field 9, but with other values of slope and/or infiltration, the choice of the best land use would differ. Regarding soil loss only, *Bamboo* systems (preferable with 30 or 40 m between hedgerows) would be the most secure land use at a field with slopes in the range 30-70% and with low (about 8500 mm h^{-1}) or varying infiltration rates (within the range 8500 - 100220 mm h^{-1}). But if infiltration is known to be high (about 100220 mm h^{-1}), hedgerows of *T. candida* with 6 m space may be a better option, causing both low runoff and soil loss. The *Bamboo* systems caused larger amounts of runoff, but according to the results, it was not important in the generation of soil loss.

Since the yield of crop has declined in the fields, farmers in the Dong Cao area have adapted other cropping managements than the shifting cultivation on their land. A land use management that involves fallow periods or tree hedgerows could mean economical loss for the farmer due to decreased crop production in a short-time period. But in a long-term perspective, there is a need to turn to a sustainable land use where the soil fertility is maintained, to produce good crop yields in the future. In this study, the model simulations indicated that the soil texture and K_{sat} in combination with surface infiltration, the two latter influenced by former land use, have an effect on the generation of runoff and soil loss and values of these factors can be improved by e.g. fallow periods.

In the modelling, attention was not paid to any differences in price or time consumption of the *T. candida* and *Bamboo* species, but they were treated equally in the management. However, these are factors that farmers need to consider; for example the cost for planting each species and the time for pruning the canopies. The type of crop between the tree hedgerows is another issue to take in account, since some crops are not suitable for intercropping. Results from the predictions showed that the soil loss could vary largely with hedgerows of *T. candida* depending on the hedgerow spacing, while hedgerows of *Bamboo* gave overall low and similar amount of soil loss irrespective of spacing. In reality, slope and infiltration rate can differ within one field. Hedgerows of *Bamboo*, in opposite to *T. candida*, maintained a relatively low and constant level of soil loss amount independent of slope and infiltration rate, why hedgerows of *Bamboo* would be to prefer in terms of soil loss.

4.6 Difficulties and sources of error using WaNuLCAS

For a user of the WaNuLCAS model that is not familiarised with detailed dynamics of biological, physical and chemical factors in an agricultural field, it is difficult to assign a field-specific value since the definitions of many parameters are difficult to comprehend. The WaNuLCAS model is a complex model consisting of hundreds of input parameters and the model outcome depends on the parameter set-up. In this study, the outcome of runoff and soil loss was investigated on the basis of a restricted number of parameters. Firstly, the number of parameters to be considered was restricted in the sensitivity analysis. Secondly, parameters to be considered were again limited in the calibration. The model output could therefore be uncertain due to parameters that were not considered but have impact on the output. For example, P18 and P19 showed great influence on runoff and soil loss in the sensitivity analysis, but were not changed from the default values in the calibration. If there would have been values of P18 and P19 from the Lam Son or Dong Cao site differing from the default values, the output could have differed largely.

Another factor that could have been of importance for the model result is how well the plot set-up in the model reflected the actual conditions in field. In the Lam Son experiment for example, the plot of the *TepAl*-treatment consisted of three hedgerows, which were represented by two hedgerows only in the model. Regarding the predictions for the fields in Dong Cao, this aspect should be even more important since the set-ups represented a larger area in field, with possibilities to more varying conditions.

4.7 Recommendations

For comparing model predictions of runoff and soil loss for different agroforestry scenarios in similar catchments as in this study, the WaNuLCAS model is a valuable tool since it allows for a wide range of agroforestry set-up options. Nevertheless, the WaNuLCAS model is designed primarily to operate at plot level and thereby up-scaled predicted model outputs can be expected to differ from measured values. Therefore it would be good to combine the WaNuLCAS simulated results with results from a model designed for larger areas, like catchments, when up-scaling simulated runoff and soil loss results to the catchment area.

In this study, the output parameters of runoff, soil loss and crop yield were in focus. It would also have been interesting to look at other outputs, if time had allowed. For further investigation and comparison of *Bamboo* and *T. candida* hedgerow systems, it could be useful to look at, for example, the evaporation and transpiration from the *Bamboo* and *T. candida* leaves, in order to try to explain the difference in simulated runoff and soil loss.

5 CONCLUSIONS

5.1 Sensitivity analysis

The sensitivity analysis showed that runoff was sensitive to changes in 10 parameters and soil loss in 9, of the 22 parameters included. Of these, some (for instance *S_KstrucDecay*, *S_WormLikeLitMetab* and *S_WormLikeLitStruc*; P13, P18 and P19) could maintain the default value in the model and still give acceptable model results.

5.2 Calibration

The model simulated runoff and soil loss amounts in the measuring period (m.p.) that did agree well with observed sums of the total 5-year period and with yearly values (good agreement in 4 years out of 5, except for soil loss in the *TepAl*-treatment) (Figure 4.2 and 4.5). Simulated runoff and soil loss peaks (maximum events) were generally much greater than measured peaks, but fewer. When simulating upland rice, runoff seemed to be extra responsive to rain falling after the slash-and-burn-management but before the crop was sown. Soil loss responded almost exclusively to these runoff events and not to big runoff events within the cropping season. Uncovered soil and weed seemed to overestimate the generation of soil loss. When simulating upland rice with hedgerows of *T. candida*, runoff and soil loss generation were not depending on the slash-and-burn-management at all. Simulating pruning management of the *T. candida*, compared to non-pruning management, seemed to overestimate the soil loss.

Besides the parameters found in the sensitivity analysis to be crucial in the determination of runoff and soil loss, the value of the saturated hydraulic conductivity, K_{sat}, seemed to play an important role to soil loss in particular, like P5, the coefficient of variance of the rain intensity.

5.3 Predictions

Simulating the same types of land use on the adjacent fields 8 and 9, differing in soil properties and slope, gave great differences in the runoff and soil loss output. Runoff and soil loss amounts for field 8 (representing lower soil quality and steeper slope than field 9) were overall twice as large as for field 9. The yield on the other hand, did not vary much between fields.

The hypothesis of this study (section 2.4) showed to be confirmed by some of the model results only. Simulating hedgerows of *Bamboo* generated about the same runoff but less soil loss amounts compared to the cassava monocropping system. Hedgerows of *T. candida* generated lower quantities of runoff than the *Bamboo* system, but instead normally greater quantities of soil loss than both the monocropping and *Bamboo* system. The sum of the cassava yield over the 5-year period was largest in the monocropping system but it did not differ much from the hedgerow systems. Neither did the 5-year sum of the cassava yield differ much between the different hedgerow systems. When varying four properties of field 8 and 9, the sum of runoff seemed to be governed by the infiltration only, the sum of soil loss of slope and infiltration, whilst it appeared like soil texture (content of clay, silt and organic carbon) and K_{sat} alone had little importance.

Increased hedgerow spacing gave increased runoff and soil loss (except for soil loss in the *Bamboo* system). Especially the *T. candida* system showed runoff and soil loss variation affected by the hedgerow spacing, and the soil loss in the shortest spacing (6 m) was much lower than for the other spacings.

At fields with soil texture and K_{sat} similar to field 8, the simulation results indicated a best agroforestry option consisting of *Bamboo* hedgerows, in terms of runoff and soil loss. But at fields with soil texture and K_{sat} similar to field 9, the *T. candida* system of 6 m between hedgerows seemed to be a better option.

5.4 Up-scaling

Up-scaling the output of the model to catchment level or sub-catchment level, showed contradictory results, why the hypothesis (section 2.4) showed to be confirmed in same cases but not in others. The simulated runoff values from the model were much lower than the measured values at catchment and sub-catchment scale, while the simulated soil losses varied and were in some cases much greater than measured values, depending on which parameter set-up that was considered.

When aiming at simulating runoff and soil loss at catchment level or up-scaling runoff and soil loss results to catchment level, an erosion model created for simulating larger areas would be useful as supplement to the WaNulCAS model.

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LIST OF APPENDICES

Appendix A. Sub-catchment areas in the Dong Cao catchment estimated from GIS

Sub-catchment	Area estimation from GIS (ha)	Area estimation from LUSLOF data base (ha)
1	2.6	2.72
2	7.7	7.63
3	9.9	9.95
4	8.4	8.39
Rest of catchment	29.4	29.23
Total area	49.7	49.53

Appendix B. Parameters chosen for sensitivity analysis and their unit, input section, default value and description

No	Parameter name in WaNuLCAS	Unit	Default value	Description
P 1	AF_DeepSubSoil	m	3	Depth of subsoil below layer 4
P 2	AF_DepthGroundWaterTable	m	0	Depth of groundwater below layer 4
P 3	AF_SlopeInit / AF_SlopeSoilHoriz	% / %	0 / 0	Slope of the soil surface / Slope of the soil horizons
P 4	E_EntrailmentCoeffBarePlot	m^2 kg^{-1} (soil) mm^{-1}	0.002	Coefficient (used in the Rose equation) for sediment movement in the absence of vegetative soil cover
P 5	Rain_IntensCoefVar	dimensionless	0.3	Variance coefficient of rain intensity
P 6	Rain_IntensMean	mm h^{-1}	50	Average rain intensity per day
P 7	Rain_IntercDripRt	mm hr^{-1}	10	Water dripping from interception surfaces
P 8	Rain_IntMult	dimensionless	3	Maximum temporary storage of water on interception surfaces
P 9	Rain_MaxIntDripDur	mm hr^{-1}	0.5	Maximum water interception delay before dripping
P 10	Rain_PondFlwRt	mm hr^{-1} per m of zone width	10	Rate of ponding surface water flowing to neighboring zone/plot
P 11	Rain_PondStoreCp	mm	5	Storage capacity of water ponding on surface
P 12	S_KSatVDeepSub	cm day^{-1}	20	K_{sat} below layer 4
P 13	S_KStrucDecay	day^{-1}	0.001	Relative rate of macropore structure decay
P 14	S_RelWormLit*i*	dimensionless	1, 0.6, 0.3, 0.1	Relative impact of soil fauna on K_{sat} increase in every layer
P 15	S_RelWormSurf	dimensionless	1	Relative impact of soil fauna on surface infiltration in every layer
P 16	S_SurfInfiltrDef[Zone]	mm day^{-1}	25	Surface infiltration rate in the absence of soil biological activity
P 17	S_SurfInfiltrInit[Zone]	mm day^{-1}	1000	Surface infiltration rate at start of simulation
P 18	S_WormLikeLitMetab	m^2 kg^{-1}	0.00001	Activity of soil fauna per unit organic input: - in litter metabolic pool
P 19	S_WormLikeLitStruc	m^2 kg^{-1}	0.0000005	- in litter structural pool
P 20	S_WormLikeSOMMetab	m^2 kg^{-1}	0.000001	- in SOM metabolic pool
P 21	S_WormLikeSOMStruc	m^2 kg^{-1}	0.00000005	- in SOM structural pool
P 22	W_ThetaInit*i*]Zone]	ml cm^{-3}	1, 0.9, 0.8, 0.7	Initial volumetric soil water content in every layer and zone

Appendix C:I. Input parameter values in the sensitivity analyses

Parameter name	**Value**
S_SoilStructDyn?	Yes (simulating a dynamic soil structure)
[1]Rain_Data	5 years, 1996-2000
[2]Temp_DailyPotEvap	5 years, 1996-2000
[2]Temp_DailyData	5 years, 1996-2000
[3]Rain_IntensMean	50 mm h^{-1}
[3]Rain_IntensCoefVar	0.3

Parameter name	**Layer**	**Depth (cm)**	**Clay (%)**	**Silt (%)**	**Total C (%)**	**Phosphorus (mg kg^{-1})**
[4]Soil layer	1	0 - 11	49.0	47.0	1.7	24.1
	2	12 - 41	49.3	42.7	1.0	14.2
	3	42 - 83	33.5	55.6	0.2	7.7
	4	84 - 101	52.0	39.0	0.5	7.7

Parameter name	**S_SurfInfiltrInit**	**S_SurfInfiltrDef**
[3]Surface infiltration (mm day^{-1})	1 000	25

Parameter name	**Layer**	**K_{sat}**
[3]K_{sat} (cm day^{-1})	1	110
	2	110
	3	110
	4	110

Parameter name	Value
[4]Plot size	Total – 22 m. Each zone – 5.5 m.
[4]Species cultivated	Rice
[4]Modifications in Crop Library	*Vegetative stage* changed from 70 to 90 days *Generative stage* changed from 50 to 60 days

Parameter name	Year	Date of sowing: Crop	Date of sowing: Tree	Date of pruning	Date of Slash & Burn
[4]Management	1	154	-	-	91
	2	133	-	-	91
	3	143	-	-	91
	4	148	-	-	91
	5	136	-	-	91

Parameter name	Value
Slope	50 %
[3]E_Entrainment	0.002

[1]) Data from both Lam Son and Hoa Binh weather station
[2]) Data from Hoa Binh weather station
[3]) Default value in the model
[4]) Based on Lam Son data (Hoang Fagerström, 2000)

Appendix C:II. Input parameter values in the calibration of the Lam Son site

<table>
<tr><th>Parameter name</th><th>Value</th></tr>
<tr><td>S_SoilStructDyn?</td><td>Yes (simulating a dynamic soil structure)</td></tr>
<tr><td>[1]Rain_Data</td><td>5 years, 1996-2000</td></tr>
<tr><td>[2]Temp_DailyPotEvap</td><td>5 years, 1996-2000</td></tr>
<tr><td>[2]Temp_DailyData</td><td>5 years, 1996-2000</td></tr>
<tr><td>[3]Rain_IntensMean</td><td>29</td></tr>
<tr><td>[3]Rain_IntensCoefVar</td><td>1.2</td></tr>
<tr><td>[4]Soil layer</td><td>
<table>
<tr><th>Layer</th><th>Depth (cm)</th><th>Clay (%)</th><th>Silt (%)</th><th>Total C (%)</th><th>Phosphorus (mg kg^{-1})</th></tr>
<tr><td>1</td><td>0 - 11</td><td>49.0</td><td>47.0</td><td>1.7</td><td>24.1</td></tr>
<tr><td>2</td><td>12 - 41</td><td>49.3</td><td>42.7</td><td>1.0</td><td>14.2</td></tr>
<tr><td>3</td><td>42 - 83</td><td>33.5</td><td>55.6</td><td>0.2</td><td>7.7</td></tr>
<tr><td>4</td><td>84 - 101</td><td>52.0</td><td>39.0</td><td>0.5</td><td>7.7</td></tr>
</table>
</td></tr>
<tr><td>[5]Surface infiltration (mm day^{-1})</td><td>
<table>
<tr><th>S_SurfInfiltrInit</th><th>S_SurfInfiltrDef</th></tr>
<tr><td>11700</td><td>4560</td></tr>
</table>
</td></tr>
<tr><td>[5]K_{sat} (cm day^{-1})</td><td>
<table>
<tr><th>Layer</th><th>K_{sat}</th></tr>
<tr><td>1</td><td>1203</td></tr>
<tr><td>2</td><td>2240</td></tr>
<tr><td>3</td><td>2868</td></tr>
<tr><td>4</td><td>2178</td></tr>
</table>
</td></tr>
<tr><td>[4]Plot size</td><td>Mono: Total – 22 m. Each zone – 5.5 m.
TepAl: Total – 22 m. Zone 1 and 4: 2.25 m, zone 2 and 3: 8.75 m</td></tr>
<tr><td>[4]Species cultivated</td><td>Mono: only rice
TepAl: rice with hedgerows of Tephrosia candida</td></tr>
<tr><td>Modifications in Crop Library</td><td>Vegetative stage changed from 70 to 90 days
Generative stage changed from 50 to 60 days
Crop cover efficiently factor changed from 0.5 to 0.25
Cq_SLA for rice reduced by half</td></tr>
<tr><td>[5]Weed specie</td><td>Co chi</td></tr>
<tr><td>Tree density</td><td>20 000 / ha</td></tr>
<tr><td>[4]Management</td><td>
<table>
<tr><td rowspan="2">Year</td><td colspan="2">Date of sowing</td><td rowspan="2">Date of pruning</td><td rowspan="2">Date of Slash & Burn (TepAl: not zone 1&4)</td></tr>
<tr><td>Crop</td><td>Tree</td></tr>
<tr><td>1</td><td>154</td><td>103</td><td>234</td><td>91</td></tr>
<tr><td>2</td><td>133</td><td>-</td><td>132, 217</td><td>91</td></tr>
<tr><td>3</td><td>143</td><td>-</td><td>142, 232</td><td>91</td></tr>
<tr><td>4</td><td>148</td><td>-</td><td>232</td><td>91</td></tr>
<tr><td>5</td><td>136</td><td>-</td><td>232</td><td>91</td></tr>
</table>
</td></tr>
<tr><td>Pruning fraction (in TepAl)</td><td>0.1</td></tr>
<tr><td>[4]Slope</td><td>40 %</td></tr>
<tr><td>E_Entrainment</td><td>0.03</td></tr>
</table>

[1]) Data from both Lam Son and Hoa Binh weather station
[2]) Data from Hoa Binh weather station
[3]) Based on daily rain intensity from Dong Cao 2002 (IWMI/MSEC, 2002)
[4]) Based on Lam Son data (Hoang Fagerström, 2000)
[5]) Based on Dong Cao data (Olsson and Schwan, 2003)

Appendix C:III. Input parameter values in the predictions for field 8 and 9 in the Dong Cao site

Parameter name	Value
S_SoilStructDyn?	Yes (simulating a dynamic soil structure)
[1]Rain_Data	Year 2000 from Hoa Binh, run for 5 years
[1]Temp_DailyPotEvap	Year 2000 from Hoa Binh, run for 5 years
[1]Temp_DailyData	Year 2000 from Hoa Binh, run for 5 years
[2]Rain_IntensMean	29
[2]Rain_IntensCoefVar	1.2

Parameter name	Layer	Depth (cm)	Clay (%)	Silt (%)	Total C (%)	[4]Phosphorus (mg kg^{-1})
[3]Soil layer, field 8	1	0 – 17	17.4	37.4	1.86	24.1
	2	17 – 43	21	34.4	1.27	14.2
	3	43 – 72	26.2	36.4	0.27	7.7
	4	72 – 100	27	39.8	0.54	7.7

Parameter name	Layer	Depth (cm)	Clay (%)	Silt (%)	Total C (%)	5Phosphorus (mg kg^{-1})
[3]Soil layer, field 9	1	0 – 10	20.4	30	2.54	24.1
	2	10 – 35	32.2	36.8	1.19	14.2
	3	35 – 80	30.2	38.8	1.5	7.7
	4	80 – 120	34.8	37.8	0.91	7.7

Parameter name	S_SurfInfiltrInit	S_SurfInfiltrDef
[3]Surface infiltration (mm day^{-1})	Varying between 8 500, 16 990 and 100 220	4560

Parameter name	Layer	Field 8	Field 9
[3]K_{sat} field 8 and 9 (cm day^{-1})	1	5834	9426
	2	4112	12248
	3	1912	11368
	4	2719	13017

Parameter name	Value
Plot size	See section 3.8.5.
Species cultivated	1. Cassava 2. Cassava with hedgerows of Tephrosia candida 3. Cassava with hedgerows of Bamboo
Weed specie	Co chi
Tree density	10 000 / ha

Parameter name	Year	Date of sowing: Crop	Date of sowing: Tree	Date of pruning	Date of Slash & Burn (TepAl: not zone 1&4)
Management	1	66	91	182	60
	2	66	-	182	60
	3	66	-	182	60
	4	66	-	182	60
	5	66	-	182	60

Parameter name	Value
Pruning fraction	0.1
[3]Slope	Varying between 30, 50 and 70 %
E_Entrainment	0.03

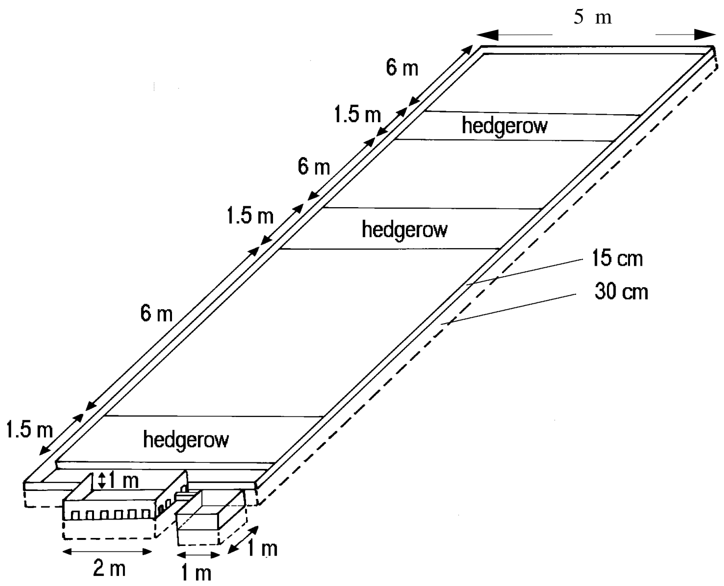
[1]) From Hoa Binh weather station
[2]) Based on daily rain intensity from Dong Cao 2002 (IWMI/MSEC, 2002) [3]) Based on Dong Cao data (Olsson and Schwan, 2003) [4]) Based on Lam Son data (Hoang Fagerström, 2000)

Appendix D. Lam Son experimental plots

The site was divided in 3 blocks, due to different use of the land two years before installation of the experiment. Two blocks had been occupied by maize and upland rice while one block had been under natural fallow. The experimental set up consisted of five different treatments (see table). Each treatment was represented in one plot in every block. Each plot was 5.0 × 22.5 m (see figure). Two tanks were installed downhill each plot, to collect runoff water and eroded soil (Hoang Fagerström, 2000).

Experimental set-up at the Lam Son-site

No	Abbreviation	Treatment
1	Mono	Monocropping upland rice
2	NaFa	Rotation of fallow with natural vegetation 2 years, followed by rice 2 years
3	TepFa	Rotation of fallow with *Tephrosia candida* 2 years, followed by rice 2 years
4	TepAl	Rice with hedgerows of *Tephrosia candida*
5	TepMu	Rice with mulching from *Tephrosia candida* from an outside plot



The design of the experimental plots in Lam Son site (the hedgerows applied only in the *TepAl*-treatment) (from Hoang Fagerström, 2000).

Appendix E. Species description

Upland rice (*Oryza sativa*)
Rice is cultivated primarily for the grain, which is an important diet in many countries, especially in Asia where also more than 90% of the world rice production takes place. Rice is a tropical, subtropical and warm temperate crop, which likes full sun, soil of fine texture and needs 4 to 6 months between planting and harvest. It is an erect annual grass, about 1.2 m tall. Many thousands of rice species are known. Upland rice is usually grown on terraced hillsides while lowland rice is irrigated and grown in flooded beds. Continuous rice cultivation depletes soil nutrition and lowers yield (PU, 2004, internet).

Tephrosia candida (Roxb.) DC
T. candida is native to the tropical foothills of the Himalayas in India and is cultivated and naturalized throughout South-East Asia. It is grown on sandy soils and on very poor eroded upland soils, such as steep slopes, where few other crops can grow. It is grown for many purposes, among others because it rehabilitates degraded land and controls erosion. It provides green manure and fuel wood and is sometimes used for crop shade and hedges along contours. *T. candida* is an herb, shrub or small tree with straggling branches from the base up to 3.5 m tall. It is deep rooting and has the ability to fix large amounts of atmospheric nitrogen. It is slow to establish but grows steadily thereafter. Maximum growth normally takes place in the second year after planting, but with regular pruning a dense cover can be maintained for many years. In Vietnam, flowering takes place from August to September (Hanum and van der Maesen, 1997).

Bamboo
Bamboo species are widely distributed and planted by many farmers in the South East Asia. Over 1250 species of bamboo have been identified. Most bamboo species are fast growing and produce large amount of biomass. The bamboos are used for building materials, animal fodder and vegetables. Bamboo can grow on marginal land not suitable for crop production. Young plants perform best under condition with partially shading the first two years after plantation. The site should be moist and well drained, so valleys and lower slopes are good positions. When intercropping bamboo with agricultural crops, the need of weed control is minimize. Shade intolerant crop species can be cultivated with bamboo 2-4 years, before the canopy of bamboo become too dense (BFRI Technologies, 2000).

Cassava (Manihot esculenta Crantz) - also called Yoca, Tapioca and Manioc
Cassava is a perennial woody shrub, grown as an annual, with an edible, starch-filled root. Cassava grows in tropical and subtropical areas and is the major source of low cost carbohydrates for populations in the humid tropics (PU, 2004, internet). Cassava has the ability to grow on marginal lands, where cereals and other crops do not grow well; it tolerates draught and low-nutrient soil. Roots can be harvested between 6 months and 3 years after planting (IITA, 2004, internet), but as the roots age they become woody and inedible. The roots are used in industry, for human consumption (prepared much like potatoes or as flour) or for animal feed (PU, 2004, internet). In some places, the leaves are also consumed as a green vegetable containing protein and vitamins A and B. In 2000, 172 million tonnes of cassava was produced and the average yield was 10.2 tonnes per hectare (IITA, 2004, internet).

Appendix F. Rainfall intensity in Dong Cao, 2002 (from IWMI/MSEC, 2002)

	Rainfall intensity* in 2002											
month	1	2	3	4	5	6	7	8	9	10	11	12
Day												
1	0	5	0	0	15	0	10	0	0	0	0	0
2	0	0	0	0	0	20	0	0	0	0	0	5
3	0	0	0	30	0	5	0	0	60	0	0	0
4	0	5	0	5	0	0	0	0	0	125	0	0
5	0	0	10	5	0	0	35	0	0	65		0
6	0	0	0	0	0	120	10	0	0	0		0
7	0	0	0	0	60	0	105	0	25	0		0
8	0	0	0	0	45	0	10	50	0	0		0
9	0	0	0	0	35	0	0	80		0		0
10	0	10	0	5	15	25	0	5	0	0	0	0
11	5	0	0	5	5	70	0	30	0	0	0	0
12	120	0	0	0	0	5	55	0	5	0	0	0
13	0	0	0	0	0	0	0	0	5	0	0	0
14	0	5	5	0	35	10	5	0	0	0	0	0
15	0	0	0	0	0	75	0	5	5	0	0	0
16	0	0	0	0	65	0	40	10	0	0	0	0
17	0	0	5	25	15	130	0	0	10	0	0	0
18	0	0	0	5	90	5	0	0	35	0	0	0
19	0	0	5	0	120	105	0	0	15	0	0	0
20	0	5	0	0	0	0	5	0	80	0	0	0
21	0	0	5	0	0	0	5	30	25	0	0	0
22	0	0	5	0	0	0	0	5	25	0	0	0
23	0	0	5	0	5	15	0	30	0	0	0	0
24	0	0	5	0	35	0	0	0	0	0	0	0
25	0	0	5	15	0	40	5	0	0	0	0	10
26	45	10	0	0	0	90	5	0	0	0	0	10
27	0	0	0	0	0	10	0	25	0	0	0	0
28	0	0	0	0	0	0	5	5	0	0	0	0
29	0		5	0	25	0	55	90	0	20	5	5
30	0		15	0	65	40	15	0	5	0	0	0
31	0		5		0		0	0		0		0

* event average, mm hr^{-1}

Appendix G. Original data of soil texture, surface infiltration and saturated hydraulic conductivity modified to model input

G:I) Modifications of soil texture

Input data of soil texture (content of clay, silt and organic carbon) was based on field data (Table G.1). Weighted averages (Table G.2) for WaNuLCAS layer 2 and 3 were calculated as

$$t_{in\_n} = \frac{\left(t_{obs\_n} \times d_{obs\_n}\right) + \left(t_{obs\_n+1} \times d_{obs\_n+1}\right)}{d_{obs\_n} + d_{obs\_n+1}}$$ where t_{in_n} = input texture for WaNuLCAS layer n,

t_{obs_n} = observed texture for layer n, d_{obs_n} = observed depth of layer n.

Table G.1. Original data of layer depth and soil texture in the Lam Son site (from Hoang Fagerström (2000))

Layer	Depth (cm)	cm layer^{-1}	Clay (%)	Silt (%)	Total C (%)	WaNuLCAS layer
1	0 - 12	11	49	47	1.7	1
2	12 - 29	17	48	47	1.2	2
3	29 - 42	13	51	37	0.7	
4	42 - 55	13	48	39	0.5	3
5	55 - 84	29	27	63	0.1	
6	84 - 102	18	52	39	0.5	4

Table G.2. Modified data of layer depth and texture as input in the calibration of the Lam Son site

WaNuLCAS layer	Depth (cm)	cm layer^{-1}	Clay (%)	Silt (%)	Total C (%)
1	0 - 12	11	49.0	47.0	1.7
2	12 - 42	30	49.3	42.7	1.0
3	42 - 84	42	33.5	55.6	0.2
4	84 - 102	18	52.0	39.0	0.5

G:II) Modifications of infiltration

Both values of *S_SurfInfiltrDef* (infiltration rate of the soil surface in the absence of soil biological activity) and *S_SurfInfiltrInit* (infiltration rate of the soil surface at the start of the simulation) were estimated from measurements of K_{fsi}, field saturated infiltration, made by Olsson and Schwan (2003). Biological activity occurring as roots was found in every examined field. To estimate a value of *S_SurfInfiltrDef*, the criteria of "the absence of soil biological activity" was here defined as the appearance of few other biological features, i.e. few or no signs of termites, ants or earthworms (e.g. nests, excrements and channels). Only two soil profiles were defined as representative for the *S_SurfInfiltrDef*. For the value of *S_SurfInfiltrInit*, all values of surface infiltration were included in the calculation of an average of initial surface infiltration as input for WaNuLCAS.

Table G.3. Original infiltration rates (from Olsson and Schwan (2003)) and calculated infiltration rates, for *S_SurfInfiltrDef* and *S_SurfInfiltrInit* as input for WaNuLCAS

Original K_{fsi} (cm day^{-1}) for Field no:									Average (mm day^{-1})	Input for WaNuLCAS (mm day^{-1})
1	2	3	4	5	6	8	9	10		
24	869 496	1434	935 1412	1741[1]	83[1]	753 1699	10022 6053	4867	9120[1] 23400[2]	4560[1] 11700[2]

[1] Used for *S_SurfInfiltrDef*
[2] Used for *S_SurfInfiltrInit*
Two values exist when two measurements were made in the field

G:III) Modifications of K_{sat}

In the calculations of average values of K_{sat} to be used in the simulations for the Lam Son site, the values of field 8, 9 and 10 fell out by mistake (Table G.4) and it was not discovered before the simulations and analysis were made. Nevertheless, a test run with the actual K_{sat} of the layers as input (Table G.5) showed no crucial difference in the result, why the old results were considered as acceptable for the analysis relevance. (Only 50% of the magnitude of the average values was used as input, see section 3.7.5.)

Table G.4. Original K_{sat} (from Olsson and Schwan (2003)) and calculated K_{sat}, as input for WaNuLCAS

Layer	Original K_{sat} (cm day^{-1}) for field						Average (cm day^{-1})	Input (cm day^{-1})
	1	2	3	4	5	6		
1	277*	1575	4845	2426	2316	2000	2407	1203
2	684*	3818	9580	2245*	6376	4177	4480	2240
3	1620*	8810	12248	1540*	5643	4551	5735	2868
4	1600	7337	9910	1754*	4177	1355	4356	2178

* Measured value.
No sign means estimated value from macroporosity (see section 3.7.5)

Table G.5. Original K_{sat} of field 8-10 (from Olsson and Schwan (2003)) and the actual average with all K_{sat} values included

Layer	Original K_{sat} (cm day^{-1}) for field			Average, including all fields in Table F.4 and F.5 (cm day^{-1})	Actual input (cm day^{-1})
	8	**9**	**10**		
1	5834	9426	9352	4228	2114
2	4112	12248	16316	6617	3309
3	1912	11368	16316	7112	3556
4	2719	13017	12834	6078	3039

G:IV) Phosphorus input data

Initial phosphorus (P) supply in all zones and layers are possible to enter in WaNuLCAS and the model converts it into P-mobile units. As for the soil texture, data of soil nutrient status at the beginning of the experiment, in April 1996, were available in Hoang Fagerström (2000). The values of inorganic bicarbonate extractable P (Bicarb-Pi) and organic bicarbonate extractable P (Bicarb-Po) were assumed to be identical with the initial P supply required in the model. However, the data were only given to a depth of 20 cm, why some assumptions were made to obtain a value for every WaNuLCAS-layer.

An average of the sum of Bicarb-Pi and Bicarb-Po in the first and second 5 cm of the topsoil in the soil profile was assumed to be representative for the soil layer 1 in the model. Further, the relationship between the available P of different layers in the default values was assumed to be valid also for the current study. The calculated value of 24.1 mg available P kg^{-1} in layer 1 was thus used as a starting point to receive the values in the sublayers (Table G.6).

To obtain additional data for the calculations of phosphorus, a soil type was chosen from an existed database in WaNuLCAS. After recommendations by Khasanah (2004), the soil type number 13, *Sepunggur*, was used since it was regarded as most similar to the soil of the study sites.

Table G.6. Modifications in original data of phosphorus (adapted from Hoang Fagerström (2000)) to receive input data

WaNuLCAS layer	Default value of phosphorus		Original data	Calculations	Input value of phosphorus (mg kg^{-1})
	mg kg^{-1}	% of topsoil value	Bicarb-Pi + Bicarb-Po (mg kg^{-1})		
1	18.8		0-5 cm: 28.6 5-10 cm: 19.6	$\frac{(28.6*5)+(19.6*5)}{(5+5)}$	**24.1**
2	11	59		(**24.1***0.59)	14.2
3	6	32		(**24.1***0.32)	7.7
4	6	32		(**24.1***0.32)	7.7

Appendix H. Modifications to data of rainfall, runoff and soil loss measurements from Lam Son

In some occasions, the daily rainfall data showed no rainfall although there was a measured runoff and/or soil loss that day according to measuring dates in Brodd and Osanius (2002). For that reason, modifications were made in both the rainfall data and the observed runoff and soil loss data as:

(1) in cases where the daily rainfall data had a similar amount of rainfall as the event rainfall data mentioned in Brodd and Osanius (2002) but one day before the runoff and/or soil loss measurement was made, it was assumed that the measurement was made the day after the heavy rainfall and then the date of the measurement was changed, so the runoff and/or soil loss would occur the same day as the heavy rainfall,
(2) in cases where the rainfall of the day before the day of the runoff and/or soil loss measurements was believed to be too small to cause the observed runoff and/or soil loss, it was assumed that the source of the daily rainfall data was incorrect (owing to differences in rainfall in the Lam Son site and the Hoa Binh station or to errors in recording the daily rainfall) and the rainfall for that day was then changed into the value according to the event rainfall in Brodd and Osanius (2002), in order to agree with the day of the runoff and/or soil loss measurements.

Modifications in the daily rainfall data and in the dates of observed runoff and soil loss (D.o.Y = Day of Year)

Year	Changed value				
	(1) Runoff/Soil loss date, D.o.Y.		**(2)** Rainfall amount (mm)		
	Old	New	D.o.Y.	Old	New
1998	231 (Aug 19)	230	151	29.4	60
			153	17.9	60
			178	12.4	70
			182	10.5	60
			183	44.2	55
			196	0.1	45
			209	0	40
			212	22.6	30
			248	3.2	40
			257	30	100
			262	6.9	20
			285	23	60
1999			239	0	38
			251	0	21
2000	177 (June 26)	176			
	193 (July 12)	192			
	194 (July 13)	193			
	234 (Aug 22)	233			

Appendix I:I. Estimating surface runoff in Dong Cao in year 2000

Original discharge (l) for every weir in year 2002 (from IWMI/MSEC, 2003)

	Discharge (l)				
Month	MW	W1	W2	W3	W4
1	14913331	0	0	1965945.6	616032
2	7230988.8	0	0	1296691.2	362880
3	6339772.8	0	0	910656	401760
4	5038848	0	0	725760	388800
5	41863392	24800	523500	2560550.4	4178304
6	94968288	12600	11032500	14463360	19030464
7	54682214	57800	8151700	4095273.6	13758941
8	15853450	0	0	1957910.4	2614118.4
9	14362272	0	0	1565568	4175712
10	86871226	33400	478100	3404246.4	19067530
11	8144064	0	0	1995840	1604448
12	17064086	0	52700	1829347.2	2469484.8

Surface runoff and the runoff percentage of sub-catchment runoff of MW

	MW	W1	W2	W3	W4
Total discharge	367331933	128600	20238500	36771149	68668474
90% of total discharge	330598740	115740	18214650	33094034	61801626
Percentage of runoff in MW	100	0.04	6	10	19

Original monthly discharge ($l\ s^{-1}$) in year 2000 in MW (from IWMI/MSEC, 2003)

Month	No of days	Runoff ($l\ s^{-1}$)	Runoff (l)
1	31	2.4	6428160
2	28	2	4838400
3	31	2	5356800
4	30	4.83	12519360
5	31	5.99	16043616
6	30	13.54	35095680
7	31	24.86	66585024
8	31	9.24	24748416
9	30	16.71	43312320
10	31	16.33	43738272
11	30	9.26	24001920
12	31	4.31	11543904

Surface runoff, calculated from the percentage of sub-catchment runoff of MW in year 2002

	MW	W1	W2	W3	W4
Total discharge	294211872				
90% of total discharge	264790685	93	14589	26506	49500
Area (ha)	49.7	2.6	7.7	9.9	8.4
Runoff ($m^3\ ha^{-1}$)	5 328	36	1 895	2 677	5 893

Appendix I:II. Estimating total soil loss in Dong Cao in year 2000

Soil loss (bed load, suspended load and total) in 1999-2002 in Dong Cao (adapted from Toan *et al.*, 2003a)

	Yearly bed load (tonnes ha^{-1})					Suspended load (tonnes ha^{-1})	Total soil loss in year 2000	
							MW	W4
Year	MW	W1	W2	W3	W4	MW		
1999	0.44	0.93	0.94	0.43	0.35			
2000	0.64	1.23	1.06	0.37	0.49		0.64 + 2.95	0.49 + 2.95
2001	3.96	6.69	5.31	1.59	3.14	2.5		
2002	0.46	1.3	1.93	0.79	0.6	3.4		
					Average	2.95		
	Total soil loss in year 2000 (tonnes ha^{-1})						3.59	3.44
	Total soil loss in year 2000 (tonnes)						178.4	28.9

Appendix J. Result of sensitivity analyses

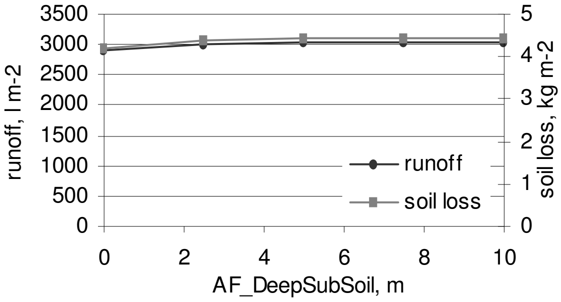


Figure J1. Sensitivity analysis of P1, AF_DeepSubSoil.

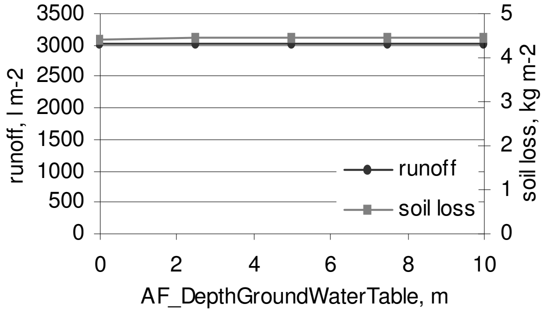


Figure J2. Sensitivity analysis of P2, AF_DepthGroundWaterTable.

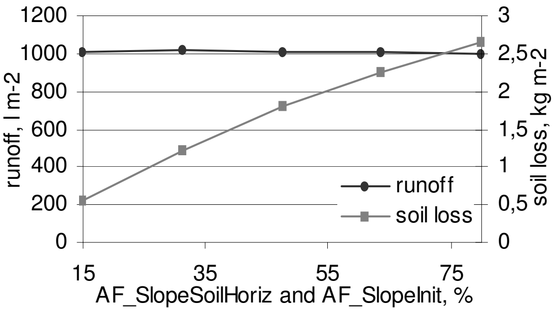


Figure J3. Sensitivity analysis of P3, AF_SlopeSoilHoriz and AF_SlopeInit.

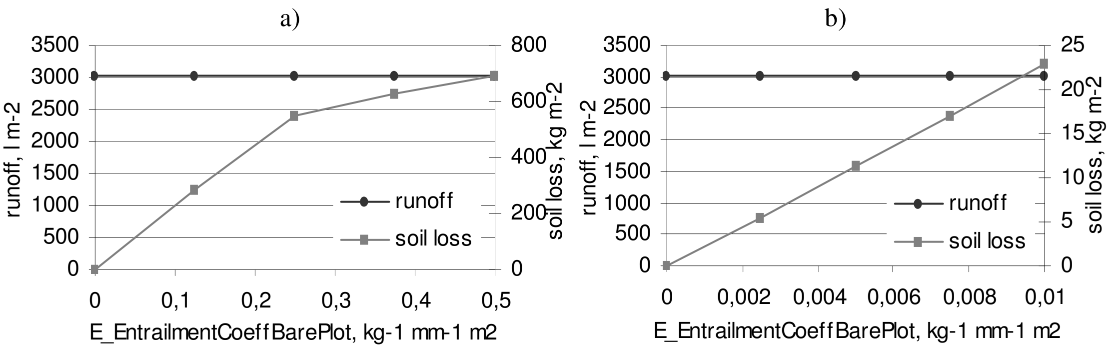


Figure J4a and J4b. Sensitivity analysis, wide (a) and narrow (b) of P4, E_EntrailmentCoeffBarePlot.

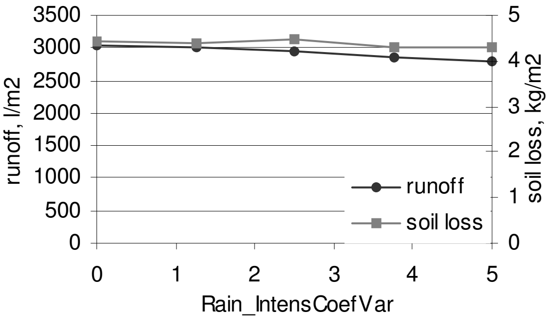


Figure J5. Sensitivity analysis of P5, Rain_IntensCoefVar.

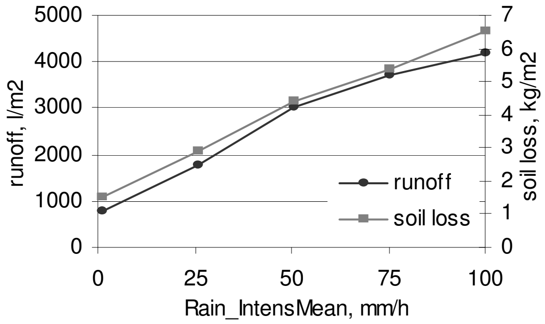
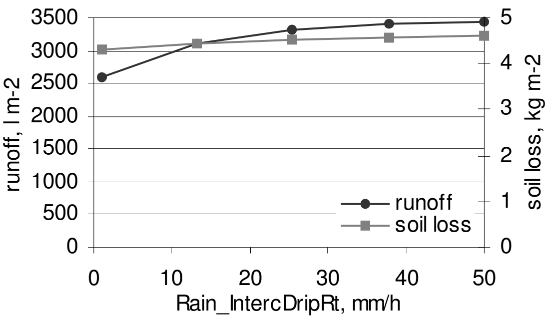


Figure J6. Sensitivity analysis of P6, Rain_IntensMean.

a)



b)

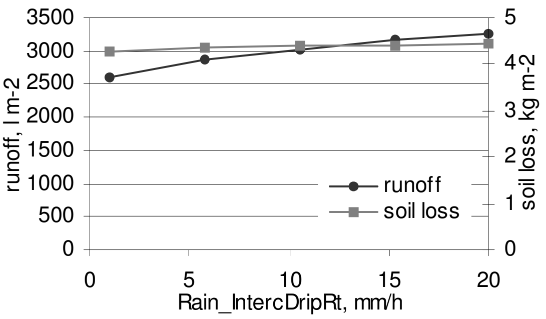


Figure J7a and J7b. Sensitivity analysis, wide (a) and narrow (b) of P7, Rain_IntercDripRt.

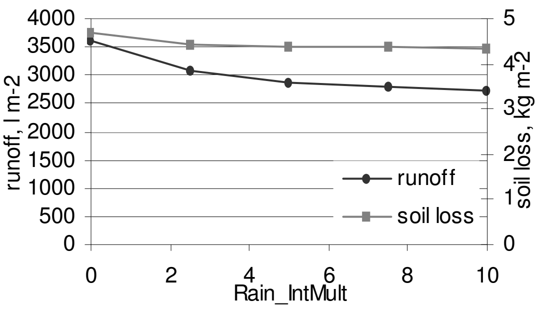


Figure J8. Sensitivity analysis of P8, Rain_IntMult.

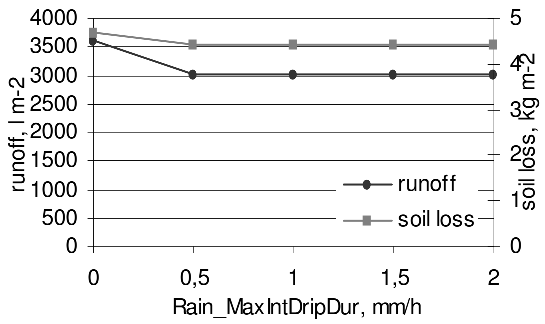
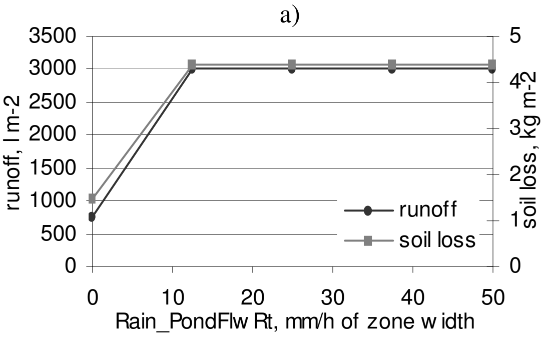


Figure J9. Sensitivity analysis of P9, Rain_MaxIntDripDur.

a)



b)

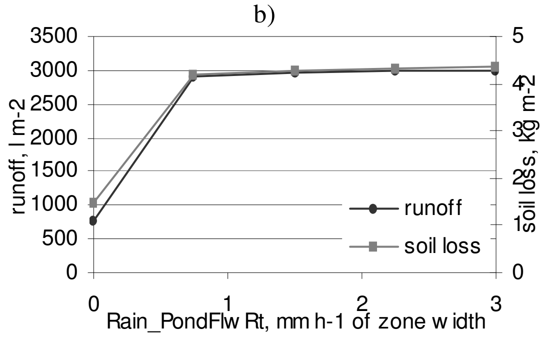


Figure J10a and J10b. Sensitivity analysis, wide (a) and narrow (b) of P10, Rain_PondFlwRt.

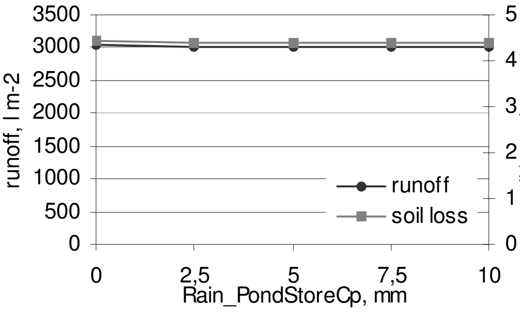


Figure J11. Sensitivity analysis of P11, Rain_PondStoreCp.

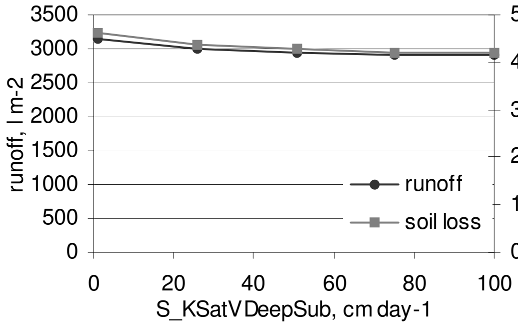
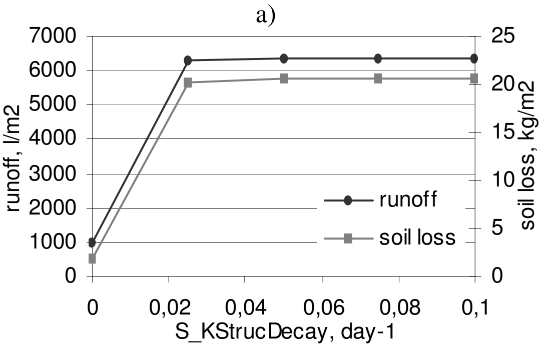


Figure J12. Sensitivity analysis of P12, S_KSatVDeepSub.

a)



b)

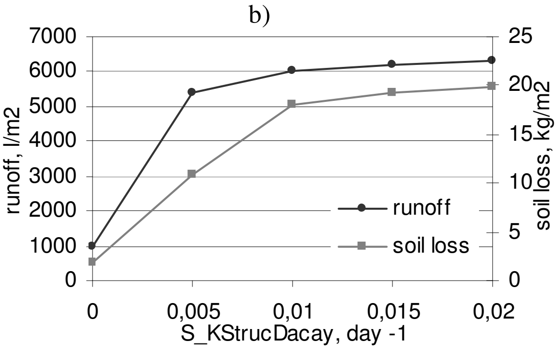


Figure J13a and J13b. Sensitivity analysis, wide (a) and narrow (b) of P13, S_KStrucDecay.

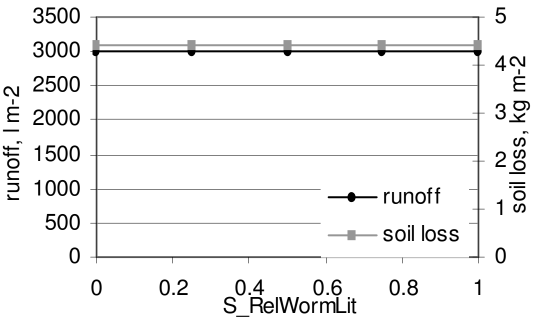


Figure J14. Sensitivity analysis of P14, S_RelWormLit.

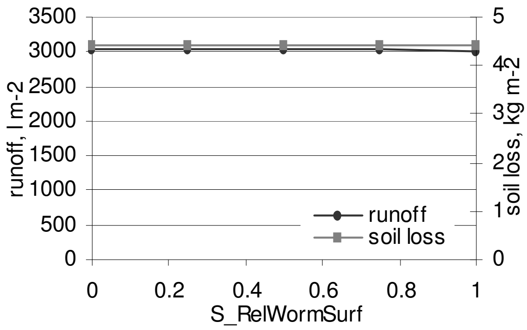
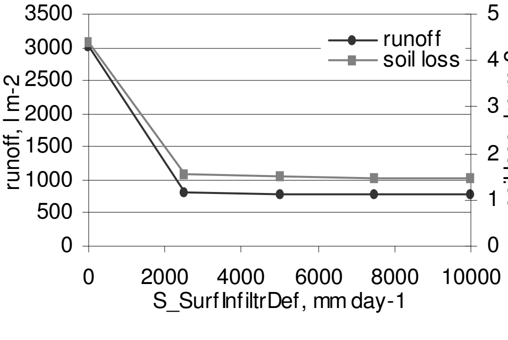


Figure J15. Sensitivity analysis of P15, S_RelWormSurf.

a)



b)

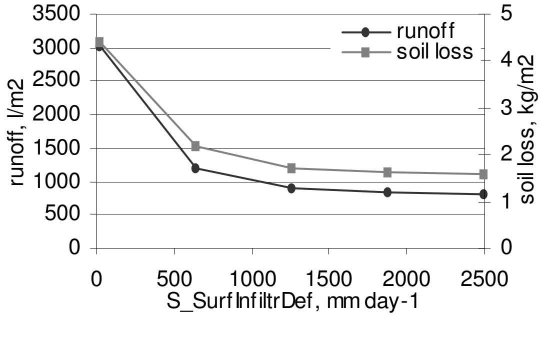


Figure J16a and J16b. Sensitivity analysis, wide (a) and narrow (b) of P16, S_SurfInfiltrDef.

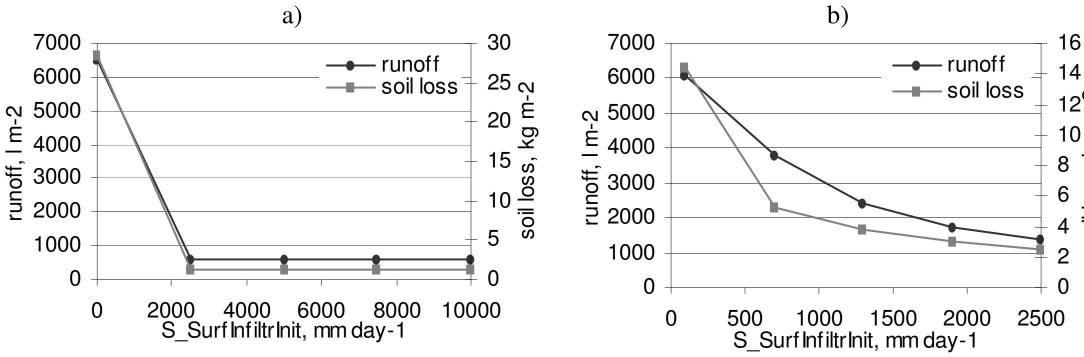


Figure J17a and J17b. Sensitivity analysis, wide (a) and narrow (b) of P17, S_SurfInfiltrInit.

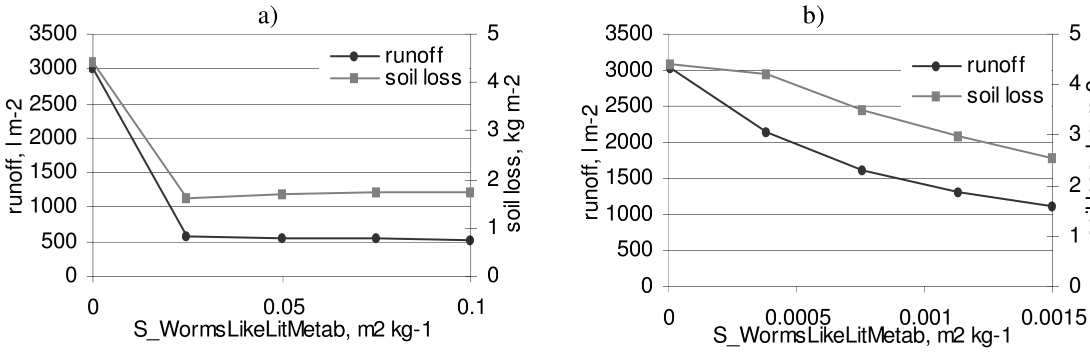


Figure J18a and J18b. Sensitivity analysis, wide (a) and narrow (b) of P18, S_WormLikeLitMetab.

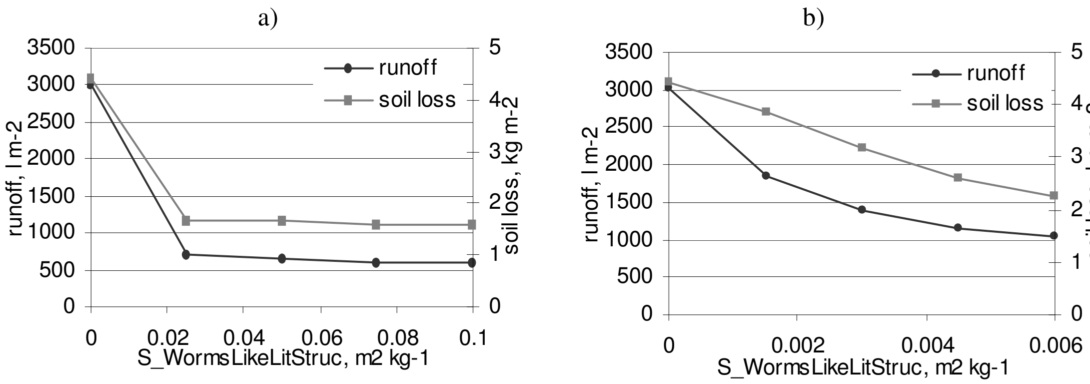


Figure J19a and J19b. Sensitivity analysis, wide (a) and narrow (b) of P19, S_WormLikeLitMetab.

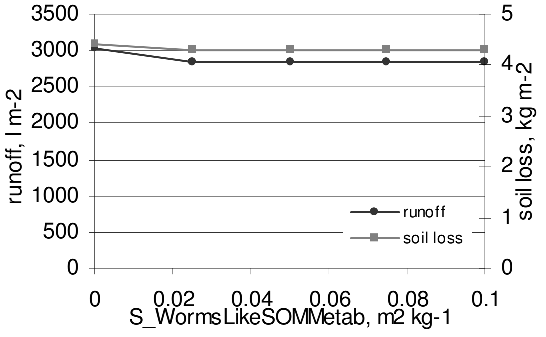


Figure J20. Sensitivity analysis of P20, S_WormLikeSOMMetab.

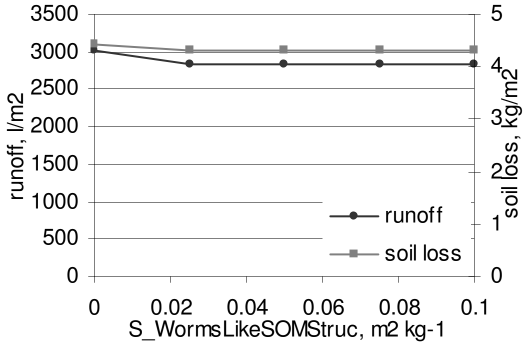


Figure J21. Sensitivity analysis of, P21, S_WormLikeSOMStruc.

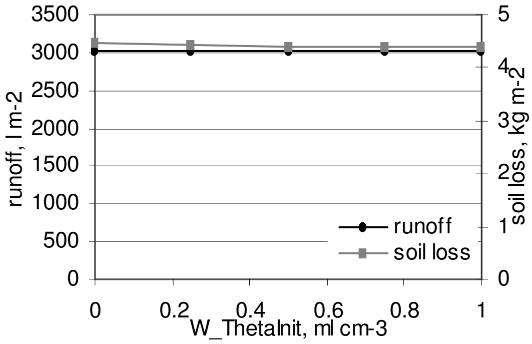


Figure J22. Sensitivity analysis of P22, W_ThetaInit.

Appendix K. Varying uncertain parameter values

Some of the input data used could be regarded as overestimated and were believed to contribute to the uneven temporal distribution of soil loss. Hence, other values of the coefficient of variance and mean, parameters P5 and P6, surface infiltration, parameters P16 and P17, and K_{sat} were investigated. Decreasing P6 by 50% (to 15 mm h^{-1}) did not affect the sums of runoff or soil loss much (see table). In contrast, reducing P5 by 50% (to 0.6) had great impact on runoff and soil loss. The total sums of runoff and soil loss were reduced by 70% and 75%, respectively.

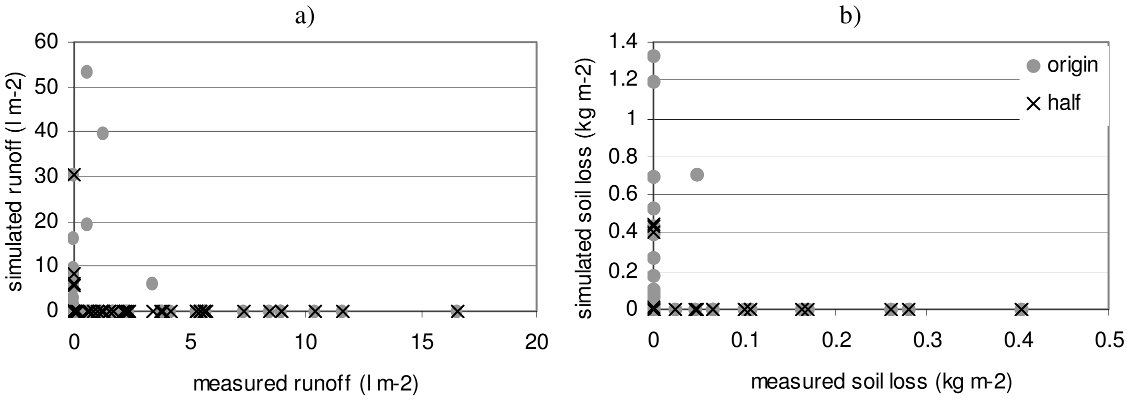
The input data of surface infiltration, P16 and P17, and of K_{sat} were based on the average of measured values, but reduced to 50%, according to section 3.7.5. However, the input values were still considered as high compared to the default values in the model, why even lower rates were tested in the calibration. Reducing P17, the initial surface infiltration rate, again by 50% (to 5850 mm h^{-1}) caused only a little increase in the amount of both runoff and soil loss (see table). Similarly, decreasing P16, the default infiltration rate, by 50% (to 2280 mm h^{-1}) did not change the result much. Decreasing the K_{sat} by 50% (to 602, 1120, 1434 and 1089 cm day^{-1} for soil layer 1 - 4 respectively) resulted in larger changes of runoff and soil loss than the infiltration parameters changes. Especially the soil loss increased notably, by almost the double of the total sum (see table).

Correlations of the simulated and observed runoff and soil loss events were made with the result from the new parameter values, but only the result of P5 showed some difference from the correlations with origin input values. The great difference in soil loss with new values of K_{sat} is therefore assumed to occur in the two first years, which were not represented in the correlations. The new parameter value of P5 did not make the simulated and measured events to match more often, but some of the highly overestimated simulated values became reduced (see figure). The new results of sums and correlations did not motivate a change in these parameter values, why the origin input values were maintained in the following modelling work.

The results in runoff and soil loss of reducing P5, P6, P17, P18 and K_{sat} compared to origin input values

	Origin input values	Reduced P6	Reduced P5	Reduced P17	Reduced P16	Reduced K_{sat}
Runoff (l m^{-2})	457 *(552)*	442 *(534)*	151 *(179)*	526 *(650)*	490 *(592)*	564 *(791)*
Soil loss (kg m^{-2})	6.12 *(12.35)*	5.97 *(11.99)*	1.26 *(3.2)*	6.68 *(14.22)*	6.52 *(13.13)*	6.32 *(21.93)*

Numbers in brackets show simulated sums for the total time period



Measured runoff vs simulated runoff (a) and measured soil loss vs simulated soil loss (b), year 1998-2000, when the value of P5 was reduced by 50%.

Appendix L:I. Simulations with soil texture and K_{sat} according to field 8, varying slope and infiltration

Simulation results of cassava monocropping

	Runoff (l m^{-2})			Soil loss (kg m^{-2})			Cassava yield (kg m^{-2})		
	Slope (%)			*Slope (%)*			*Slope (%)*		
Infiltration (mm day^{-1})	*30*	*50*	*70*	*30*	*50*	*70*	*30*	*50*	*70*
8500	420.05	424.76	427.35	10.07	16.04	20.87	1.43	1.43	1.42
16990	366.4	372.06	375.06	8.42	13.54	17.7	1.46	1.45	1.44
100220	186.41	196.97	203.33	2.59	4.55	6.3	1.49	1.48	1.48

Simulation result of the *T. candida*-system

Hedgerow spacing	6 m			20 m			30 m		
	Slope [%]			*Slope [%]*			*Slope [%]*		
	30	*50*	*70*	*30*	*50*	*70*	*30*	*50*	*70*
infiltration [mm day^{-1}]				**a) Runoff (l m^{-2})**					
8500	275.08	285.12	287.02	329.17	336.04	340.19	345.94	351.91	355.78
16990	218.85	231.81	234.78	272.79	280.98	283.85	283.41	289.46	292.61
100220	51.08	62.52	70.75	109.98	124.73	131.62	143.24	153.9	158.3
				b) Soil loss (kg m^{-2})					
8500	7.04	11.04	14.31	13.61	22.45	29.45	16.95	27.27	46.03
16990	4.34	7.44	9.69	12.65	21.87	27.62	16.37	26.62	35.14
100220	0.2	1.18	2.03	7.79	15.74	21.43	13.62	20.81	27.57
				c) Cassava yield (kg m^{-2})					
8500	1.05	1.07	1.09	1.16	1.15	1.15	1.15	1.14	1.13
16990	1.06	1.07	1.09	1.17	1.16	1.15	1.15	1.14	1.14
100220	1.09	1.1	1.12	1.2	1.19	1.18	1.18	1.17	1.16

Simulation result of the *Bamboo*-system

Hedgerow spacing	20 m			30 m			40 m		
	Slope [%]			*Slope [%]*			*Slope [%]*		
	30	*50*	*70*	*30*	*50*	*70*	*30*	*50*	*70*
infiltration [mm day^{-1}]				**a) Runoff (l m^{-2})**					
8500	366.69	374.66	378.48	397.54	404.67	409.13	399.26	404.77	408.26
16990	310.9	319.92	324.7	332.79	341.54	345.81	335.71	342.16	345.7
100220	142.05	158.8	167.14	180.7	192.16	198.94	184.92	195.59	200.61
				b) Soil loss (kg m^{-2})					
8500	1.15	2.83	3.57	0.22	0.51	0.8	0.25	0.56	0.77
16990	1.07	1.78	3.56	0.08	0.28	0.44	0.12	0.31	0.45
100220	1.13	2.47	2.99	0	0	0	0	0	0
				c) Cassava yield (kg m^{-2})					
8500	1.3	1.29	1.28	1	0.99	0.99	1.01	1	1
16990	1.31	1.3	1.3	1.01	1	0.99	1.02	1.01	1
100220	1.36	1.34	1.33	1.03	1.02	1.02	1.04	1.03	1.02

Shadowed cells represent simulations with slope and infiltration according to field 8

Appendix L:II. Simulations with soil texture and K_{sat} according to field 9, varying slope and infiltration

Simulation results with cassava monocropping

	Runoff ($l\ m^{-2}$)			Soil loss ($kg\ m^{-2}$)			Cassava yield ($kg\ m^{-2}$)		
	Slope (%)			*Slope (%)*			*Slope (%)*		
Infiltration (mm day^{-1})	*30*	*50*	*70*	*30*	*50*	*70*	*30*	*50*	*70*
8500	416.64	420.33	422.09	9.87	15.66	20.37	1.54	1.54	1.54
16990	364.13	369.3	371.72	8.26	13.24	17.29	1.57	1.56	1.56
100220	189.99	199.55	204.7	2.72	4.77	6.54	1.59	1.58	1.58

Simulation result of the *T. candida*-system

Hedgerow spacing	6 m			20 m			30 m		
	Slope [%]			*Slope [%]*			*Slope [%]*		
	30	*50*	*70*	*30*	*50*	*70*	*30*	*50*	*70*
infiltration [mm day^{-1}]				**a) Runoff ($l\ m^{-2}$)**					
8500	272.39	285.46	291.18	324.85	331.21	333.79	340.98	345.68	348.22
16990	216.08	232.33	239.6	268.09	274.95	278.06	278.65	283.64	286.34
100220	49.57	68.31	79.11	89.06	98.93	103.5	119.83	126.53	129.98
				b) Soil loss ($kg\ m^{-2}$)					
8500	5.21	8.51	11.16	6.92	13.73	18.52	9.91	16.27	22.2
16990	3.09	5.76	7.39	6.49	10.06	13.27	8.73	14.02	19.26
100220	0.15	0.97	1.77	5.87	10.81	14.21	8.44	13.3	17.86
				c) Cassava yield ($kg\ m^{-2}$)					
8500	1.07	1.07	1.07	1.19	1.19	1.19	1.19	1.19	1.19
16990	1.07	1.07	1.07	1.2	1.19	1.19	1.2	1.2	1.2
100220	1.09	1.09	1.09	1.21	1.21	1.21	1.21	1.21	1.21

Simulation result of the *Bamboo*-system

Hedgerow spacing	20 m			30 m			40 m		
	Slope [%]			*Slope [%]*			*Slope [%]*		
	30	*50*	*70*	*30*	*50*	*70*	*30*	*50*	*70*
infiltration [mm day^{-1}]					**a) Runoff (l m^{-2})**				
8500	368.91	376.09	379.66	386.39	392.58	396.82	386.95	391.84	394.92
16990	314.83	323.75	328	327.5	334.61	338.1	329.96	335.59	338.4
100220	154.43	168.97	175.28	175.39	186.96	192.05	179.57	188.78	193.45
					b) Soil loss (kg m^{-2})				
8500	0.85	1.28	2.44	0.24	0.54	0.81	0.27	0.55	0.9
16990	0.76	1.16	1.58	0.08	0.29	0.49	0.14	0.32	0.54
100220	0.76	1.75	1.94	0	0	0	0	0	0
					c) Cassava yield (kg m^{-2})				
8500	1.35	1.35	1.34	1.12	1.12	1.11	1.13	1.13	1.12
16990	1.36	1.36	1.36	1.13	1.12	1.12	1.14	1.14	1.13
100220	1.38	1.37	1.37	1.14	1.13	1.13	1.15	1.15	1.14

Shadowed cells represent simulations with slope and infiltration according to field 9

Appendix M. Runoff and soil loss differences due to slope and infiltration - for the hedgerow scenarios showing the best result of soil loss

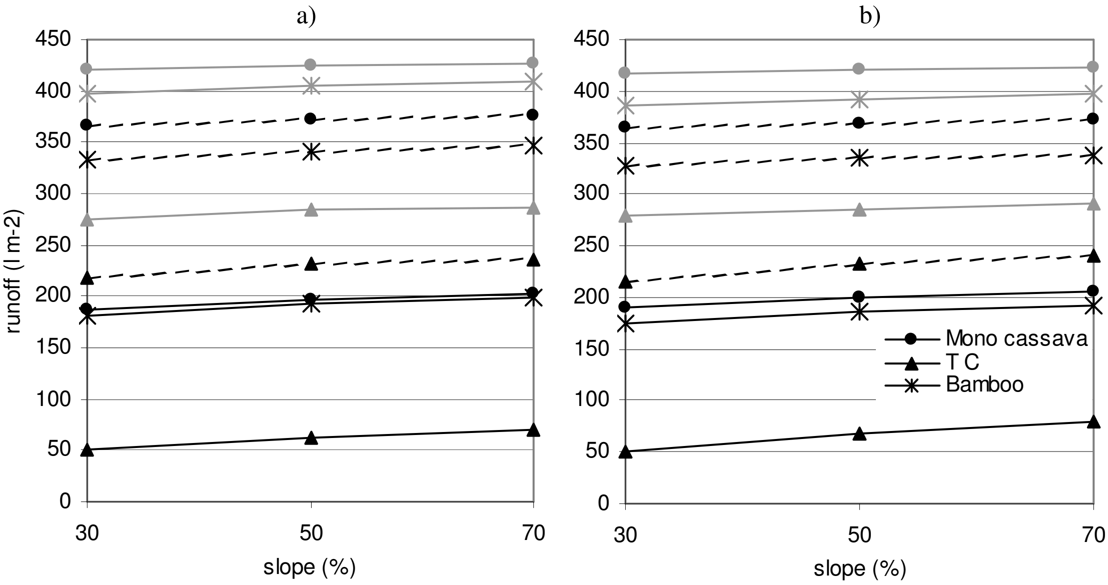


Figure M.1. Runoff for different infiltration rates, varying between slopes, from simulations with texture and K_{sat} according to field 8 (a) and field 9 (b). Grey lines = 8500 mm h^{-1}, black broken lines = 16990 mm h^{-1} and black lines = 100220 mm h^{-1}.

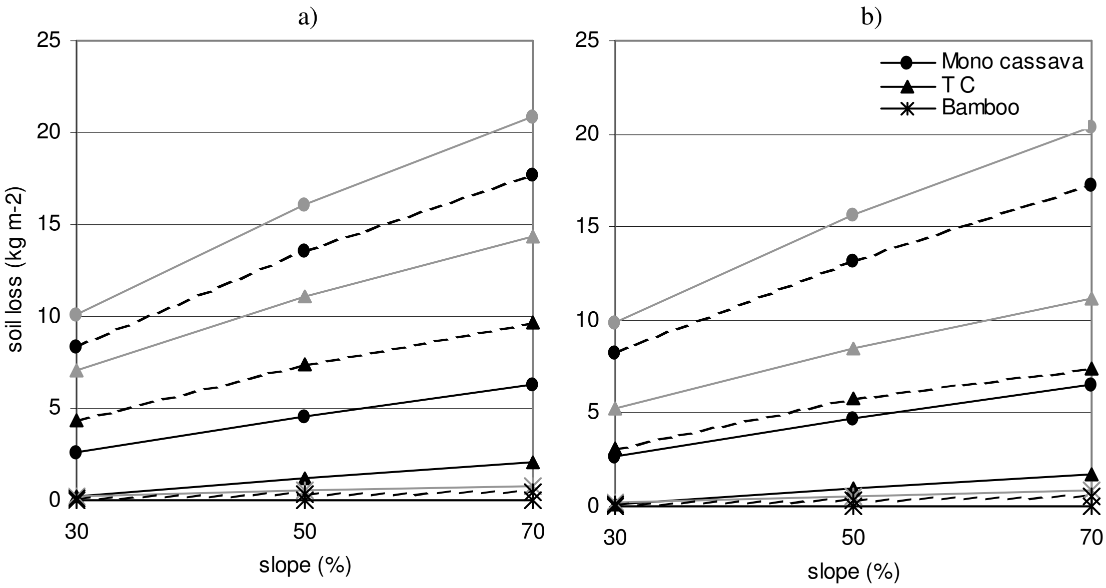


Figure M.2. Soil loss for different infiltration rates, varying between slopes, from simulations with texture and K_{sat} according to field 8 (a) and field 9 (b). Grey lines = 8500 mm h^{-1}, black broken lines = 16990 mm h^{-1} and black lines = 100220 mm h^{-1}.