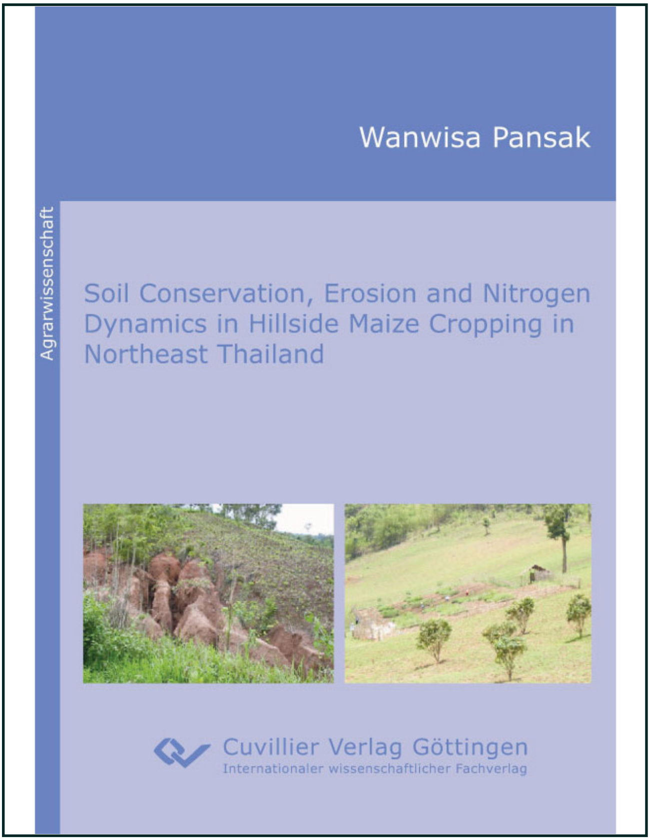
Wanwisa Pansak (Autor)

Soil Conservation, Erosion and Nitrogen Dynamics in Hillside Maize Cropping in Northeast Thailand



https://cuvillier.de/de/shop/publications/1136

CHAPTER 1

General introduction

1. General introduction

Soil is under increasing threat from a wide range of human activities that are undermining its long-term availability and viability. One third of the world's agricultural soil or almost 2 billion hectares of land is affected by soil degradation (Ritsema et al. 2007). Within this area, about 1966 million hectares are affected by erosion (Lal 2007). Soil erosion is a global issue because of its severe adverse economic and environmental impacts. The major on-site impact of erosion is the loss of crop productivity and this is mirrored in reductions of crop yield and water and nutrient use efficiency. In regions of the world with variable rainfall distribution the loss of topsoil increases the vulnerability of human food supplies. Off-site impacts of erosion relate to the economic and ecological costs of sediment, nutrients, or agricultural chemicals being deposited in streams, rivers, and lakes. Adoption of soil management practices to reduce erosion may have profound effects on future world food supplies.

1.1 Erosion effects on soil nutrients and crop productivity

Presently, soil erosion affects more than 300,000 km^2 or 65% of the cultivated land area of Thailand (Kunaporn 1999). Almost 17% of agricultural land in Northeastern Thailand is classified as vulnerable area for soil erosion (Land Development Department 1998). In Northeast Thailand, degradation of agricultural land by water induced erosion causes nutrient depletion, low soil productivity, and an ever lower productivity of important food crops. The eroded areas, however, are still used year by year for subsistence agriculture whereas the matrix lands are intensively utilized for income generation by cash crop production. In addition, shortening of fallow periods caused by a steadily growing population contributes to the low and even decreasing crop production.

Soils differ in their susceptibility to loss of productivity as soon as the topsoil is eroded. The differences are related to the depth of the topsoil and the amount of nutrient fertility or presence of unfavourable conditions in the subsoil. Rose and Dalal (1988) summarized the results of a series of experiments conducted on wheat in semiarid regions of Australia. They observed that wheat yield declined linearly with increasing loss of topsoil plotted on a logarithmic scale. For a soil loss of about 10 Mg ha^{-1} (about 1 mm depth of soil), yield reduction was about 20% for sites with a shallow topsoil. The yield reduction was about 50% corresponding with 100 Mg ha^{-1}, 90% for 1000 Mg ha^{-1}, and total loss for 2000 Mg ha^{-1} of soil loss. The rate of decline was more moderate for soils with medium to deep profiles than for the shallower soils with a texture contrast profile or a saline subsoil. For soils with medium to deep profiles, yield reduction was about 5% for 10 Mg ha^{-1} of soil loss, 15% for 100 Mg ha^{-1}, 20% for 1000 Mg ha^{-1}, and 25% for 2000 Mg ha^{-1}.

Loss of fertility is also a major impact of soil erosion, especially in old and highly weathered soils in which soil organic carbon and plant nutrients are concentrated in the upper few centimeters of the soil profile. Loss of soil fertility is the principal cause of yield decrement on eroded soils (Peterson 1964). Nutrient losses are much severer on arable lands, where supplemental fertilizer application may have a masking effect on crop yields (Cleveland, 1995). Kongkaew (2000) reported that in Northern Thailand, N losses by erosion amounted to 30 kg ha^{-1} per year under farmer practice. However, N losses by erosion were only 20% of the total losses, whereas leaching produced 50-80% of the total N losses. Moreover, Sajjapongse (1995) presented that on slopes of 5-7% at the Bavi site in Vietnam, high losses of plant nutrients were observed on bare soil (26 kg N, 13 kg P, and 38 kg K) and farmer's practice (15 kg N, 10 kg P, and 30 kg P) over two years. In contrast, Fagerström et al. (2002) found in Northern Vietnam erosion induced N losses of up to 150 kg ha^{-1} for upland rice, grown over a period of two years on fields with an average slope of 20-28%. Furthermore, experiments conducted at the International Institute of Tropical Agriculture (IITA) in Nigeria showed that the total nutrient loss (PO_4-P, NO_3-N, Ca, Mg and K) in plow-till treatment was 26.8 kg ha^{-1} for the first season, 2.0 kg ha^{-1} for the second season, and 28.8 kg ha^{-1} for both seasons. In contrast, the annual total nutrient loss for both seasons was 3.7 kg ha^{-1} for no-tillage, 14.9 kg ha^{-1} and 7.7 kg ha^{-1} for Leucaena at hedgerow distances of 4 m and 2 m, and 8.6 kg ha^{-1} and 9.5 kg ha^{-1} for gliricidia at hedgerow distances of 4 m and 2 m, respectively (Lal 1976). Lal (1996) also reported that nutrient losses in runoff were higher from watersheds sown to leguminous cover (*Mucuna utilis*) or grazed pastures than from watersheds cropped to corn-cowpea rotations with no-till system. The maximum annual loss of nutrients in runoff ranged from 13.8 kg ha^{-1} for mucuna fallow on degraded soils, 13.5 kg ha^{-1} for grazed pastures on degraded soils, 8.9 kg ha^{-1} for mucuna fallow on less degraded soils, 4.4 kg ha^{-1} for grazed pastures on less-degraded soils to 3.7 kg ha^{-1} in alley cropping systems. Leucaena hedgerows established on contour lines at 4-m intervals were effective in decreasing runoff, soil erosion, and nutrient loss.

1.2 The role of soil conservation measures in erosion control

Soil conservation measures play an important role in reducing soil erosion on sloping farmlands in hilly areas. Monsalud et al. (1995) reported that the erosion of steep sloped maize and groundnut fields was effectively controlled by introducing hedgerow of gliricidia with napier grass at the Tanay site, Philippines. The annual erosion of hedgerow plots was only 3 t ha^{-1} year^{-1}. Moreover, Paningbatan et al. (1995) found that leguminous shrub hedgerows reduced the annual erosion of maize and mung bean fields from 100 to 200 t ha^{-1} year^{-1} to amounts of less than 5 t ha^{-1} year^{-1}. Similar results were observed in China and Spain where as much as 30 to 80% of runoff water was reduced by introducing hedgerows to the system owing to a prolonged infiltration time due to the hedgerows, and improved soil infiltration rates (Huang et al., 2006; Raya et al., 2006). Additionally, hedgerow systems also had an important role in reducing N losses from aqueous erosion. In Kenya, Owino et al. (2006) proved the effectiveness of narrow grass strips in controlling nutrient loss. Napier grass (*Pennisetum purpureum*) reduced NO^{-}_{3}-N and NH^{+}_{4}-N losses by 45-50%.

In Thailand, suitable soil conservation systems for minimising soil erosion have been proposed by several development agencies for more than twenty years. Among them were planting of Vetiver grass strips and perennial fruit trees on bench terraces, maintaining soil cover by leguminous species, and inter-cropping of perennial trees with annual food crops. Each of these conservation systems was promising but in different areas and ways. The success of soil conservation measures often depended on the physical and socio-economic-limiting factors which are involved in a particular area. Locally well adaptated and promising options were integrating perennial crops such as mango, banana, papaya, pineapple, and fodder grass into cropping of important annual food crops such as maize, upland rice, peanut, and cassava. These options were the most interesting ones in terms of financial returns, land efficiency, effectiveness in soil and water conservation, and crop yields as compared to other soil conservation practices (Anecksamphant 1994; Turkelboom et al. 1996). The safety-net role of perennial plants in cropping systems has been widely discussed since the nineties. Schroth (1995) emphasised the ‘safety net’ function of tree root systems which according to Van Noordwijk et al. (1991) and Rowe et al. (1999) may prevent nutrient losses and improve nutrient cycling. According to nutrients in soils the magnitude of losses was probably minimized by a higher uptake of deeper rooting perennial plants, fertilizer application synchronised with crop demand, and planting of cover crop. Cover crops also play an important role in erosion control and improving soil fertility. Annual cover crops such as local black bean (*Vigna unguiculata*) and lablab bean (*Lablab purpureus*) are able to suppress weeds well (Pintarak et al. 1993). Tillage has to be frequently conducted when there is weed infestation. Then tillage system always resulted in higher soil erosion on hillsides as the bare tilled soil is susceptible to erosive rainfalls. Thus, soil cover provided by cover crops may be a reasonable practice for reducing soil erosion and suppressing weeds because the tillage is minimised. This had been verified by IBSLRAM experiments in Thailand where soil loss was reduced to less than 10 Mg ha^{-1} yr^{-1} by a soil cover of lablab straw (Kongkaew 2000). In terms of yield improvement, planting cover crops improved grain yield of rice by 50 to 70% (Turkelboom and Van Keer 1996).

1.3 The disadvantage of soil conservation measures

To date, however, integrating annual food crops into cropping systems with edible tree species or hedgerow systems have not been widely adopted by farmers because of technical problems and lack of fit with farmers' needs (Bewket 2007; Knowler and Bradshaw 2007). The limiting factors in adoption of contour hedgerow systems consist of: i) fragmented land ownership makes it difficult for farmers to invest optimally in soil and water management systems. ii) extra labour is required for pruning and hedgerow maintenance. iii) many farmers lack in the skills to design and build conservation structures. Substandard and poorly constructed structures are often being the result. iv) land-tenure systems determine the ownership of the structures and influence farmers' interest in conservation and in maintaining the structures. v) irregular rainfall period, event, and intensity reduces the effectiveness of vegetative erosion-control practices (Garrity, 1999). Reduction by 15-25% of cropping area due to additional hedgerow planting and competition between hedgerows and crops is among main farmers' concerns when applying hedgerow systems. Many studies showed that yield in rows adjacent to hedgerows declined due to competition for light, water, and nutrients (Agus et al. 1999; Friday and Fownes 2002; De Costa and Surenthran 2005; Dercon et al. 2006a; Kinama et al. 2007; Pansak et al. 2007). Finally, economic factors play a key role in determining whether farmers will adopt such technology or not. Contour hedgerow systems have the disadvantage of providing only limited early returns on investment (Bayard et al., 2007). Farmers repeatedly complain about the fact that improved yield response only comes several years after hedgerow establishment (Kiepe 1996). Due to limitations mentioned above, farmers are unlikely to adopt contour hedgerow system. Therefore, alternatives, which reduce soil degradation and at the same time meet farmer interests, are required.

On steep slopes, the impact of contour hedgerow systems on soil properties and crop response has been studied in detail over the past decade (Agus et al. 1997; Turkelboom et al. 1997; Dercon et al. 2003). However, although there are enough indications that spatial variability in soil properties and crop response and consequently the effectiveness of contour hedgerow systems are related to soil translocation by tillage and competition between annual crops and hedgerows, research is scanty in separating the impact of both processes, i.e. soil translocation and competition. In order to get better insight in the processes driving competition between crop and hedgerow, carbon isotope composition of the crops grown in the alleys can offer a possible outcome. Dercon et al. (2006b) highlighted the potential use of ^{13}C isotope discrimination in maize to signal water stress at low to high nitrogen availability. This study showed that changes in δ^{13}C values in maize could be related to soil moisture status and nitrogen supply. However, even changes in ^{13}C isotopic discrimination due to nitrogen availability could be indirectly linked to water stress. The relationship between ^{13}C isotopic discrimination and water stress is well documented for C_4 plants. Therefore, the use of ^{13}C isotopic discrimination is a good diagnostic tool useable under field conditions to identify causes of competition between crop and hedges which are imperative to better understand competition leading to a decline in crop response closed to the hedges.

1.4 Erosion modelling

Soil conservation systems are still required to be developed and studied from time to time for meeting farmer needs, but experimental testing for their potential application domain or design is costly and time consuming. In addition to the study at the experimental sites, investigation of field properties by modelling can also play an important role in both meeting practical needs of soil conservation goals and advancing the scientific understanding of soil erosion processes. Since modeling can be done in relatively short developing time compared with the establishment of the field experiment, it could be more suitable for predicting long term effects of soil conservation. Development of improved soil erosion prediction technology is required to provide conservationists, farmers and other land users with the tools they need to examine the impact of various management strategies on soil loss and sediment yield and plan for the optimal use of the land. Many erosion models were developed during the last four decades to predict the impacts of soil loss on agricultural productivity. An important line of currently used models started with the Universal Soil Loss Equation (USLE) (Wischmeier & Smith 1965, 1978) and branched into other empirical models such as Revised Universal Soil Loss Equation (RUSLE) and Modified Universal Soil Loss Equation (MUSLE). These empirical models have, until now, been applied to examine the experimental works in plot sites around the world because of their relative simplicity and small number of input parameters compared to other more complex erosion models. USLE, RUSLE and MUSLE models can predict soil erosion by water at plot scale (a standard plot was defined by Wischmeier & Smith (1978) as a land with 22.1 m long, 1.8 m wide size, and 9% of slope). Because of the empirical character of these models, there are some inconveniences to use them. One of them is the need to measure, for each specific situation, a single summary crop or soil parameter, which has other implicit parameters inside. It means that one cannot isolate the effect of each parameter. In addition, the processes that modify the intensity of erosion under various soil and crop conditions cannot be properly explained. Some process models (or physical models) were developed in comparison with USLE-related models. Examples of these models are Rose equation (Rose et al. 1988), Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel 1980), Griffith University Erosion System Template (GUEST) (Misra and Rose 1990, 1996), and the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing 1995). The distinct advantage of the physically based models is that they can predict off-site impacts of erosion such as sediment yield, runoff, sediment enrichment rate, and nutrient loss.

1.5 WaNuLCAS modelling

The Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model is a process-based model of water, nutrient and light capture in agroforestry systems at plot scale. WaNuLCAS was developed to represent tree-soil-crop interactions in a wide range of agroforestry systems where trees and crops overlap in space and/or time (simultaneous and sequential agroforestry) (Van Noordwijk et al. 1998). The model is based on soil science, tree and crop physiology and integrates above and below ground architecture of crops and trees in a spatial and temporal way. WaNuLCAS is developed under the Stella® modeling environment (STELLA 1994) and linked to Microsoft Excel spreadsheets for input data. The Stella shell allows the users to modify parameters and also add additional model structure. Simulations require a defined soil profile (physical and chemical properties per layer), degree of slope and climate conditions. 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 (van Noordwijk and Lusiana 2000). The model has an option to predict water induced erosion. Thus, it can be used to explore positive and negative effects of various combinations of trees and crops, its management, soil, and weather on runoff and soil loss which the output parameters give information on a daily time step. Soil erosion submudule in WaNuLCAS uses Rose equation for calculating event soil loss. This equation is based on the concept of simultaneous erosion and deposition (Rose 1985; Rose and Freebairn 1985; Rose 1998). In this approach, three continuous processes-rainfall detachment, flow detachment, and sediment deposition - are considered simultaneously.

Currently, WaNuLCAS is the most flexible model available for the evaluation of management options in agroforestry systems, crop rotations and hedgerow intercropping systems at different hedgerow spacing and pruning regimes, crop-fallow mosaics and parkland systems with a circular geometry based on site-specific information and farmer management objectives. Simulation results that can be generated by the model include nutrient dynamics, water balances, light use, crop and tree biomass, and crop yield.

1.6 Objectives

The goal of this study was to describe the dynamics of runoff, soil loss and nitrogen losses by erosion and leaching risk under various soil conservation systems and two N-fertilizer application regimes. It also aimed at understanding the interactions between a crop and hedgerow/grass barrier species with regard to crop yield performance.

More specific objectives of this study are:

- To assess the short to medium term changes in soil erosion, runoff, N losses and crop response in a comparative study as affected by contour barrier/hedgerow and conservation agriculture systems under minimum tillage.
- To assess the use of ^{13}C isotopic discrimination, in combination with standard methods in determining N availability and uptake, in order to better understand (i) competition for water and N between crops and barrier species, (ii) water and N uptake by crops under contour hedgerow systems and (iii) to derive a conceptual framework to assess relationships between crop response, N and water availability and δ^{13}C.
- Using field experimental data to calibrate and validate the erosion submodule of the WaNuLCAS model

- To better understand the role of various soil conservation measures on controlling erosion by using the WaNuLCAS model
- To use the model to assess the magnitude and dynamics of key processes influencing the efficiency of soil conservation measures.

1.7 Outline of the study

This thesis is mainly compiled from two published and one submitted papers. The research topic is dynamics of nitrogen losses of hillside cropping systems with soil conservation measures in Northeast Thailand. The field experiment was established at Ban Bo Muang Noi village in Loei province of Thailand (17°33' N and 101°1' E, 572 m a.s.l.) on a moderate slope gradient ranging from 21-28%. Crop performance, runoff, soil loss and N losses by erosion and leaching were collected from erosion plot after every rainfall event under different soil conservation measures as related to different N-fertilizer application over a period of three consecutive years (2003-2005). In this thesis book Chapter 2 presents the results of a study of changes in the relationship between soil erosion and N loss pathways after establishing soil conservation systems in uplands of Northeast Thailand. Chapter 3 describes ^{13}C isotopic discrimination: a starting point for new insights in competition for nitrogen and water under contour hedgerow systems in tropical mountainous regions. In Chapter 4 a study on assessing alternative conservation strategies on a hillside cropping system of Northeast Thailand by using WaNuLCAS is presented. This work is completed by general discussion and summary.