Building on qualitative datasets and participatory processes to simulate land use change in a mountain watershed of Northwest Vietnam

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A B S T R A C T

In this article we investigate if qualitative soil fertility datasets derived during participatory processes can be combined with a corresponding land use change model (i) to improve the understanding of the social-ecological complexity of land use change and (ii) to allow testing of alternative scenarios even in data-poor environments. To test this hypothesis, a participatory assessment approach was combined with the spatially explicit, soil fertility driven FALLOW (Forest, Agroforest, Low-value Landscape Or Wasteland?) model. For a case study village in Northwest Vietnam, participatory evaluations with two age groups of farmers were employed in an iterative way to derive qualitative and quantitative model input data to test scenarios of current and improved management on upland soil fertility evolution with FALLOW. The indigenous colour-based soil quality classification was successfully integrated into the Trenbath FALLOW soil module. The model baseline scenario was validated by calculating the goodness-of-fit of model outputs with land cover maps (F = 0.78) from remote sensing. Model scenario analysis suggested a masking effect of ongoing soil fertility decline by use of fertilizers and hybrid crop varieties, indicating a resource overuse that becomes increasingly irreversible without external interventions. Simulations further suggest that success of introduction of improved cropping management methods becomes less effective with increasing soil degradation and cannot fully restore initial soil fertility. We conclude that the coupled semi-quantitative approach is useful at the village level as it generated meaningful insights into local land use change dynamics without the need for long-term and data-intensive studies.

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1 Introduction

Changes in land cover and land use are an inherent characteristic of landscapes (Bürgi et al., 2004). Whereas land cover comprises the observed biophysical attributes of the earth’s land surface (Lambin et al., 2003), land use is defined by the purposes for which humans exploit the land cover (Di Gregorio and Jansen, 2000). In this paper we use the term land use to represent land use and land cover simultaneously. Variations of land use change are determined by space and time at the interface of biophysical environment, socioeconomic activities and culture. Land use change driving factors with long turnover times condition the boundaries of environmental sustainability, whereas factors with short turnover times can result in drastic changes of ecosystem functioning (Newell et al., 2005; Schoorl and Veldkamp, 2001; Walker et al., 2004).

Land use models represent land use systems as a function of their biophysical and socioeconomic driving forces. They can be used to explain causes and consequences of land use dynamics through scenario building (Veldkamp and Lambin, 2001; Verburg, 2006). In the mountainous areas of Northern Vietnam, a rising population and emerging market for agricultural produce resulted in the expansion of agricultural production areas at the expense of local resource degradation (Rambo, 1997; Vien, 2003). Previous land use change modelling studies in these areas elucidated the diversity of present land use systems from commune to district levels through empirical, questionnaire-based GIS studies (Castella et al., 2005a; Lentes, 2006) or agent-based approaches (Castella et al., 2005b; Castella and Verburg, 2007). However, in such an
erosion-prone environment, it is important to take into account the degradation of soil fertility as a key factor of plant production. Furthermore, conventional soil fertility assessment methods are laborious and expensive (cf. Schuler et al., 2006; Neef, 2008). Here, a land use model is a useful tool to assess feedback mechanisms and causal relationships at the human-environment interface following the assumption that a landscape is a social-ecological system where modelling approaches can support management activities (Argent, 2003).

The epistemic uncertainty in environmental assessments calls for participatory approaches to modelling and context-sensitive research. Participatory research can incorporate local knowledge and local stakeholders’ perspectives into science-based modelling approaches to enhance the opportunity to jointly identify solutions for environmental problems, such as soil degradation (Haag and Kaupenjohann, 2001; Neef et al., 2006; Pahl-Wostl, 2007). Schuler et al. (2006), for instance, compared soil maps derived by participatory or soil chemical analysis respectively. They concluded that the integration of local soil knowledge and knowledge of local cropping practises with scientific soil classification allowed for a rapid and cost-saving compilation of information for land-evaluation purposes at the sub-catchment level. Despite the apparent potential of participatory research, there are limitations which need to be considered. In particular the development of qualitative land use indicators in a stakeholder-led process may get corrupted by ‘dominant participants’ resulting in biased outputs (van Asselt Marjolein and Rijkens-Klomp, 2002).

In the context of our study, participatory assessment tools in conjunction with a land use change model in an iterative process were employed to improve the understanding of the linkage of soil fertility degradation and land use change. It was hypothesised that (i) information derived from engaging local stakeholders into the research process could serve as input to parameterize the soil fertility module of the FALLOW (Forest, Agroforest, Low-value Landscape Or Wasteland?) model (van Noordwijk, 2002) (described in Section 2.2), and (ii) that the combination of information obtained from stakeholders and model scenario analysis could generate new insights into the local complexity of land use change. For this purpose, a participatory assessment approach was used drawing on participatory rural appraisal methods outlined by Chambers (1994) and the Soft-System Methodology of Checkland (2000). Local stakeholders’ knowledge and perceptions were included in the research process based on the assumption that participation of non-scientists in scientific research is needed when analysing complex social-ecological systems, i.e. land use systems. The approach was employed to explain land use change patterns of upland cropping fields driven by soil fertility dynamics in a case study village in Northwest Vietnam (Section 3). Model calibration and validation building on the participatory derived datasets and satellite based information are described in Section 4, where also a scenario analyses focused on the assessment of stakeholder recommendations on how to improve upland soil fertility. Following the presentation of results, we critically assessed the robustness and reliability of the participatory datasets employed for FALLOW model parameterisation and discussed the hidden local soil degradation phenomenon disclosed by simulated scenarios (Section 5). Our concluding remarks summarize the potential and limitations of the integrated assessment approach and provide suggestions for further studies in this field of research.

2. Materials and methods

2.1. Study site

The study was conducted in Ban Put, one of six villages of the administrative unit of Chieng Khoi commune, Son La province, Northwest Vietnam (Fig. 1). The area is characterised by an extended high plateau with valleys at altitudes of 400–500 m a.s.l. and limestone formations rising up to 975 m a.s.l. (Clemens et al., 2010). The local climate is dominated by monsoonal patterns with a distinct rainy season from April to October and a relatively dry and cold season from November to March. The average annual precipitation amounts to 1238 mm, with average monthly temperatures ranging from 17.5 °C in January to 27.9 °C in June. Ban Put village is located at 21° 09’50” N and 104° 19’08” E, encompassing a total area of 358 ha. The current population consists of 467 inhabitants belonging to the Black Thai ethnic minority group. The village land use area is subdivided into forest based (375 ha), upland cropping (47 ha), paddy rice (11 ha), fruit and tree plantations (30 ha), and fishponds (10 ha). The major agricultural farming systems are paddy rice (Oryza sativa), maize (Zea mays), cassava (Manihot esculenta) and mango (Mangifera indica) (Chieng Khoi Commune, 2007).

![Fig. 1. Topographic and infrastructure features of Ban Put village, Son La province, NW Vietnam.](image-url)
2.2. The FOLLOW model

FOLLOW is a spatially explicit land use and land cover change model with a yearly time step (van Noordwijk, 2002; Suyanto et al., 2006). The model threat land and land use change simultaneously, assuming that land-use dynamics are a major determinant of land-cover changes. We used FOLLOW version 1.0 which was encoded in the PCraster Environmental Modelling software language (http://pcraster.geo.uu.nl/). In the model, farmers were assumed to be main agents of land use and land use change based on a multi-criteria analysis of (i) plot attractiveness to expand a land use system as function of soil fertility, plot accessibility, attainable yield, and potential costs arising from transportation and land clearing, (ii) allocation of labour and land to available options of investment, and (iii) diminishing and increasing marginal returns on soil fertility and land productivity.

The approach to plot-level proportionally declines during cropping periods and increases during fallow periods with a characteristic half recovery time. During a fallow period soil fertility (F) can be restored with an asymptotic approach up to a maximum value:

\[ F = \frac{F_{\text{init}}}{K_{F}} + \left(1 - \frac{K_{F}}{K_{F}}\right) \left(1 \right)^{-t} \]

with, \( F_{\text{max}} \) being the maximum soil fertility level reached after an infinitely long fallow period (e.g. soil under permanent forest), \( K_{F} \) the ‘half-recovery’ time or time (years) needed to halve the difference between actual and maximum soil fertility, and \( t \) the length of fallow periods in years. During a cropping period, soil fertility \( F_{t} \) at time \( t \) declines with a land use specific soil fertility depletion rate \( D_{DLU} \):

\[ F_{t} = F_{\text{init}} \left(1 - D_{DLU} \right)^{(t-1)} \]

with, \( F_{\text{init}} \) being the soil fertility status at the start of the cropping period. Fertilizer application \( K_{\text{init}} \) affects soil fertility and yield by reducing the land use specific depletion factor \( D_{DLU} \) with \( K_{\text{init}} \) defined as 1 – efficiency of fertilizer in maintaining 1 unit of soil fertility (dimensionless), and \( f_{\text{s}} \) the fraction of soil fertility depleted per year land use type:

\[ D_{DLU} = D_{DLU} \cdot K_{\text{init}} \]

In this approach, cumulative crop yield per cropping cycle \( Y_{\text{cum}} \) is a function of a crop specific conversion factor \( c \) of soil fertility \( F_{t} \) to crop yield (in Mg), and the land use specific depletion rate \( D_{DLU} \) with \( c \) the length of cropping period (years):

\[ Y_{\text{cum}} = c \cdot F_{t} \cdot \left(1 - D_{DLU}\right)^{-1} \]

Overall, the response domain within farmers operate is determined by the biophysical environment \( F_{\text{init}} \) depends on soil type, \( K_{F} \) depends on fallow vegetative and farm management \( f_{\text{s}} \) for example on soil tillage, \( K_{\text{init}} \) on fertilizer use and type (mineral, organic, green manuring), \( c \) on crop genotype or crop practises).

Total crop production from the whole landscape together with revenues gained from other possible economic production systems (e.g. forest resource utilisation activities or tree plantations) contribute to food security and household economic resources. Farmers in the model will select suitable farming plots based on their plot attractiveness. Plot attractiveness \( A_{\text{attr}} \) at coordinate \( (i,j) \) is based on the ratio between soil fertility and field accessibility defined by a function of distance to settlements, roads, and rivers. The farmer agent classifies fields by soil fertility, based on crop response to inherent soil fertility and chooses the best area to crop. Consequences of landscape dynamics are assessed in impact modules (Supplement 1) through biophysical and socioeconomic indicators i.e. annual food security or soil fertility at landscape level. Food security is determined by farmers’ annual per capita food requirements (FoodReqPC) calculated in staple food equivalents (Mg capita -1 year -1) and the actual population size (PopSz) at time \( t \). The spatial implementation follows the above assumptions generating for each time step a spatially explicit land use and land cover, and soil fertility map (Suyanto et al., 2009; van Noordwijk, 1999, 2002; van Noordwijk et al., 2008).

The model calibration procedure requires (i) spatial inputs such as initial land cover and land use, forest protection area, initial soil fertility, elevation and slope distance to roads or settlement maps (see also: Supplement 2), and (ii) variables to parameterize soil fertility and socioeconomic modules, i.e. population growth, labour requirements and prices. A default parameter setup was available on the basis of field measurements of benchmark sites in the humid and sub-humid tropics (van Noordwijk, 2002), i.e. with \( F_{\text{max}} \) ranging from 1 (degraded soil) to 20 (primary forest soil).

2.3. Participatory assessment of model input parameters

Following the primary goals of this study, we employed participatory tools derived from conceptual ideas of Soft-System-Methodology (Checkland, 2000) and Participatory Rural Appraisal (Chambers, 1994) to derive model input parameter datasets. As a guidance for the participatory framework, we chose a set of model input parameters comprising endogenous variables (EN) of farmers’ decisions on land use intensification, field management, and its ecological consequences, exogenous variables (EX) determined by the ecological and socioeconomic systems, i.e. distance to cropping fields, population growth, and influence of land use policies (Supplement 2). Building on an interdisciplinary research team composed of an agro-ecologist and a social scientist assisted by three local research assistants the participatory assessment was conducted in three stages:

2.3.1. Stage 1 – overview of study site (January 2007)

The approach started with defining the problem situation (Checkland, 2000), here “land use change dynamics” through reconnaissance surveys, and the identification of actors and related system components. Initial field surveys and semi-structured interviews were conducted to understand the causes and consequences of current land use systems. An information feedback loop (Fig. 2) was designed to ensure data consistency and to derive model input datasets. Various rounds of focus group discussions were organized with the participation of in total 32 villagers: five village administrative committee members, five key farmers, defined as persons with crop management knowledge gained from extension and training courses, and 22 randomly selected farmers without formal agricultural training, subdivided into male (11) and female (11) participants relying on farming as main source of income.

As a preparatory step, a portable topographic 3D model (0.4 m = 0.3 m) of Chuong Khoi commune was made in the context of current cropping systems, plot resource balances, and causes and consequences of current land use systems. An information feedback loop (Fig. 2) was designed to ensure data consistency and to derive model input datasets. Various rounds of focus group discussions were organized with the participation of in total 32 villagers: five village administrative committee members, five key farmers, defined as persons with crop management knowledge gained from extension and training courses, and 22 randomly selected farmers without formal agricultural training, subdivided into male (11) and female (11) participants relying on farming as main source of income.

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cropping patterns were monitored by (i) field visits of upland managed plots of stage two participants, and (ii) transect walks at 500, 1000, 1500, and 2000 m distance from the village centre (Fig. 1) between two opposing hilltops in a southeast to northwest direction, covering an average distance of 650 m. GPS points (Garmin CSX 60) were taken at upland plot centres and at intervals of 20 m during a transect walk with land use classified according to stage 2 descriptions. Based on the collected information, a land use map 2008 was drafted in ArcGIS 9.3 by (i) using polygons of settlement, paddy rice and forest reserve areas identified during the session area of interest, (ii) converting field GPS data into quadratic polygons (ArcGIS extension ET Wizard) with an edge length of 31.6 m, (iii) and classifying the remaining area by ortho-rectified digital photos which were taken from hilltop positions in a 360° angle and along the upland area road networks. The resulting map was converted into raster format with ArcGIS 9.3 and finally edited with the PCRaster MAPEDIT 1.7 tool.

3. Findings of the participatory assessment

Following the initial assessment and reconnaissance survey, interviewed local actors identified that upland rice, the formerly most common upland crop, was replaced by maize in the past three decades. It was also stated that forest protection programmes banned any farming activity in the remaining forests. The government initiated a formal land allocation process in 1995 which was completed in 2000. According to this baseline information, the research team organized the focus group discussion rounds of stage two.

3.1. Focus group discussions

3.1.1. Land use history

Following the final discussions, both age groups agreed to sub-classify the time periods into four stages: (i) before 1988, (ii) 1988 to 1995, (iii) 1995 to 2000 and (iv) 2000 to 2008 (Table 1). In this timeframe, land tenure changed from a cooperative allocation system to individual household use rights, and cropping area expanded from foothill and moderate slopes to steep slopes and hilltop positions.

The change of upland cropping was characterized by the abandonment of swidden farming (three-year crop-fallow rotation system) for permanent cropping systems with a shift of upland rice and traditional maize and cassava to hybrid maize and cassava crop varieties; tree plantations were implemented by government reforestation programs (Fig. 3). Traditional field preparation techniques changed from using a planting stick and slash and burn methods, to the present system of soil tillage by animal plough on

### Table 1
Change of upland crop management and related socioeconomic factors in Ban Put village as revealed by participatory focus group discussions.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Land tenure system</td>
<td>Allocation</td>
<td>By cooperative</td>
<td>Transition to individual land use</td>
<td>Introduction of household use rights</td>
<td>Tenure right expires: 2018 for crop—2048 for tree—based systems Fixed positions</td>
</tr>
<tr>
<td>Location of upland fields</td>
<td>Foothill, moderate slope</td>
<td>Expansion to steeper slope and hilltop positions</td>
<td>Permanent cropping</td>
<td>Permanent cropping</td>
<td></td>
</tr>
<tr>
<td>Cropping system</td>
<td>Swiddening</td>
<td>Transition to permanent cropping</td>
<td>Slash and burn</td>
<td>Slash and burn, hoeing</td>
<td></td>
</tr>
<tr>
<td>Land preparation</td>
<td>Slash and burn</td>
<td>Slash and burn</td>
<td>Slash and burn, hoeing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop varieties</td>
<td>Local</td>
<td>Local, introduction of hybrids</td>
<td>Local and hybrids jointly used</td>
<td>Hybrids dominant, some local persist</td>
<td></td>
</tr>
<tr>
<td>Planting method</td>
<td>Planting stick</td>
<td>Planting stick</td>
<td>Planting stick</td>
<td>Planting stick</td>
<td></td>
</tr>
<tr>
<td>Fertilizer use</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Soil fertility</td>
<td>Good, starting to decline</td>
<td>Declining</td>
<td>Declining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farming constraints</td>
<td>None</td>
<td>Upland rice yields</td>
<td>Soil degradation</td>
<td>Soil degradation</td>
<td></td>
</tr>
<tr>
<td>Population density</td>
<td>Low, starting to increase</td>
<td>Increasing</td>
<td>Increasing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government programs</td>
<td>None</td>
<td>Reforestation</td>
<td>Extension service</td>
<td>Extension service</td>
<td></td>
</tr>
</tbody>
</table>
moderate and hoeing on steep slopes, and fertilizer use. The decline of soil fertility was described by stakeholders as rising threat to the farming systems.

3.1.2. Cropping systems

Participants defined the cropping preference for maize, intercropped maize-cassava, cassava and tree-based systems based on soil physical characteristics, choosing soil colour and texture as main preference criteria (Supplement 3). In total, eight soil classes were identified, with the soil colours black, red, and yellow as main indicators, subdivided into transition classes (red-black, red-yellow, yellow-black) and texture subclasses (red-clay, red-sandy). Furthermore, soil colour units were combined with inherent soil fertility levels to describe crop yield potential (Table 2). Black soils are the most fertile and productive soils. Farmers perceived them as very suitable for annual food or cash crop production. Red-coloured soils were classified as moderately fertile, suitable for all cropping and tree-based systems. Yellow-coloured soils received lowest fertility rankings suitable for cassava and tree-based systems.

In stakeholders’ perception, high soil fertility represents a high crop yield potential which corresponds with the Trenbath approach to link crop yield to soil fertility (Eq. (4)). By correlating farmers yield assessments with soil colour units we converted farmer descriptions receiving a score of 10.

3.1.3. Plot resource balance

Table 3 presents a summary of a flowchart (Supplement 4.1) constructed by local participants to discuss plot-based resource balances. The flowchart incorporated management and socio-economic factors, such as prices and labour requirements (Supplement 4.2—4.3) whereas the balance solely focused on input and output quantities of an exemplified upland plot of 1000 m².

Maize-based cropping systems received the highest nitrogen fertilizer inputs compared to cassava or intercropping systems. Based on stakeholder estimations, mean crop yield for maize was 3591 kg ha⁻¹ with a standard deviation of 2003 kg ha⁻¹, whereas cassava yielded on average 5605 kg ha⁻¹ while lower yields were reported in maize-cassava intercropping systems. In general, yield estimations were based on the number of sacks, which participants sold to local traders. The soil erosion class was determined as ‘moderate’ for maize and ‘very’ for cassava and maize-cassava intercropping systems. Based on the previously defined range (see also: Material and Methods), farmers observed erosion fluxes frequently during rainfall events, resulting in reduced crop yields and topsoil losses.

Causes and consequences of the existence of current cropping systems: Soil degradation was the overarching problem hampering all cropping systems (Table 4). Participants linked causes to perceived consequences as follows: (i) fertilizer application rates have been increased to circumvent declining maize and cassava yields, (ii) pest and disease pressure increased as a consequence of

Table 2

<table>
<thead>
<tr>
<th>Local soil classification</th>
<th>Inherent soil fertility</th>
<th>Suitable land use systema</th>
<th>FALLOW soil fertility units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maize</td>
<td>Intercropb</td>
</tr>
<tr>
<td>Black</td>
<td>Good</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Red-Black</td>
<td>Moderate</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Red</td>
<td>Moderate</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Red-Clay</td>
<td>Moderate</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Red-Sandy</td>
<td>Moderate</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Yellow-Black</td>
<td>Moderate</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Red-Yellow</td>
<td>Low</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Yellow</td>
<td>Low</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

a ++ very suitable, + suitable.
b intercrop = maize and cassava.

d calculations were based on NP (5:10:13) and urea rates.


d further explanations see: Materials and Methods.

Table 3

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>Input materialb (kg ha⁻¹)</th>
<th>N fertilizerc (kg ha⁻¹)</th>
<th>Yieldd (kg ha⁻¹)</th>
<th>Erosivitye (0–3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize (n = 37)</td>
<td>17.5 (2.5)b</td>
<td>145 (37.4)</td>
<td>3591 (2003)</td>
<td>3</td>
</tr>
<tr>
<td>Cassava (n = 24)</td>
<td>701 (50)</td>
<td>35.2 (41.2)</td>
<td>5605 (3845)</td>
<td>2</td>
</tr>
<tr>
<td>Intercropping</td>
<td>(n = 43)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>34.5 (45.3)</td>
<td>24.7 (11.2)</td>
<td>550 (349)</td>
<td>2</td>
</tr>
<tr>
<td>Maize</td>
<td>29.1 (22.8)</td>
<td>39.5 (41.2)</td>
<td>2294 (2209)</td>
<td>2</td>
</tr>
</tbody>
</table>

a Seed and cassava stick.
b Number in brackets are standard deviation.
c Calculated based on NP (5:10:13) and urea rates.
d For further explanations see: Materials and Methods.

e we assumed this is valid, as farmers derived their plot suitability on a similar basis employing linear steps between good to low inherent soil fertility levels (Table 2). It follows that black soils were given a score of 15, red-black soils 12.5, red 10, red-yellow 7.5 and yellow soils 5, respectively. Remaining texture subclasses were added to red soils, receiving a score of 10 and transition class yellow-black was assigned to the moderate fertile soil classes following stakeholders’ descriptions receiving a score of 10.

Table 4

<table>
<thead>
<tr>
<th>Causes</th>
<th>Consequences</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abandon fallow periods</td>
<td>Soil degradation</td>
<td>Reinroduce plot-based</td>
</tr>
<tr>
<td>Changing soil properties</td>
<td>Maize and cassava yields decline</td>
<td>fallow system</td>
</tr>
<tr>
<td>Hoeing and ploughing</td>
<td>Soil compaction</td>
<td>Use green manure &amp; leguminous plants to improve soil structure</td>
</tr>
<tr>
<td>Hybrid crop varieties</td>
<td>Pest and disease pressure increase</td>
<td>None</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>Reduced water holding capacity</td>
<td>Reinroduce plot-based</td>
</tr>
</tbody>
</table>

we assumed this is valid, as farmers derived their plot suitability on a similar basis employing linear steps between good to low inherent soil fertility levels (Table 2). It follows that black soils were given a score of 15, red-black soils 12.5, red 10, red-yellow 7.5 and yellow soils 5, respectively. Remaining texture subclasses were added to red soils, receiving a score of 10 and transition class yellow-black was assigned to the moderate fertile soil classes following stakeholders’ descriptions receiving a score of 10.

3.1.3. Plot resource balance

Table 3 presents a summary of a flowchart (Supplement 4.1) constructed by local participants to discuss plot-based resource balances. The flowchart incorporated management and socio-economic factors, such as prices and labour requirements (Supplement 4.2—4.3) whereas the balance solely focused on input and output quantities of an exemplified upland plot of 1000 m².

Maize-based cropping systems received the highest nitrogen fertilizer inputs compared to cassava or intercropping systems. Based on stakeholder estimations, mean crop yield for maize was 3591 kg ha⁻¹ with a standard deviation of 2003 kg ha⁻¹, whereas cassava yielded on average 5605 kg ha⁻¹ while lower yields were reported in maize-cassava intercropping systems. In general, yield estimations were based on the number of sacks, which participants sold to local traders. The soil erosion class was determined as ‘moderate’ for maize and ‘very’ for cassava and maize-cassava intercropping systems. Based on the previously defined range (see also: Material and Methods), farmers observed erosion fluxes frequently during rainfall events, resulting in reduced crop yields and topsoil losses.

Causes and consequences of the existence of current cropping systems: Soil degradation was the overarching problem hampering all cropping systems (Table 4). Participants linked causes to perceived consequences as follows: (i) fertilizer application rates have been increased to circumvent declining maize and cassava yields, (ii) pest and disease pressure increased as a consequence of

Table 4

<table>
<thead>
<tr>
<th>Causes</th>
<th>Consequences</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abandon fallow periods</td>
<td>Soil degradation</td>
<td>Reinroduce plot-based</td>
</tr>
<tr>
<td>Changing soil properties</td>
<td>Maize and cassava yields decline</td>
<td>fallow system</td>
</tr>
<tr>
<td>Hoeing and ploughing</td>
<td>Soil compaction</td>
<td>Use green manure &amp; leguminous plants to improve soil structure</td>
</tr>
<tr>
<td>Hybrid crop varieties</td>
<td>Pest and disease pressure increase</td>
<td>None</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>Reduced water holding capacity</td>
<td>Reinroduce plot-based</td>
</tr>
</tbody>
</table>
utilising hybrid seed varieties, (iii) soil erosion and abandonment of fallow periods reduced plot water holding capacity, and (iv) tillage by hoe and plough resulted in soil compaction. In this context, stakeholders recommended to (i) increase crop yield by increasing fertilizer rates, (ii) increase soil fertility by applying green manure or using leguminous species, and (iii) reintroducing a plot-based swidden fallow rotation system to improve soil properties and to combat soil degradation.

3.2. Verification of land use patterns by village elders and through field observations

The village elders confirmed that every period of land use change encompassed an area expansion in inclination, elevation and distance from the village centre. Until 1988, upland fields were located within a radius of 1000 m to the present settlement areas, with the exception of forest areas prevailing on middle and steep slopes. A small number of swidden plots were located on fertile plains with distances up to 2000 m from the settlement centre. In 1988 to 1995, villagers expanded cropping areas from fertile plains to steep and moderate slope positions. After 1995, upland crop area expanded further uphill, and a small secondary forest patch abandoned until 2000 was converted into cropland from 2000 to 2008.

Field monitoring found a majority of intercropped maize-cassava based farming systems within the study area. In total 162 upland fields were visited out of which 86 plots were classified as maize cassava intercropping, 22 as maize, 20 as cassava, 26 as agroforestry, and 8 tree plantation plots, respectively. Although participants of the focus group discussions did not mention agroforestry systems, results of field monitoring emphasized the inclusion of an agroforestry land use class. Agroforestry was defined as a combination of annual cropping (maize, cassava) with fruit trees (mango, litchi, longan, banana) or timber tree species (teak, pine). A plot was classified as agroforest if at least 10 trees with a minimum height of 2 m were found in plot sizes of 500–1000 m².

4. FALLOW model baseline scenario

4.1. Calibration

The baseline scenario was calibrated to resemble the stakeholder described timeframes of 1975–2008. Calibration was divided into two parts by preparing (i) factor maps which guide the location of future change, i.e. initial land cover, forest protection area, inherent soil fertility, elevation and slope, distance to roads or settlement and (ii) variables to parameterize the Trenbath soil fertility and socioeconomic modules, i.e. population growth and labour requirements. The following section gives emphasis especially on part (ii) whereas (i) is represented in more detail in Supplement 5.

The inherent soil fertility map (InhFert) was derived following stakeholder descriptions that before 1988 upland soils were of black soil colour. It received a score of 15 following the developed site fertility conversion scheme presented in Table 2. The change of swidden to annual cropping systems was simulated by using upland rice, hybrid maize (Maize HY1) and improved hybrid maize (Maize HY2) varieties as representative crops. Outputs of focus group session cropping systems and plot resource balance were drawn to calibrate upper and lower yield potential (Ymax Ymin) (Table 5). Similarly, datasets of the prepared flowchart (Supplement 4.1) were utilized to calibrate annual labour requirements for the maize cropping systems whereas input parameters for upland rice were derived from Saito et al. (2006) (Table 5).

For the categorical soil fertility depletion variable (JD), 1 defines a complete soil fertility stock decrease by mineralisation during one year of cropping (van Noordwijk, 2002). Initially, fD was set to 0.3, which followed the assumptions of Trenbath (cf. in: van Noordwijk, 1999) for a “shifting cultivation fallow rotation system”, here represented by the upland rice swidden system. The stepwise increase of soil depletion depicted by session land use history resembled the change of upland rice to hybrid maize and improved hybrid maize varieties in 1991 and 2000, with the associated intensification of farm management practises, e.g. soil tillage (Table 5). On the other hand, crop conversion efficiency (c) was stepwise increased to resemble the use of improved and hybrid seed varieties as they possess a higher crop yield potential compared to traditional ones. Farm management intensification as described in session causes and consequences, and plot resource balance were calibrated by reducing the fallow period (tf) from three to zero years, and by increasing the three cropping periods (tc) of a swidden rotation to eighteen consecutive years (until 2018) in an annual farming system respectively. A half recovery time (Kf) of 15 years was parameterized based on a study of Dung et al. (2008) for an upland rice-cassava swiddening system under similar environmental conditions in Northern Vietnam. Fertilizer application was started in 2000. In the model default setting (van Noordwijk, 2002) a KFert value of 0.3 was suggested, however, we reduced fertilizer efficiency rate (Kfert) to 0.25 in view of the negative impact of soil erosion on fertilizer use efficiency.

In the FALLOW approach, the socioeconomic module is driven by simulated annual population food demands, deduced by multiplying population density and the per capita food demand of a staple food source; in our case rice comprised the major staple food source amounting to 0.5 Mg equivalents year⁻¹ (Saint-Macary et al., 2010). Richter (2008) found that Ban Put village comprised 31

| Table 5 |

<table>
<thead>
<tr>
<th>Trenbath input variable</th>
<th>Units</th>
<th>Time period</th>
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<tbody>
<tr>
<td>Ymin</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>Ymax</td>
<td>1.25</td>
<td>1.75</td>
</tr>
<tr>
<td>Mean</td>
<td>0.75</td>
<td>1.13</td>
</tr>
<tr>
<td>Depletion rate (fD)</td>
<td>Dimensionless</td>
<td>0.3</td>
</tr>
<tr>
<td>Fallow period (tf)</td>
<td>Year</td>
<td>3</td>
</tr>
<tr>
<td>Half recovery time (Kf)</td>
<td>Year</td>
<td>15</td>
</tr>
<tr>
<td>Crop conversion efficiency (c)</td>
<td>Dimensionless</td>
<td>0.25</td>
</tr>
<tr>
<td>Cropping period (tc)</td>
<td>Year</td>
<td>3</td>
</tr>
<tr>
<td>Fertilizer efficiency (Kfert)</td>
<td>Dimensionless</td>
<td>na</td>
</tr>
</tbody>
</table>

*na — not applicable; HY — Hybrid variety.

² Assumed permanent cropping until 2018.
inhabitants in 1965 and census data identified 467 villagers in 2007 (Chieng Khoi Commune, 2007). Based on this information, an annual population increment (PopInc) of 10 inhabitants was calculated assuming a linear growth rate based on the findings of session land use history.

4.2. Spatial validation procedure

The validation of simulated spatial patterns of land use change models requires a comparison with maps of real land use and land cover change. Such datasets should be completely independent from the calibration data (Pontius et al., 2006; Rykiel, 1996). In order to be able to validate our modelled land use change dynamics with land cover data derived from satellite image classification we clustered the previously described upland farming systems into one land cover class called ‘upland cropping’, and combined settlement and paddy as well as grassland and shrub areas into combined land use classes.

For this study, we employed the multiple-resolution goodness-of-fit (GOF) validation procedure (Costanza, 1989; Supplement 5) using land cover maps, further referred to as “reference maps”, from an SPOT satellite image in 1992 and a LISS III satellite image in 2007 (Thi et al., 2009). Drawing on Pontius et al., (2004) suggestion “to compare model runs with a null model that assumes complete persistence of land use across the simulated time period”, this study measured the accuracy of the null model as the percentage of pixels in agreement between the reference map of 1992 and the reference map of 2007 (Fig. 4a) with Fig. 4b comparing areas between simulated land cover in 2007 (FALLOW 2007), and the devised reference maps (Reference 1992, and 2007).

Fig. 5 shows that the location accuracy of pixels for the FALLOW baseline scenario simulation was more accurate than the null model for pixel resolutions lower than 32 m. The goodness of fit ($F_t$) value of 0.78 represents a weighted average of the agreement over the pixel size varying between 1 (31 m) and 33 pixels (993 m) with most weight given to small window sizes (Castella and Verburg, 2007). We also compared simulated land use trajectories with secondary datasets at the Chieng Khoi commune level (Fig. 6). The model reflected the development of land use and land cover at village level following the patterns at commune level. However, simulated secondary forest area in the village did not increase initially as in the commune statistical data, rather decreased continuously from the beginning of the simulation period in 1975 until 1994. Statistical data suggested that the decrease of secondary forest area came to a halt at commune level somewhat later and at lower level in 1999.

The simulation of annual crop yield was sensitive to inherent soil fertility, the opening up of new forest areas at the beginning of the simulation, and the introduction of hybrid crop varieties and
fertilizer use (Fig. 7). The exogenous defined shift in the model from upland rice swiddening to maize hybrid cropping systems followed focus group descriptions. Together with the conversion of fertile forest areas to cropland (Fig. 6) the shift resulted in a simulated increase of average annual crop yields of 1.5–1.75 Mg for the period of 1990–1995. The increase of cropping area during the simulation period was at the expense of fallow areas resulting in a decline of inherent soil fertility from predominantly black into average red-yellow soil conditions (soil fertility value ~ 7.5). The combined use of maize hybrid varieties and fertilizers from 2000 onwards initially masked soil degradation enhancing maize production to an annual average of 2–3.2 Mg ha⁻¹. However, application of fertilizer apparently did not strongly influence inherent soil fertility development as simulated soil fertility remained within red-yellow soil conditions (soil fertility value ~ 7.8). Here, model outputs and farmers description followed similar trends pointing towards the degradation of soil fertility as commonly perceived problem of upland cropping.

4.3. Scenario analysis

Scenario analysis is a tool to deal explicitly with different assumptions about the future (Refsgaard et al., 2007; Rykiel, 1996). In our case, scenario analysis was used to test consequences of stakeholder-based suggestions how to combat declining upland soil fertility. The previously employed baseline calibration was utilised by extending the model runtime until 2019. The year 2019 coincides with the assumed end of the officially guaranteed land use rights for crop-based systems (so-called red book certificates), where the provincial government is expected to reallocate land use rights among villagers.

Three scenarios were chosen focusing on local soil fertility management schemes: (i) Increase fertilizer application rates (IncFert) – to test three levels of fertilizer use efficiency (K_fert) to follow stakeholders assumption that an increase of fertilizer rates or application of organic manure after the year 2000 improves soil fertility, (ii) Earlier Fertilizer Application (EarlyFert) – start fertilizer application five years earlier (in 1995) than implemented by farmers using various levels of K_fert to test the hypothesis that an earlier intervention (e.g. less degraded soils) results in a faster recovery of soil fertility, and (iii) Reintroduce improved swiddening (ReIFallow) – reintroduce a three year improved swiddening (crop fallow rotation) system after 2008, and apply fertilizer from 2000 onwards by using three levels of K_fert.

The simulation outputs (Fig. 8) indicated that only twofold fertilizers use efficiency increase (IncFert 0.5), e.g. cover crops and fertilizer use, resulted in a moderate built-up of soil fertility at the landscape level. Earlier use of fertilizer would delay the decline of soil fertility for current baseline scenario EarlyFert 0.25; but in association with improved crop management (EarlyFert 0.5) could stabilise soil fertility at acceptable level suitable for maize production. The simulated scenarios of reintroduction of improved swiddening (ReIFallow) showed a positive effect on soil fertility development for all tested fertilizer use efficiencies but only in
fertile soils (red and red-yellow soils) with a tendency of further degradation. Fertile soils, e.g. black-red and black soils, occurred on plots more distant from settlement areas. When taking a snapshot into 2018, soil fertility further declined with most plots pertaining to moderate to low fertility conditions (Fig. 9b; red-yellow and yellow). In this context, fertile or black soil fields almost vanished with black-red soil plots prevailing closer to settlement areas, and scattered over the study area.

5. Discussion

5.1. Building on focus group discussions to parameterize the FALLOW model

The proliferation of stakeholder engagement has positively influenced modelling efforts in recent years, especially when supporting decision making processes for environmental management (Lagabrielle et al., 2010; Voinov and Bousquet, 2010). In our case, participatory focus group discussions were employed to integrate knowledge domains of stakeholders from an analytical and soft system perspective across disciplinary boundaries at the village level. This approach formalised stakeholders knowledge by drawing common diagrams and logical frameworks, especially as soft system analysis focuses on the importance of subjective perceptions and socially structured reality (Pahl-Wostl, 2007). Building on the principal study hypothesis, the participatory approach reduced stakeholder and research team driven bias, particularly by introducing feedback loops and verification of information by elderly villagers as additional respondent group. Generated focus group discussion outputs revealed that land use history and evolution of crop management intensification correlated well with findings of Sikor and Truong (2002) in Yen Chau district. However, Dao et al. (2002) and Keil et al. (2008) reported higher local mean maize yields (5.5 and 6.2 Mg ha\(^{-1}\) respectively) than obtained in this study. Differences in yield estimates could have resulted from variations in crop yield potential due to site-specific soil and climate variations (Wezel, 2000), or due to weight variations given by improper or manipulated scaling devices of local grain buyers (Dao et al., 2002). An additional reason could be the use of proxy indicators during the participatory approach, as in contrast to exact measurements differences given by varying corn size or moisture content cannot be disclosed. Comparing labour requirements for upland maize farming provided by participants (Supplement 4.2) with those reported by Dao et al. (2002) and Keil et al. (2008), showed that overall ranges were similar, however, Keil et al. (2008) remarked that soil types and steepness of farmland may result in high variation of required input labour.

Regarding farmers’ soils classification, Clemens et al. (2010) confirmed topsoil colour as a major indicator of soils’ crop suitability, as i.e. black soils are the most preferable soil types in Chieng Khoi commune due to their higher total N, total C and CEC contents than red or yellow soils. This underscores the overall model calibration concept linking soil fertility and soil colour, further supported by the FALLOW model approach of crop choice relative to soil fertility classes (or predefined boundaries). Challenges with such an approach may arise in the choice of an adequate soil colour-soil fertility calibration approach due to interactions between soil fertility and crop management in the field. It might be questionable if the employed equal-distant calibration approach (Table 5) did represent the stakeholder described land use evolution satisfactorily. However, as stakeholders did not describe more drastic changes of soil fertility with yield changes, e.g. by pointing towards exponential developments, we assume that the employed equal-distant calibration approach (Table 5) captured the local soil fertility evaluations adequately in this case.

**Fig. 8.** FALLOW model scenario analysis to test stakeholder-based assumptions how to combat decline of upland soil fertility: \(K_{\text{fert}0.1} = \) fertilizer + cover crop, \(K_{\text{fert}0.25} = \) current fertilizer use, \(K_{\text{fert}0.1} = \) reduced efficiency of fertilizer due to soil degradation, e.g. soil erosion. Scenario IncFert = increase fertilizer application rates, starting in 2000; EarlyFert = fertilizer application started in 1995; ReFallow = reintroduce three year improved swiddening (crop fallow rotation) system in combination with fertilizer use; arrows indicate start of fertilizer use in 2000 (IncFert, EarlyFert, ReFallow) and start of a three year improved swiddening system in 2008 (ReIFallow). Combination with improved fertilizer management (\(K_{\text{fert}0.5}\)) a substantial increase in soil fertility occurred. Nevertheless, all scenarios demonstrated that even when soil fertility improved in the course of time only the upper plateau at the red soil level equivalent (soil fertility with an average value of 10) could be reached.

Using scenario IncFert 0.25 as an example for the current upland crop management (Fig. 9a), the following patterns were observed: (i) soil fertility depletion was most severe close to settlement areas, where yellow soils were most prevalent. The implementation of forest protection sites resulted in areas which were able to maintain black soil conditions, e.g. black clustered zones. In the simulation, the majority of plots in 2008 were found to be moderately
The presented study falls in line with recent attempts to incorporate participatory approaches in various forms into environmental simulation approaches (Voinov and Brown Gaddis, 2008; Voinov and Bousquet, 2010). Limitations of such an approach lie in the nature of expert’s knowledge boundaries of space, i.e. Ban Put village and time, i.e. 1988 to 2008, as this pre-defines the overall modelling exercise. Several authors (Saito et al., 2006; Schuler et al., 2006; Vigiak et al., 2005) describe it as a common drawback one has to bear in mind when building on qualitative local knowledge. Still other authors, i.e. Ritzema et al. (2010) argue that participatory modelling can compensate data scarcity in case study areas. Within the scope of this study, the dynamic, non-linear conceptual soil fertility approach of the FALLOW model facilitated the inclusion of qualitative and semi-quantitative information. It revealed that qualitative expert knowledge is an option to parameterize a land use simulation model such as FALLOW. Such a combination can be especially useful in data-poor environments as prevalent in most tropical and subtropical regions where new directions are needed to address shortcomings of traditional simulation models (Ritzema et al., 2010).

5.2. The ‘hidden soil degradation’ phenomenon

Scenario analysis pointed to an increasing soil degradation masking the effect of hybrid maize and fertilizer use. In farmers’ perceptions, soil degradation is compensated by the positive yield effect of hybrid crop varieties and fertilizer use. Yet, scenario simulations did not confirm stakeholder assumptions that a simple increase of fertilizer rates will improve soil fertility, as FALLOW simulations rather found the opposite trend. Although, experimental data from northern Thailand confirmed that increased fertilizer use led to larger amounts of crop residues recycled and reduced erosion, due to enhanced soil cover, alone it could not offset the impact of soil management intensification (Pansak et al., 2008). In the case of Chieng Khoi commune, Boll et al. (2008) found that fields with longer distances to homestead possess a younger cropping history with

Fig. 9. a. Spatial soil fertility development of scenario IncFert 0.25 in 2008 and 2018, b. Evolution in areas of soil fertility classes by soil colour in uplands of Ban Put from 2007 to 2018 for scenario IncFert 0.25.
higher yield potential compared to fields closer to homesteads. The scenario analysis confirmed this spatial trend. It also demonstrated that soil degradation is moving towards critical red to yellow soil levels (Fig. 9) with a higher vulnerability for soil erosion (Clemens et al., 2010). Remaining options of local land managers lie in the change of current cropping practises or the abandonment of fields for fallow as also described by farmers in the focus group session causes and consequences. In that sense, farmers tend to revert the time of fallow from a couple of months to years. Clearly, the reduction of fallow periods poses a serious threat to long-term sustainability of upland sites in Northwest Vietnam. Dung et al. (2008) estimated that for successful soil amelioration, a fallow period of 15–30 years would be needed to rebuild soil organic carbon and soil nitrogen contents. Low levels of current soil fertility pose also a challenge to potential soil conservation strategies as the build-up of soil fertility will be slow once soil degradation is advanced (Wezel et al., 2002) as demonstrated in the scenario simulations (Fig. 9). Here, agroforestry or intercropping systems could be an option, i.e. using Tephrosia candida as fallow or hedgerow (Fagerström et al., 2001) or jack bean (Canavalia ensiformis) as relay or cover crop (Pansak et al., 2010). Still, a successful introduction of soil conservation techniques has to take farmers’ criteria, such as crop management, labour inputs and economic viability into account, as past examples in Northern Vietnam have proven that the human dimension of soil conservation were often neglected (Clement and Amezaga, 2008; Fagerström et al., 2001; Saint-Macary et al., 2010; Valentin et al., 2008). Here lies an apparent advantage of the FALLOW model, as it allowed the possibility of integrating different knowledge domains to produce simulations that could be relevant for local stakeholders and decision-makers. In contrast to process-based biophysical and spatially explicit modelling approaches, i.e. LUCIA (Marohn et al., 2010), the FALLOW model concept builds on ‘minimum necessary degree of complexity’ (Seppelt et al., 2009) for prospecting impact of alternative land use management options building on the dynamic, non-linear Trenbath soil fertility approach (van Noordwijk, 1999). The low data input requirements compared to data-demanding mechanistic model approaches allowed the disclosure of meaningful insights into the local soil degradation phenomena relevant for strategic planning. However, the FALLOW approach is limited in its ability to quantitatively evaluate effectiveness and impact of different management options relevant for extension services. Correspondingly, model outputs should thus be considered as semi-quantitative trends with meaningful development projections within the given boundaries.

The evolution of annual crop yield and soil fertility is depending on the selected categorical variables and the induced change of cropping systems calibrated according to stakeholder descriptions. Clearly, the robustness of the quantitative simulation ability relies on its comparison to qualitative information. The comparison of model baseline simulations with secondary data at commune level demonstrated a reasonable good land cover change trend agreement. The predictive spatial-explicit capabilities of the FALLOW model where evaluated with the goodness-of-fit method and indicated that the simulated land use map in 2007 did correlate well with a satellite derived land cover map at pixel resolutions lower than 32 m. Nevertheless, model evaluation relying on remote sensing derived land cover data have also certain limitations, i.e. difficulties in distinguishing shrub land and forest in the context of the Chieng Khoi commune (Thi et al., 2009), while local statistical data are also not always reliable particularly where forest conservation plans by governments clash with farmers demand for cropland. It is therefore acknowledged that data limitations arose regarding the quantification of spatial location and variation in land use functions which is considered as a main challenge of spatial model explorations (Claessens et al., 2009; Verburg et al., 2009).

5.3. Lessons of the integrated assessment approach

The study demonstrated its value in a dynamic and changing environment. The combination of participatory and semi-quantitative simulation assessment approaches was useful because (i) focus group discussion findings revealed problems of declining soil fertility related to land use change and cropping intensification, and (ii) drawing on the FALLOW model simulations indicated resource degradation masked by current cropping strategies. This could be further confirmed by scenario simulations pointing towards the rising difficulties to reverse the downward trend of soil fertility development by the current crop management schemes.

‘Modelling with stakeholders’ (Voinov and Bousquet, 2010) can enhance system understanding and its dynamics as in the case of land use change to identify and clarify the impacts of solutions to a given problem in environmental decision making processes. However, like all other approaches for collaborative learning and decision support, its credibility and usefulness needs thorough validation and uncertainty assessment. For this study, two contrasting validation tools were used. On the one hand, the developed feedback loop employed as an over spanning concept in the focus group discussion reduced output uncertainty, and also provided a consent based stakeholder decision framework. On the other hand, the quantitative goodness-of-fit method which served as validation tool to compare the simulated land use change trajectories with their observed counterparts. Remaining uncertainty led finally to the decision to define the presented approach as a semi-instead of complete quantitative assessment approach. Moreover, in contrast to participatory modelling approaches, e.g. Becu et al. (2008), the present study can be rather understood as a first step for a decision making process in a data-poor environment. It underscores the claim that models which integrate various knowledge domains can be credible and legitimate tools to inform and support the need of sustainable natural resource management options (Lusiana et al., 2011). In this process, it is not always necessary to involve the stakeholders in the whole cycle of model development and evaluation (Jakeman et al., 2006), but rather adjust the type and degree of stakeholder participation to the model’s real needs which can feed and invigorate the modelling process with new data, ideas and perspectives (Voinov and Bousquet, 2010; cf. Neef and Neubert, 2011).

6. Conclusion

The presented study has an important message to convey at community level. If resource managers resist changing current cropping practises, environmental degradation will adversely affect the livelihoods of farmers and will be increasingly difficult to reverse. Yet this problem has a much broader regional dimension as the presented case study is a typical example of the regional challenges the north-western mountain provinces of Vietnam are currently facing. This study has shown that building on an iterative participatory approach suitable input variables can be obtained for semi-quantitative modelling and hence can be used as a methodological pathway to foster the implementation of sustainable upland cropping practises. The combined approach has shown to be a useful tool due to its open and adaptive research strategy in a data-poor environment.

Acknowledgement

The authors would like to thank the villagers of Ban Put and Mr. Ha Van Keo for their support and openness during the course of field work time. This research was conducted in the framework of


