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INTENSIFICATION OF UPLAND AGRICULTURE IN THAILAND: DEVELOPMENT OR DEGRADATION?

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ABSTRACT

The large scale conversion of extensive swidden agriculture to intensive market oriented production of maize in upland areas of South East Asia is a cause of environmental concern. This study investigates how intensive maize cultivation affects soil quality in an upland area of Northern Thailand by comparing commonly used indicators of soil quality in soils from maize fields used at various intensities. Relations between these indicators and concentration of permanganate oxidizable carbon (Pox-C) – a low cost proxy for soil quality – are also examined. The extent, type and drivers of land use changes between 2002 and 2012 are investigated by classification of high resolution satellite images, interviews, participatory mapping and questionnaires. We document a widespread change from traditional swidden agriculture to intensive cultivation of maize that is mainly brought about by economcic and political drivers. We show that the concentration of Pox-C in the top soil of the maize fields is closely related to common indicators of soil quality and to farmers' perceptions of soil quality. Most of the other soil quality indicators are negatively – albeit not significantly – related to intensity of maize cultivation. There is a strong negative correlation between intensity of maize cultivation and concentration of Pox-C in the upper 5 cm of the soil where the Pox-C concentration declines with a rate of 40 mg year under maize^{-1}. We conclude that Pox-C is a sensitive indicator of effects of land use intensity on the soil and a useful integrative measure of soil quality.

KEY WORDS: Soil quality; Permanganate oxidizable carbon; Maize cultivation; Swidden agriculture; Farmers' perceptions

INTRODUCTION

Land use changes have shaped the face of the Earth for thousands of years (Ellis *et al.*, 2013), but in recent decades, they have been particulary rapid and extensive in the tropics, where one of the most widespread changes has been the transition of traditional land use systems to intensified systems focussing on production of cash crops (Lambin & Meyfroidt, 2011; van Vliet *et al.*, 2012). The intensified land uses are putting the soil system under pressure and will have an impact on soil functions, but the severity, extent and consequences of soil degradation remain poorly documented (Brevik *et al.*, 2015; Keesstra *et al.*, 2016). In the uplands of South East Asia, the past few decades have witnessed a widespread shift from subsistence oriented swidden agriculture to intensified systems with continuous cultivation of annual cash crops (Schmidt-Vogt *et al.*, 2009; van Vliet *et al.*, 2012). The term 'swidden agriculture' is here defined as 'a land use system that employs a natural or improved fallow phase, which is longer than the cultivation phase of annual crops, sufficiently long to be dominated by woody vegetation, and cleared by means of fire' which is in accordance with Mertz *et al.* (2009). The intensification has in many cases been encouraged or enforced by economic or political pressure and has for many farmers offered immediate economic benefits, while at the same time provided a potentially risky livelihood, exposing farmers to market fluctuations, higher inequality and reduced access to land (van Vliet *et al.*, 2012). The impacts of this agricultural intensification on the environment – for example, on soil quality, biodiversity, ecosystem services and carbon stocks of the region are also a cause of concern (Bruun *et al.*, 2009; Rerkasem *et al.*, 2009; Ziegler *et al.*, 2009).

In Thailand, large areas previously used for extensive swidden agriculture have over the recent decades been converted into continuous cultivation of maize to supply fodder for the region's growing livestock industry, and maize is now one of the most important cash crops in upland areas of Northern Thailand, where about 70% of Thailand's area under maize is found (Yap *et al.,* 2016). Most of the maize cultivation systems are managed by smallholders, who to a large extent rely on micro-credit from institutions supported by the Thai government (Ahlin & Jiang, 2008; Ekasingh, *et al.*, 2007). The formalization and outreach of microfinance facilities in remote rural areas increased significantly after 2001 when the former Thai president Thaksin implemented a comprehensive set of micro-credit programmes as an attempt to accelerate Thailand's recovery from the Asian crisis by stimulating agricultural growth. These programmes made it possible for everyone to obtain a short-term loan without

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presenting collateral; hence, millions of farmers that previously did not have access to formal credit could engage in production of annual cash crops that rely on external inputs – such as hybrid seeds, fertilizers and herbicides (Ekasingh *et al*., 2004). It is a common perception that the expansion and intensification of maize production in Northern Thailand can be explained by the emergence of credit opportunities and increasing maize prices alone (Pongkijvorasin & Teerasuwannajal, 2015), while little attention has been paid to studying the role of national policies related to natural resource management in Northern Thailand.

The continuous maize cultivation in upland areas is generally based on sole applications of mineral fertilizers, and over the last decade, reports of decreasing yield levels have become increasingly common (Pongkijvorasin & Teerasuwannajal, 2015) and the biophysical sustainability of continuous maize cultivation on the inherently infertile soils in the sloping upland areas is questioned by researchers (Ziegler *et al*., 2009; Tuan *et al*., 2014). A few studies have investigated the effects of intensified maize cultivation on erosion (Tuan *et al*., 2014; Turkelboom, *et al*., 2008), but so far, no studies have presented empirical evidence of the effects of the continuous maize cultivation on soil quality in the upland parts of mainland South East Asia.

There is no universal definition of the broad concept of soil quality that can be studied with different foci – for example, from food quality, human health or environmental perspectives (Karlen *et al*., 2003). We define soil quality as '*the capacity of the soil to support plant growth without causing environmental degradation of the soil or the environment*' (Doran & Parkin, 1994). According to this definition the term encompasses chemical, biological and physical parameters such as nutrient content, pH, organic matter and aggregate stability. Different sub-pools of soil organic carbon (SOC) have been proposed as integrative indicators of soil quality as they reflect key soil processes such as nutrient cycling and C accrual (Culman *et al*., 2012; Haynes, 2005; Karlen *et al*., 1997). The sensitivity of these sub-pools to changes in land use and management as well as their positive relation to soil quality is well documented (Grandy & Robertson, 2007; Wander, 2004), but the analyses required to determine these sub-pools are time-consuming and require complex laboratory manipulation. Therefore, scientists, land managers and extension services are searching for other integrative measures of soil quality that are sensitive to changes in land use and management while at the same time being cheap and relatively easy to measure, and robust to short term variation through the season.

The concentration of permanganate oxidizable carbon (Pox-C) in the topsoil has been suggested as a relatively cheap and easily measureable indicator of land use or management induced changes in soil quality (Weil *et al.*, 2003). This parameter can be determined in the field and has shown promising results on temperate soils (Culman *et al*., 2012) on which several studies have found Pox-C concentration to be a more sensitive indicator of the effects of tillage treatments than total SOC content (Melero *et al.*, 2009; Weil *et al.*, 2003). Strong correlations between Pox-C and several commonly used soil quality indicators (i.e. microbial biomass, particulate organic carbon and basal respiration) have also been documented (Weil *et al.*, 2003; Melero *et al.*, 2009; Culman *et al.*, 2012).

The number of studies of relations between concentration of Pox-C and soil quality in tropical soils is very limited, but there are reports of positive relations between Pox-C and physical (aggregate stability) and chemical (Effective Cation Exchange Capacity) soil parameters in Australian Oxisols (Bell *et al.*, 1998). Moreover, Bruun *et al.* (2013) documented a significant decline in the Pox-C concentration of the topsoil in response to a land use change from swidden agriculture to oil palm cultivation in Sarawak, Malaysia, but did not relate concentration of Pox-C to general soil quality. The vast majority of studies applying the Pox-C method have been carried out in temperate regions; hence, experience from using the method in tropical soils is limited as is evidence from land use systems that do not involve tillage.

In response to the research gaps and methodological challenges documented above, we study land use intensification taking place in an upland village in Northern Thailand in the period between 2002 and 2012 and investigate (1) the drivers behind the intensification; (2) the effects of this intensification on soil quality; (3) the relation between concentration of Pox-C and a range of commonly used soil quality indicators in a Thai Ultisol; and (4) the relations between farmers' perceptions of soil quality and bio-chemical indicators of soil quality. The choice of 2002 as reference year is based on the extensive set of policies and credit programmes aiming at increasing agricultural growth that was implemented in the beginning of the 2000s, and on the availability of a very high resolution satellite image as well as geo-referenced *in-situ* information about land use types from this year.

MATERIALS AND METHODS

A series of field studies were carried out in Nan Province in Northern Thailand in the period between 2010 and 2012. Nan Province is the second largest maize-producing province in Thailand and the area under maize in this province tripled between 2005 and 2009 (Yap *et al.,* 2016). We focused on the village of Ban Huai Puk, that is, a village with 160 households and 540 inhabitants located in Sanian sub-district, Muang district (Figure 1). The rural poverty level in the sub-district is between 20% and 30%, corresponding to the level of the poorest half of the districts of Northern Thailand (Jitsuchon & Richter, 2007). The biophysical characteristics of the study area are considered typical for Nan Province and for the upland areas of the rest of Northern Thailand. The area consists of hilly landform, typically with inclinations between 15° and 25°, and elevations between 300 and 800 m a.s.l. Small strips of flat land is found along some of the streams. The upland soils of the area are classified as Red Yellow Podzolic soils according to the Thai soil classification system, which translates

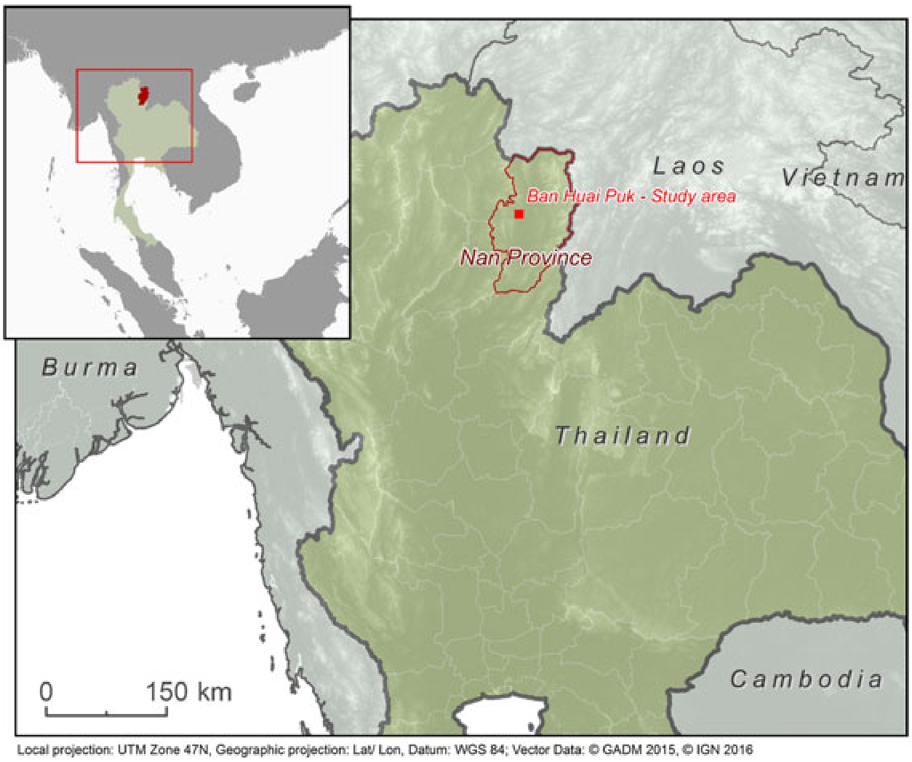

Figure 1. Location of the study area.

into Ultisols in the USDA soil classification system (Moormann & Rojanasoonthon, 1967). Ultisol is the dominant soil type of Nan Province and of Northern Thailand as a whole (Pendelton, 1949). About 40% of Nan Province consists of slopes with inclinations between 15° and 25° and areas with inclinations within this range are typically used for maize cultivation (Sripun, 2016). The mean annual temperature is 26 °C and the mean annual rainfall is 1250 mm – distributed in a wet season from May to September (930 mm) and a dry season from October to April (320 mm) (Globalweather, 2015).

Questionnaire Surveys, Interviews and Participatory Mapping

In 2010, a questionnaire survey with 32 randomly selected households was carried out to collect data about the farming system including the development in agricultural activities over the last 10 years, and data on farmers' perceptions of soil quality (referred to as questionnaire survey 1). In 2011, this survey was supplemented with a questionnaire survey with 25 maize growing households (covering 50 maize plots) focussing on obtaining detailed information about the management and land use history of the active maize plots (referred to as questionnaire survey 2). These households were revisited in 2012 and interviewed about the maize yields and constraining factors in the 2011–2012 cropping season. The questionnaire surveys were also used to select maize plots to be included in two sub-studies focussing on effects of land use intensification on soil quality and on farmers' perceptions of soil quality, respectively. Qualitative data was generated from in-depth interviews ($n = 20$) and ranking exercises focussing on financial aspects of maize production, including information about indebtedness and farmers' criteria behind land use decisions. Moreover, a participatory mapping exercise focusing on present and past land use was carried out and combined with a group interview on causes and consequence of land use changes (Rasmussen *et al.*, 2015). Three in depth interviews about the local soil classification system were carried out and followed by a focus group interview with a soil mapping exercise aimed at obtaining an overview of the distribution of different soil types within the village area (Defoer & Budelman, 2000). Interviews were also conducted with the owner of a nearby silo where most farmers sold their produce, and with the head of the Department of Agricultural Extension in Sanian sub-district.

Land Use Mapping

The land use classification was based on two very high resolution, multispectral and pan-sharpened images from 2002 and 2010. A QuickBird-2 image subset with 0·6 m spatial resolution and 16% cloud cover from 31·12·2002 as well as a GeoEye-1 cloud free subset with 0·5 m spatial resolution from 04·02·2010 were purchased. An object-oriented classification approach was chosen in order to reduce spectral mixing and for a better distinction between landscape elements because of their geographical and geometrical features such as shape or texture (Blaschke, 2010). Single pixels of each image were first grouped into regions representing objects within a multispectral segmentation. The most important land use classes were defined as: 'active field', 'young fallow' (vegetation < 10 years, dominated by bamboo), ‘old fallow’ (vegetation > 10 years, dominated by trees) and ‘plantation’ (mainly rubber and fruit orchards). The land use classification was performed within a two-step supervised classification (Lu & Weng, 2007) starting with a stratification of the study site in vegetation/non-vegetation areas by using spectral and geometrical characteristics as well as the Normalized Difference Vegetation Index. Next, the non-vegetation class was classified as active fields, and subsequently, the vegetation class was classified as young fallow, old fallow and plantations using a sample set relying on ground truth, expert evaluation and a nearest neighbour classification. The validation of the classification was based on exhaustive expert knowledge on land use distribution obtained through six field campaigns. This knowledge was repeatedly confirmed by local farmers through field walks and inspection of the study area from high-elevation points in the field. Because of the small size of the area, the high separability of land use classes, and the in-depth knowledge on local land use, we did not perform a formal quantitative validation of the classification.

The ‘Chronosequence’ Study

For the purpose of investigating the effects of land use intensity on concentration of Pox-C, sampling plots were selected to represent a chronosequence of maize cultivation intensity (referred to as ‘chronosequence’ study in the following) ($n = 16$). Only plots with inclinations between 15° and 25° were included as this slope interval was considered representative of the plots used for maize cultivation (this was confirmed by the fact that we only had to exclude one single field due to this criterion). Plots with an uncertain land use history were avoided.

The ‘Soil Quality’ Study

The relations between farmers’ perception of soil quality and bio-chemical soil quality indicators were investigated in a sub-study referred to as the ‘soil quality’ study. Sampling plots were selected based on farmers’ statements on soil quality. In questionnaire survey 1, farmers were asked about their perception of the soil quality of all their maize plots. In cases where the same farmer had a maize plot with ‘good’ soil and a maize plot with ‘bad’ soil, these two plots would be selected, sampled and treated as one pair in the ‘soil quality’ study ($n = 16$).

Soil Sampling, Preparation and Analyses

Soil from the plots included in the ‘chronosequence’ study was sampled from three replicate profiles located on the middle of slopes. Volume specific soil samples were collected with a 100 cm^3 metal core from four depths: 0–5 cm, 10–20 cm, 30–40 cm and 50–60 cm. Soil from plots included in the ‘soil quality’ study was sampled in the same way, but only from one profile per plot.

Samples were air dried onsite and prior to analysis dried for 24 h at 80 °C, weighed, crushed and sieved through a 2 mm mesh. Stones were weighed and the bulk densities of samples containing stones were corrected assuming stones to have a bulk density of 2·6 g cm^{-3}. All samples from one profile $site^{-1}$ were analysed for soil texture. All samples from all profiles were analysed for pH levels, concentrations of SOC, N and Pox-C, and samples from the two upper layers were furthermore analysed for concentrations of plant available, P, exchangeable base cations, acid cations, free iron and aluminium (hydr-) oxides and for Cation Exchange Capacity (CEC). Soil texture was determined by the hydrometer method. The pH level was determined in a 1:2·5 soil:water solution, concentration of total SOC and total Nitrogen were determined by Continuous Flow Isotope Ratio Mass Spectronomy. Concentrations of Pox-C were determined according to the method described by Weil *et al.* (2003) and revised by Gruver (2004): 2·5 g dry crushed soil was weighed to a Falcon tube, 18 ml of milli-Q water and 2 ml of 0.2 M $KMnO_4$ in 1 M $CaCl_2$ adjusted to pH 7 were added sequentially. Samples were shaken for 2 min and left to settle for 10 min. An electronic pipette was used to transfer 1.00 mL supernatant to clean Falcon tubes and diluted with 19 mL of milli-Q water. Absorbance at 550 nm was measured with a Hach pocket colorimeter. Samples were analysed in batches of eight, and a consistent procedural time was maintained.

Plant available P was determined by the Olsen method (Olsen & Sommers, 1982). Base cations were extracted with 1 M ammonium acetate and measured with Atomic Absorption Spectrophotometry (AAS) (Thomas, 1982). Acid cations (Al and H) were determined by titration after extraction with 1 M potassium chloride (Yuan, 1959). CEC was determined as the sum of basic and acidic cations. Total content of free iron and aluminium (hydr-) oxides was estimated as dithionite-citrate-bicarbonate extractable iron and aluminium using the method described in (Mehra & Jackson, 1960) and AAS.

Land Use Intensity

The plot specific land use history was parameterized using an Accumulated Cropping Index (ACI) calculated for the last 10 years. The ACI is a calculation of (the land use intensity similar to the commonly used R-value that is defined as the number of years under cultivation divided by the total number of years since the land was cleared (Ruthenberg, 1980). The ACI is a modification of the Accumulated Farming Index (AFI) applied by Birch-Thomsen *et al*. (2007) and is calculated by assigning the values 10–0 to each of the past 10 years starting with the value 10 for the current year and ending with 0. If an area was used for maize for the past 2 years, fallowed for 4 years before that and used again for maize for 4 years before then, an ACI of $10 + 9 + 0 + 0 + 0 + 0 + 4 + 3 + 2 + 1 = 29$ would be assigned. This means that more recent cultivation activities have a greater impact on the ACI value than they would have according to the R-value. The number of years under maize during the last 10 years was used as an alternative measure of land use intensity.

Calculations and Statistics

Concentrations of Pox-C were calculated according to the following formula:

$$\text{Pox-C}\ \left(\text{mg kg}^{-1}\right) = \left[0.02\ \text{moll}^{-1} - (\text{a} + \text{b} \times \text{absorbance})\right]$$
$$\times \left(9000\ \text{mg C mol}^{-1}\right) \times (0.021\ \text{solution}/0.0025\ \text{kg soil})$$

Where $0{\cdot}02\ \text{mol L}^{-1}$ is the initial concentration of MnO_4 in the reactant, a is the intercept of the standard curve, b is the slope of the standard curve, and 9000 mg is the amount of mg C oxidized by 1 mol of MnO_4.

Statistical analyses were conducted using SPSS 20 for Windows. Homogeneity of variance was tested with Levene's test of equality of error variance, and histograms were used to confirm assumptions of normality. The Pearson correlation coefficient and regression analyses were used to investigate relations between land use intensity and soil parameters. Pearson correlation was used to investigate relations between individual soil parameters. Paired sample *t*-test test was used to explore the relation between farmers' perceptions of soil quality and selected physical and chemical soil parameters.

RESULTS AND DISCUSSION

Land Use Changes

The agricultural area of Ban Huai Puk was delineated based on the participatory mapping exercise and geo-referencing of the accessible parts of the border of the area. The total size of the area was $14{\cdot}15\ \text{km}^2$ (Figure 2). The area under active fields more than tripled from $1{\cdot}52\ \text{km}^2$ to $5{\cdot}16\ \text{km}^2$ between 2002 and 2010 (Figure 2). This development has mainly taken place at the expense of the area under old fallows which declined from $8{\cdot}73\ \text{km}^2$ to $5{\cdot}14\ \text{km}^2$ during this period. However, a minor decrease in the area under young fallows can also be observed (Figure 2).

In the swidden agriculture system, which was the dominant land use type in the area prior to 2002, the common practice was to leave a piece of land fallow between 5 and 15 years followed by 1–2 years of cultivation. Fallows were cleared by slashing and burning the vegetation. Typically, the rotation intensities were higher in the areas closest to the village – as seen from the mosaic of active fields and young fallows in the proximity of the village area in the 2002 image (Figure 2) – whereas areas further away from the village were used less intensively. In 2010, the land use intensity within the greater village area had increased, and most of the areas under old fallows were either found on hill tops or in areas with severe management restrictions (e.g. a community forest located between the two village clusters). It is noted that the 2010 classification shows no signs of agricultural expansion into areas that were not already used in 2002.

In 2002, upland rice was cultivated by 100% of the respondents, while maize was cultivated by less than 25% of the respondents ($n = 32$) and cotton only to a very limited extent. In 2010, 53% of the respondents cultivated upland rice, whereas maize was cultivated by 90% ($n = 32$) and cotton had disappeared. The average area under maize was $3{\cdot}5\ \text{ha household}^{-1}$ while the average area under rice was $0{\cdot}9\ \text{ha household}^{-1}$. Based on information from the questionnaires, it is estimated that the total area under maize was more than five times larger than the area under upland rice.

Also, the area under plantations almost tripled from 2002 to 2010, but this land use type still only made up a relatively small proportion of the total study area ($0{\cdot}97\ \text{km}^2$ or less than 7% of the total area). More than a third of this increase can be attributed to the establishment of a large scale commercial rubber plantation in the south eastern part of the study area.

The Maize Cropping System

In the maize cultivation system fields were cleared of weeds and prepared between January and May without any mechanization or tillage. The maize was sown in June by means of dibble sticks, and all respondents used hybrid maize seeds with the most commonly used type being CP888. Urea was the most commonly used fertilizer, sometimes supplemented with minor amounts of 30:0:0 or 15:15:15 NPK fertilizers. Average nutrient additions were $50\ \text{kg N ha}^{-1}$, $7\ \text{kg P ha}^{-1}$ and $14\ \text{kg K ha}^{-1}$. All respondents used herbicides during the growing season and 90% ($n = 25$) relied on loans to purchase the inputs. Maize was harvested manually during October to December with reported yields between 900 and $3500\ \text{kg ha}^{-1}$ ($n = 50$). In the early 2000's, some maize fields were occasionally left fallow, but the use of fallowing as a part of the maize cultivation system became very rare in the latter part of the time period under study. Most of the farmers sold their produce to middlemen who brought it to one of the many maize silos around Nan city. In 2012, the silos in Nan sold about 80% of the maize produce to the Charoen Pokphand Group (CP) – the largest agribusiness company in Thailand.

General Soil Characteristics

The clay content of all sites increased with depth from 34·0–37·3% in the upper 5 cm of the soil to 46·7–53·0% in the layer between 40 and 60 cm (Table I). The homogeneity of the clay content validates the assumption that the inherent soil properties of the sites included in the chronosequence study are similar. The pH levels decreased with depth from an average of 5·8 in the upper 5 cm of the soil to an average of 5·3 in the layer between 40 and 60 cm (Table I) and fall within the typical pH ranges of Ultisols in Thailand (Trakoonyingcharoen *et al.*, 2005). The range in CEC values of soil from the different sites was relatively wide, but all values are considered low and within a range that is typical for soils dominated by kaolinite. The same observation applies to the content of bases and plant available P (Bruun *et al.*, 2006; Trakoonyingcharoen *et al.*, 2005). Contents of iron and aluminium (hydr-) oxides are considered to be relatively high in comparison to other reported values from Asian Ultisols (Bruun *et al.*, 2010).

Pox-C and Soil Quality

The Pox-C concentration of the 0–5 soil layer is positively and significantly correlated with all investigated indicators of soil quality (Table II). The same pattern is found in the

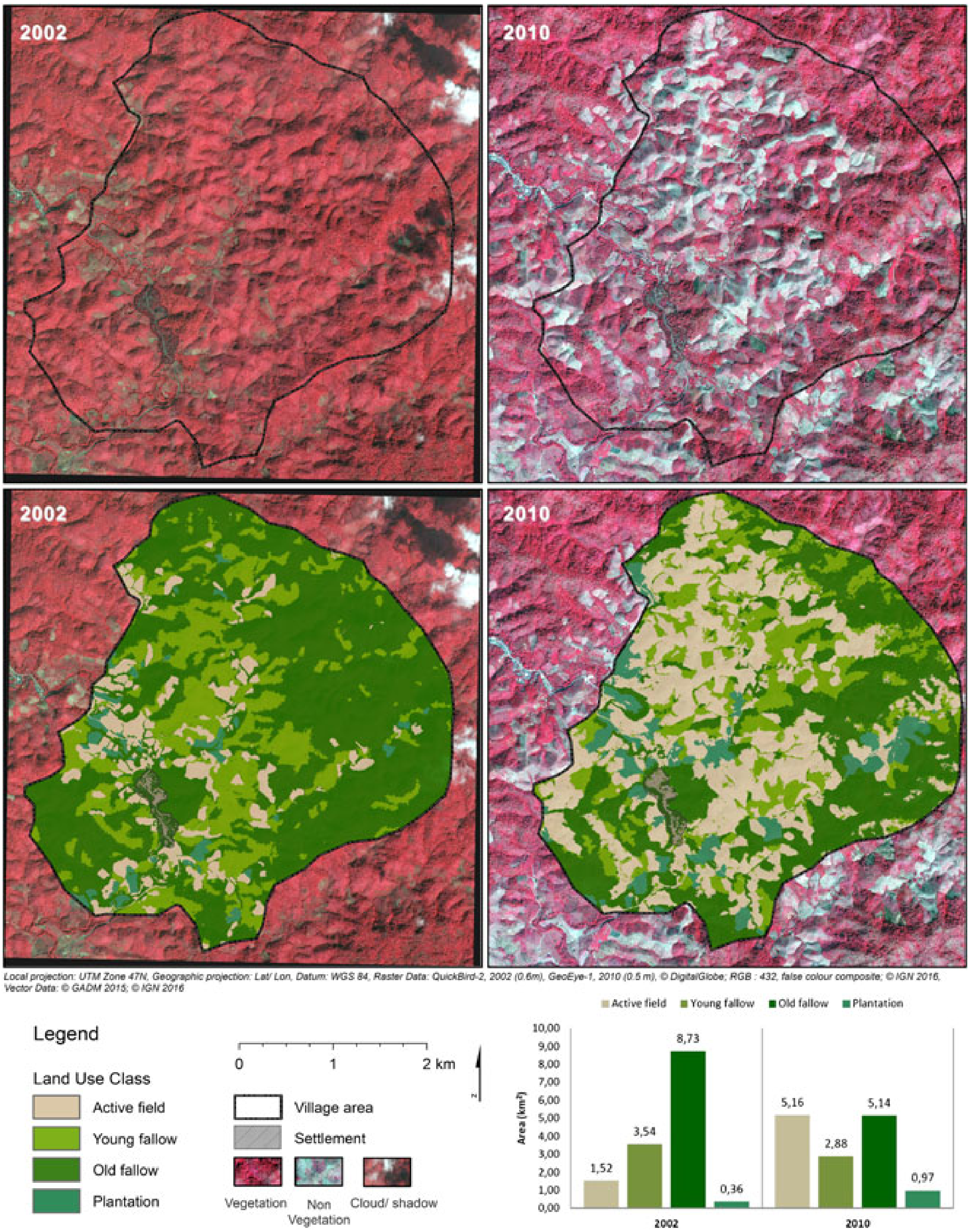

Figure 2. Land use classification of the agricultural area of Ban Huai Puk in 2002 and 2010.

10–20 cm soil layer–except for the correlations between Pox-C and pH, K and Ca that are not significant in this layer. It is noted that pH level is also correlated to most of the investigated soil quality parameters (in both soil layers), whereas the commonly used indicator of soil quality – SOC – is only significantly correlated to concentrations of N and K (and to Pox-C) (Table II). This pattern suggests that concentration of Pox-C represents an integrative measure of soil quality and that soil pH level – another easily measurable parameter – is also a useful indicator of soil quality in these depleted Ultisols.

Relations Between Farmers' Perception of Soil Quality and Soil Bio-Chemical Parameters

The local soil classification system was based on observable physical properties of the humus containing topsoil, and sub-soil layers were only included if they were found close to the topsoil or mixed with this. The soil types found within the agricultural area of Ban Huai Puk were: Din Dam (black soil): A soil with a soft, thick and dark coloured topsoil; Din Daeng (red soil): A soil in which the hard reddish subsoil was exposed at the soil surface; Din Jang (tasteless soil): A soil with a pale coloured topsoil that has been degraded

Table I. Descriptive statistics of the soil parameters from all sites

Soil parameter	Depth (cm)			
	0–5	10–20	30–40	40–60
Clay (%) ($n=16$)	34·0–37·3 (36·0)	40·0–43·7 (41·6)	44·3–48·0 (46·4)	46·7–53·0 (50·3)
pH ($n=46$)	4·9–6·7 (5·8)	5·2–6·4 (5·8)	4·6–6·4 (5·3)	4·6–6·4 (5·3)
SOC (%) ($n=46$)	1·4–4·3 (2·8)	1·0–2·2 (1·5)	0·6–2·0 (1·00)	0·4–1·1 (0·8)
Pox-C (mg kg^{-1}) ($n=46$)	96–1056 (503)	0–720 (129)	0–0 (0)	0-0 (0)
N (%) ($n=46$)	0·14–0·30 (0·23)	0·1–0·2 (0·15)	0·07–0·18 (0·11)	0·07–0·12 (0·09)
CEC (cmol(+)kg^{-1}) ($n=16$)	7·6–24·3 (15·9)	6·8–16·3 (10·4)	—	—
Mg (cmol(+)kg^{-1}) ($n=16$)	1·8–10·8 (6·2)	0·6–6·2 (3·5)	—	—
K (cmol(+)kg^{-1}) ($n=16$)	0·1–0·8 (0·3)	0·1–0·5 (0·2)	—	—
Ca (cmol(+)kg^{-1}) ($n=16$)	4·5–13·5 (8·9)	3·8–10·0 (6·0)	—	—
Base cations cmol(+)kg^{-1}) ($n=16$)	6·5–24·1 (15·5)	4·6–16·2 (9·8)	—	—
Plant available P (mg kg^{-1}) ($n=16$)	1·5–7·3 (3·8)	0·7–2·7 (1·6)	—	—
Fe and Al (hydr-) oxides (g kg^{-1}) ($n=24$)	29–47 (37)	33–51 (42)	—	—

Mean values are shown in brackets. Three replicate samples site^{-1} were analysed for pH and concentration of SOC, Pox-C and N, while one sample site^{-1} was analysed for CEC, concentration of base cations, plant available P and Fe and Al (hydr-) oxides.

because of intensive cultivation. Furthermore, farmers distinguish between upland and lowland soils. Most lowland soils were classified as Din Dam while Din Jang was only found in upland areas. Farmers described a 'Good' soil as a soil that is '*dark*', '*soft*', '*easy to dig*', '*able to hold a lot of water*' and '*feels cold*'. A good soil would always belong to the 'Din Dam' soil type. A 'Bad' soil was described as a soil with a '*hard*' or '*stiff*' surface and/or with a '*reddish*' top soil. According to the interviewees a bad soil would always be referred to as Din Daeng or Din Jang although a soil classified as Din Daeng may also be described as 'average'. Soil colour, consistency, and water retention capacity are also among the most used criteria for soil classification in indigenous systems found in other parts of the tropics (Barrera-Bassols & Zinck, 2003; Breuning-Madsen *et al.*, 2010; Mertz, *et al.*, 2010).

Farmers' perceptions of 'Good' and 'Bad' soils were compared with selected bio-chemical soil quality indicators. The sensitivity of the soil parameters to the perceived difference in soil quality can be gauged statistically by the t-value that indicates with how much certainty the two populations of soils were different by a paired *t*-test. The analysis show that pH levels, contents of Ca and contents of Pox-C exhibit the most consistent difference between the two groups of soils and thus that farmers' perception of soil quality is closely related to these parameters (Table III). It is noteworthy that the concentration of SOC has the second lowest *t*-value, which shows that the permanganate oxidizable carbon fraction is a sensitive fraction that is associated with other soil properties than SOC. No significant relations were found below 5 cm.

Effects of Maize Cultivation on Soil Quality

The effects of intensity of maize cultivation (measured as years under maize and ACI) on soil quality were explored by correlation and regression analyses. Most of the

Table II. Correlations between soil parameters

	SOC ($n=58$)	N ($n=58$)	pH ($n=58$)	CEC ($n=24$)	Mg ($n=24$)	Ca ($n=24$)	K ($n=24$)	Bases ($n=24$)	Plant available P ($n=24$)	Al and Fe (hydr-) oxides ($n=24$)
0–5 cm										
Pox-C	0·546**	0·668**	0·347**	0·582**	0·378*	0·545**	0·446*	0·540**	0·509*	−0·154
SOC	1	0·835**	−0·063	0·375	0·267	0·290	0·470*	0·341	0·214	−0·389
N	x	1	0·156	0·442*	0·298	0·389	0·392	0·410*	0·191	−0·371
pH	x	x	1	0·733**	0·578**	0·702**	0·246	0·741**	0·267	0·180
10–20 cm										
Pox-C	0·593**	0·493**	0·145	0·612**	0·540*	0·457	0·339	0·545*	0·734**	0·125
SOC	1	0·855**	0·036	0·281	0·162	0·195	0·451*	0·218	0·187	−0·144
N	x	1	0·032	0·238	0·085	0·238	0·436*	0·197	0·202	−0·164
pH	x	x	1	0·566**	0·451*	0·711**	−0·273	0·642**	0·425*	0·419*

Correlations are based on soil samples from the 'chronosequence study' as well as samples from maize fields included in the 'soil quality' study.
Pox-C, permanganate oxidizable carbon; SOC, soil organic carbon.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Table III. The relationship between farmers' perception of soil quality and selected soil parameters in the 0–5 cm layer of eight pairs of soils from Ban Huai Puk

Soil Parameter	Bad	Good	t-value	Probability
pH	5·69	6·10	3·079	0·018
Ca (cmol(+)kg^{-1})	7·4	10·4	2·561	0·037
Pox-C (mg kg^{-1})	442	588	2·551	0·038
Plant available P (mg kg^{-1})	3·5	7·7	2·162	0·067
Mg (cmol(+)kg^{-1})	6·2	5·5	−1·193	0·272
Bases (cmol(+)kg^{-1})	13·6	15·3	0·885	0·406
N (%)	0·21	0·22	0·814	0·442
CEC (cmol(+)kg^{-1})	14·4	15·6	0·719	0·495
Bulk Density (g cm^{-3})	1·00	0·96	−0·640	0·543
K (cmol(+)kg^{-1})	0·3	0·3	0·423	0·685
SOC (%)	2·47	2·52	0·162	0·876
Fe and Al (hydr-) oxides (g kg^{-1})	37·3	37·1	−0·039	0·971

$n = 16$

correlations between the land use intensity parameters and the investigated soil quality parameters of the 0–5 cm and 10–20 cm soil layers are negative, albeit only a few of the correlations are significant (Table IV). No major differences are found in the strength and pattern of correlations between the two land use indicators and the soil quality parameters. Strong negative correlations are found between ACI and concentration of Pox-C in the upper 5 cm of the soil ($R = -0·717$, $p = 0·002$) and between 'years under maize' and concentration of Pox-C in the upper 5 cm of the soil ($R = -0·634$, $p = 0·008$). The relationships between Pox-C and ACI as well as between Pox-C and 'years under maize' are best represented by linear regression functions (Figure 3). On average, the content of Pox-C in the upper 5 cm of the soil declines with 40 mg y-under-maize^{-1} (Figure 3). There are indications that the concentration of Pox-C in the upper 5 cm of the soil may increase with the exact same rate when the soil was left fallow (40 mg y-under-fallow^{-1}) (Burup, 2015), but this needs further studies to be confirmed. The negative correlation coefficient between Pox-C and ACI is slightly stronger than the correlation coefficient between Pox-C and 'years under maize' – in the upper 5 cm of the soil (Table IV). This suggest that the Pox-C content in the upper 5 cm of the soil is affected by the accumulated effects of cultivation intensity over the last 10 years and hence by fallowing.

The absence of significant correlations between concentrations of Pox-C in the 10–20 cm layer and 'years under maize' and ACI suggests that current land use intensity only affects Pox-C in the upper 5 cm of the soil – in which concentrations on average are 3·5 times higher than in the 10–20 cm layer. It is, however, noteworthy that all of the selected soil quality parameters are negatively correlated to the indicators of land use intensity, but the correlation is only significant with respect to N concentration ($p = 0·012$ for ACI and $p = 0·043$ for years under maize). In this layer a nearly significant correlation between content of Pox-C and ACI ($R = 0·456$, $p = 0·076$) is also found.

Based on these findings, we conclude that concentration of Pox-C in the upper 5 cm of the soil is sensitive to the land use intensity in the investigated system. This is in agreement with studies of annual cropping systems from temperate areas (Culman *et al*., 2012; Weil *et al*., 2003), but it has not been documented for annual cropping systems under tropical conditions before.

More than 55% of the respondents stated that the soil in their active maize fields was either 'bad' or 'very bad' ($n = 32$) and more than 70% of the farmers ascribed low yields in the 2011–2012 cropping season to low soil quality, which was in most cases ascribed to successive maize cultivation ($n = 50$). Furthermore, 45% of the respondents ($n = 32$) stated that they had observed a clear trend of declining yields, declining soil quality and increased need for fertilizer inputs after successive years of maize cultivation. The setup of our study does not allow for an investigation of relations between yields and content of Pox-C as yields were recorded at field level and the soil sampling scheme does not allow for an extrapolation of the results

Table IV. Correlations between land use intensity and selected soil parameters[a]

	ACI	Years under maize	ACI	Years under maize
	0–5 cm		10–20 cm	
Pox-C	−0.717**	−0.634**	−0.456	−0.335
SOC	−0.205	−0.158	−0.356	−0.243
N	−0.381	−0.338	−0.664**	−0.589*
pH	−0.445	−0.400	−0.436	−0.421
CEC	−0.308	−0.910	−0.344	−0.358
Bases	−0.309	−0.293	−0.351	−0.360
Plant available P	−0.047	0.088	−0.167	−0.028
Fe and Al (hydr-) oxides	−0.214	−0.267	0.056	−0.047
Bulk Density	0.087	0.216	0.018	0.126

$n = 16$.
[a]No correlations were found in the soil layers below 20 cm.
Pox-C, permanganate oxidizable carbon; SOC, soil organic carbon; CEC, cation exchange capacity.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

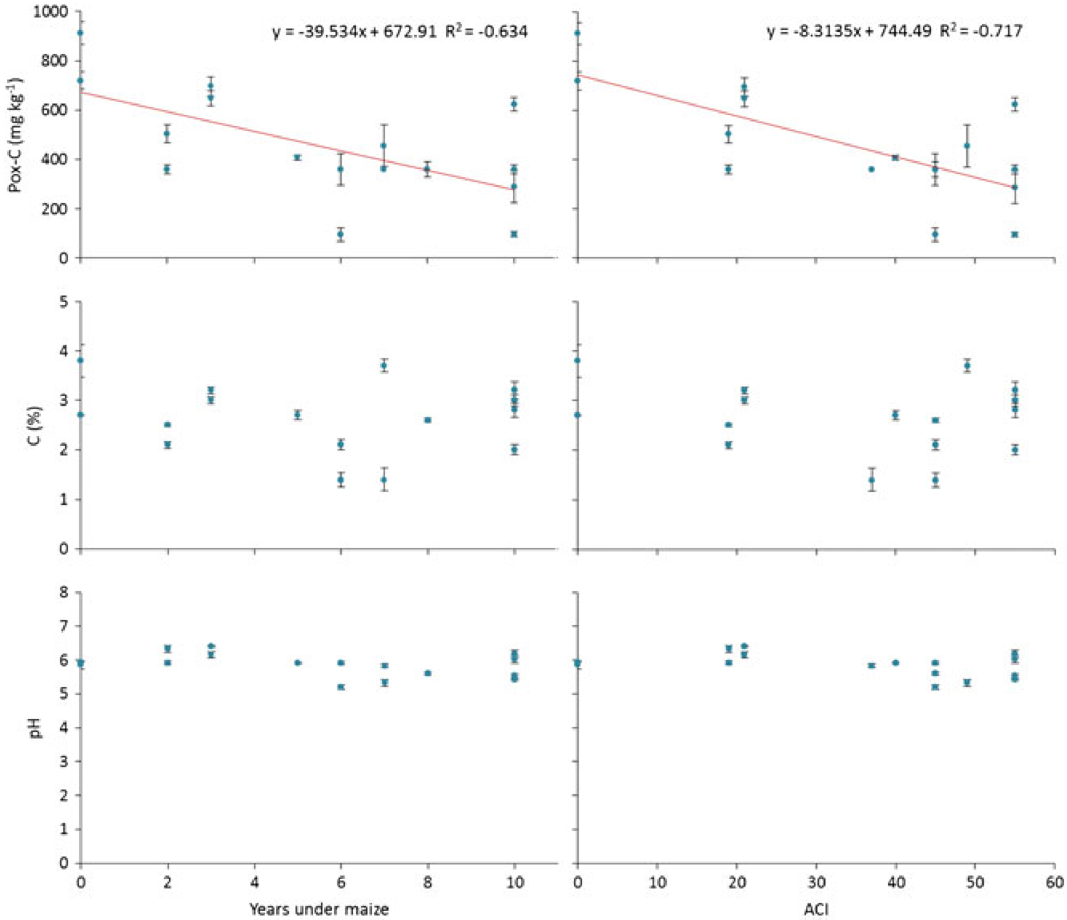

Figure 3. Correlations between land use intensity and selected soil parameters in 0–5 cm.

to entire fields. We do strongly recommend conducting studies on the relations between Pox-C and yield levels.

Causes of the Observed Land Use Changes

The abandonment of the traditional swidden agriculture system and intensification to almost continuous cultivation of maize in the study area is largely driven by a combination of economic and political factors.

The triple increase in domestic maize prices in 2005–2011 (from about \$0·13 kg^{-1} to about \$0·37 kg^{-1}) is considered one of the most important drivers of the expansion of maize cultivation at the national level (Pongkijvorasin & Teerasuwannajal, 2015), and the favourable prices were also mentioned as an important reason for increased cultivation of maize by all of the interviewed farmers in Ban Huai Puk. Many farmers also referred directly to the government's support programmes, such as maize pledging schemes that guarantee the farmers a minimum price for the maize as an incentive for expanding and intensifying the maize cultivation activities. However, lack of alternative low investment cash crops capable of growing on the infertile upland soils was also frequently mentioned as a reason for the sole focus on maize cultivation, as was 'ease of cultivation'. Cultivation of maize is generally considered 'easy' in the sense that it does not require a lot of knowledge nor skills as compared with cultivation of other upland crops. The farmers in Ban Huai Puk have never received any advice on maize cultivation through the official extension channels; instead, they mostly rely on information from the suppliers of agricultural inputs and on sharing experiences with other farmers in and around the village.

More than 65% of the respondents ($n = 32$) started to cultivate maize after 2001 when the Thai Government launched a comprehensive set of micro-credit programmes and declared a 3-year debt moratorium (Ekasingh *et al.*, 2004). In 2011, almost 90% of the maize growing farmers in Ban Huai Puk relied on short term loans from the Bank for Agriculture and Agricultural Cooperatives (BAAC), and many stated the possibility of obtaining credit for maize cultivation as an important reason for continuing to grow this crop. The objective of the micro loans from BAAC is to meet the production costs (e.g. seed, fertilizers and herbicides) over a single cropping season and the loan has to be repaid after harvest with interests of 8–12% y^{-1}. In case of harvest failure, declining maize prices or illness many farmers struggle to pay back their debt and 50% of farmers that were interviewed about the financial aspects of maize cultivation ($n = 20$) stated that their debt was accumulating. Similar situations are reported by other studies from maize farming areas in Thailand and reports of maize farmers being trapped in a vicious spiral of debt are common (Ekasingh *et al.*, 2004; Pongkijvorasin & Teerasuwannajal, 2015).

The complete abandonment of the traditional swidden agriculture system has also to a large extent been driven by a tightening of the land use policies and an increased severity of the penalties for violating these. Over the recent decades, different Thai governments have increasingly enforced a ban on swidden agriculture that was originally declared in 1960. In the late 20th century, an era with strong political focus on establishment of forest conservation areas began, and as swidden agriculture was blamed for causing deforestation, attempts to eradicate the system were intensified (Hares, 2009; TDRI, 1987). Since early 2000, the farmers in Ban Huai Puk have experienced increased inspections by government officials and most recently by soldiers. Some farmers from the village have been fined for open burning, and two persons have been accused of forest encroachment and imprisoned after being caught when clearing what they perceived as their older fallows. The enforcement of the ban on swidden agriculture and the different opinions about what constitutes a fallow and a forest means that farmers are afraid of leaving their land fallow and thereby risk being accused of open burning or of forest encroachment when clearing it.

Current policies and governmental rethoric related to maize cultivation in Northern Thailand are evidently somewhat contradictory in the sense that the government on one hand has provided substantial economic subsidies for maize cultivation in the uplands and enforced the ban on the use of fallowing, but, on the other hand, maize farmers are currently – especially in Nan – being blamed for deforestation and unsustainable intensive land use practices (Bangkok Post, 2015). This might point towards the implementation of more 'Command and control' policies in the uplands in the foreseeable future to circumvent, for example, deforestation and additional changes in smallholders' land use practices and livehoods.

Policy Implications

The results of this study show a consistent negative trend in almost all of the investigated soil quality indicators as a result of continuous cultivation of maize. As documented here, the negative effects of continued maize cultivation was not a surprise for the farmers: The local soil classification system and farmers' perceptions of good and bad soils were to a high degree based on parameters of agronomic relevance that change in response to management, and farmers were also well aware of the effects of continuous cultivation on the soil, and concerned about continuing to cultivate fields that showed signs of soil degradation. Leaving such fields fallow was, however, perceived as an increasingly dangerous option because of the stricter enforcement of the ban on burning of fallowed fields during the 2000s and in some cases not considered economically possible because of indebtedness. Faced with declining maize yields, indebtedness, beginning soil degradation and heavily enforced restrictions on leaving land fallow, the farmers of Ban Huai Puk are left with very limited room to manoeuvre and vulnerable to external stress.

The challenges faced by the farmers in the study area are far from unique. 'Command-and-control' policies aiming at stopping swidden agriculture have been put in place by many governments in South-East Asia, and have repeatedly been criticized for criminalizing farmers and forcing them to unsustainable intensification on permanent fields (Büscher & Dressler, 2012; Castella *et al.*, 2006; Mertz *et al.*, 2013; Ziegler *et al.*, 2011). This is, for example, also the case in Northern Laos where land policies aiming at eradicating swidden agriculture by allocating limited areas for intensive commercial agricultural production – especially of maize – while preserving other areas as forests have forced farmers to intensify production in upland areas (Castella *et al.*, 2013). This has indeed lead to an increase in small-scale commercial maize production under different types of contract farming systems that imply a risk of indebtedness and of increased livelihood vulnerability (Castella *et al.*, 2013). Moreover, the expected forest conservation effects have not been realized as areas set aside for forest regrowth are increasingly being converted to maize production (Vongvisouk *et al.*, 2016). In neighbouring Myanmar, small-scale commercial maize farming is also expanding, and in the mid-2000s, the military government decided to set aside more than 700 000 ha of 'vacant and fallow' land for contract farming of maize for the Thai market (Woods, 2015). So far, no assessments of the effect of intensified maize production on soil quality in Myanmar and Laos have been published, but given the biophysical similarities between the uplands of these two countries and our study site, the result of the present study are expected to be highly relevant in Laos and Myanmar.

There is no easy solution to the challenges faced by the indebted maize farmers that are experiencing declining soil fertility and declining yields, but as a minimum, we suggest to engage the local stakeholders in integrated land use planning instead of the current 'Command and control' approach. We also suggest that improved soil fertility measures, diversification of crops and/or extensification are needed. Alternative crops would have to be well-suited to the agro-ecological and socio-economical characteristics of smallholder production systems in upland areas and, for example, be able to grow on the degraded upland soils and provide opportunities for fast income generation with relatively low initial investment requirements. Development of sustainable agricultural practices in the upland areas is currently not a priority of the Thai extension service that is mainly focussing on promoting cultivation of high value crops in lowland areas, expanding the area under irrigation and production of compost which has very limited relevance for upland areas. The extention services embedded in the conventional extension system are based on a top-down management system, where the creation, facilitation and transfer of knowledge and information is a one-way linear process of communication from public national research institutions to farmers through extension officers. In order to ensure a sustainable agricultural development in the upland areas, the extension efforts need to be based on the production circumstances in upland agricultural production systems and to recognize and build on the local knowledge of the people living there as well as on established research-based knowledge. Hence, it would demand a more participatory demand driven extension service approach, which pays attention to farmers' knowledge and perception of soil quality and land management practices. The Pox-C method could clearly be of relevance within the extension service as it provides a fast, cheap and field based assessment of the quality of upland soils.

CONCLUSION

We document that the observed intensification of the traditional swidden agriculture system to continuous maize cultivation in the study area is mainly brought about by economical and political drivers. On the one hand, farmers have been forced out of the traditional fallow-based system because of the official policies aiming at eradicating the system, and at the same time, they have been drawn into maize cultivation by the relatively high maize prices, policies ensuring plentiful credit opportunities and governmental support schemes. We document that the concentration of Pox-C declines with a rate of $40\,\mathrm{mg\,y^{-1}}$ during successive maize cultivation – a rate that matches reported increases in Pox-C concentrations under fallows in similar agro-ecological conditions. We also show that the concentration of Pox-C in the top soil of fields from the investigated maize cropping system is closely related to commonly used bio-chemical indicators of soil quality as well as to farmers' perceptions of soil quality. Considering the ease of measurement, we find that concentration of Pox-C is indeed a useful integrative measure of soil quality. Hence, we conclude that Pox-C is a sensitive indicator of effects of land use intensity in the investigated system. Combined with the low acquisition and operating costs, and the applicability in the field, the method has potential to be applied by the conventional extension service system or by private companies, NGOs or farmer based organizations. Finally, we suggest that future extension efforts should focus on finding integrated solutions that acknowledge the production realities of smallholders in upland areas.

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