Impact of fallow length on soil structure and soil water characteristics in a swidden cultivation system of western Thailand

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Abstract
The term swidden cultivation refers to fallow-based farming where land use is rotated near a permanent settlement and has a specific management plan within that area, as opposed to the more traditional understanding of shifting cultivation where both fields and settlements are moved to new sites. In parts of western Thailand, certain socio-political pressures are leading to reductions in fallow length, with possible repercussions on the sustainability of such farming systems. Changes in soil structure, soil water characteristics and organic carbon content were investigated in a swidden cultivation system, and an adjacent natural forest. Using the chronosequence approach of sampling closely spaced sites, differences in soil properties were assessed and an evaluation made of the changes to these properties over a typical fallow period of 10 years. Such changes have important repercussions not only for the successful re-establishment of vegetation after cultivation and the sustainability of that swidden system, but also for the influence they have on plant growth rates, soil erosion and local hydrology. The regeneration of soil properties during the fallow period were also considered.

Soil structure remained in good condition for all fallow years tested, compared with undisturbed forest, as shown by the maintenance of small bulk density values and large porosities. The already small plant available soil water capacities did not change and organic carbon contents were maintained at reasonably large levels for all treatments, though assumptions were made about the changes in quality. This lack of change to the soil physical properties are assumed to be due to the low intensity of the farming method and the intrinsic soil resilience related to its inherent soil characteristics. These results indicate that if fallow times are shortened, under these conditioned tested, no detrimental impacts on soil physical properties will occur. However, such a conclusion does not take into consideration the wider soil chemical and biological properties.

Key Words
Shifting cultivation, bulk density, soil porosity, aggregate stability.

Introduction
The removal of natural forest vegetation has major impacts on soil properties, both chemical and physical (Lal 1984). The burning of the dried surface trash expels many of the accumulated nutrients, whilst exposure of the bare soil surface to raindrop impact results in soil structural degradation and accelerated erosion, particularly on sloping lands (Hudson 1981). This is compounded by subsequent soil management systems and time before cultivation abandonment, in the case of fallow systems, until the restoration of natural vegetative cover. The severity of these problems are dependent upon the various methods of deforestation and subsequent management.

Lal (1981) reported erosion is greater (20 t ha^{-1}) following mechanized land clearance compared to the manual land clearance using machete and axe (0.4 t ha^{-1}). Bulk density values have been shown to increase following deforestation and cultivation (Popenoe 1957; Lal 1975), with corresponding reductions in infiltration rates and porosity, increasing the risk of erosion and drought. This will be reflected in the soil water characteristic curve that describes the amount of plant available water, governed by pore space distribution (Hillel 1998), which is important in agricultural systems that have little dependable rainfall. Regardless of any disturbance, such as through land clearance, tropical soils in their natural state frequently have small inherent soil water storage capacities anyway (Sanchez 1976; Greenland 1979). Inherent soil properties will also influence changes in attributes such as soil aggregate stability when the soil is physically disturbed and wetted (Emerson 1967; Greenland *et al*. 1975). Disturbances to a system through land clearance and cultivation inevitably lead to increased rates of organic carbon decomposition

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(Syers and Crasswell 1995). Carbon release rates after land use changes can be separated into three main categories as defined by the IPCC (1996): immediate release from on- and off-site burning; delayed release from on-site decay of slash, and; long-term release of soil carbon.

Using the principle of the fallow system, soil fertility can be restored after cultivation by allowing for the natural re-vegetation of the disturbed areas, through renewed inputs of root activity and organic material. Despite a number of studies focusing on the re-establishment of vegetation, information is generally lacking on the corresponding changes to soil physical properties (Deuchars *et al*. 1999). The length of the fallow and the forest regeneration does not necessarily mean that soil properties, which are important in terms of water storage and erosion control, will also return to the natural state.

This study will consider an area of evergreen and deciduous forest in western Thailand that has been swidden cultivated for up to 200 years (Renard 1979). In recent years, there has been increasing political pressure to relocate the farming community out of sensitive forest conservation zones, restricting and reducing the area of the traditional farming lands that can be used ultimately leading to a reduction in the length of fallow (Buergin 2002a). This is compounded by small increases in local population (Boonpinon 1997). The objective of this study is to assess the changes in soil properties of a fallow system as it stands today in one part of western Thailand. Specifically, this study seeks to investigate *whether there is a trend towards regeneration of soil health over a typical fallow period of 10 years and to assess the potential long-term implications of future shorter fallow periods on such regeneration.*

Materials and methods

Site description

The study site is located in the Western Forest Complex in Kanchanaburi Province, Thailand (latitude 16° N). It is located in a small valley (240 m a.s.l.), with moderately steep sloping valley sides (13-25°), within the upper Kwai Noi River catchment area. The soils of the area are predominantly classified as Acidic, Mesotrophic, Brown Dermosols (Isbell 1996) (Table 1).

Areas for farming are selected on the basis of a complex system of family and community decision-making (Boonpinon 1997; Buergin 2002a), with a single cropping season, of less than one year, followed by the normal fallow time in the study area of about 10 years. Vegetation is cut by hand and left to dry for several months before being burnt prior to the onset of the rainy season when crops are planted. These crops rely entirely on rainfall for growth. The average annual rainfall is 1990 mm (Trebuil *et al*. 1996). The cropping system is that of upland rice, intercropped with vegetable crops to spread the risk. All cultivation is done manually with no input of artificial fertilizers or pesticides. Soil samples were taken from the surface horizon only (0-5 and 5-10 cm) corresponding to the depth of soil most impacted by the local management regime as well as raindrop impact.

A chronosequence approach of sequential sampling of sites that are close together, provides a satisfactory method of assessing the magnitude and changes in soil properties over the different fallow times. Such sites have already been identified and established in the study area (Boonpinon 1997; Buergin 2002b) with additional detailed checks on the ground being made with local farmers. Four sites were used for this study representing fields of different fallow length (0, 6, 8 and 10 years). An additional undisturbed (primary) forest site was also selected in an adjacent area. Spatially, these sites were in close proximity to one another to satisfy the conditions of the chronosequence approach of study. The limitations of the study site characteristics (i.e. few fields that were of the same fallow length in close proximity to one another) did not allow for site replication. Within each site, however, between 3-9 subplots were used from which replicate sub-samples were taken for measurements. The study was conducted over a 3-day period in February 2003, this being the dry season in Thailand.

Dry soil bulk density (BD) measurements, at 0-5 and 5-10 cm soil depths, were made using metal cylinders (5 cm diameter × 5.2 cm length) with 9, 9, 3, 9, and 4 samples being taken from the forest (3 plots), 10 year fallow (3 plots), 8 year fallow (1 plot), 6 year fallow (3 plots) and 0 year fallow (1 plot), respectively. Total soil porosity was calculated from the BD measurements. The soil water release characteristic was determined on duplicate sub-samples taken from the BD samples, at 0-5 and 5-10 cm soil depths, using the pressure chamber method (Klute 1986). Only the matric suctions at field capacity

(FC) of 33 kPa and permanent wilting point (PWP) at 1500 kPa were determined, since these define the available water capacity, which is specifically relevant to an area that relies entirely on rainfall for crop production. Soil air-filled capacity (coarse porosity) was obtained as the difference between total soil porosity and the volumetric water content at FC (Townend et al. 2001). Particle size analysis was carried out using the sieving and sedimentation method described by Rowell (1994). Aggregate stability, using the water coherence test of Emerson (1967), was evaluated for 10 replicates at 0-5 and 5-10 cm depths from each of the plots. Organic carbon content was determined on triplicate samples using the Walkley-Black dichromate method (Nelson and Sommers 1982).

Table 1. Soil profile attributes at the experimental site.

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	Textural class	Organic carbon (%)	Roots	Structure
0-5	Ah	32.6	32.0	35.4	CL	3.22	Abundant	Fine sub-angular blocky
5-20	A2	37.7	26.7	35.7	CL	2.01	Abundant	Sub-angular blocky
20-50	B1	27.5	30.5	42.0	C	1.18	Common	Moderate sub-angular blocky
50+	B2	nd	nd	nd	nd	0.81	rare	Moderate sub-angular blocky

Sand, silt and clay contents for Ah, A2 and B1 horizons are presented as the average of 9, 3 and 4 samples, respectively.
nd: not determined.

Statistical analysis

The purpose of the study was to investigate whether there was significant soil degradation in terms of soil physical properties and if so, whether there was a trend towards regeneration of the soil attributes considered over a typical fallow period of 10 years. Using this information, an assessment of the potential impact of future shorter fallow periods on soil properties may be made in the context of soil regeneration.

Correlations between age of fallow and BD, water content at FC and PWP, porosity, air capacity, organic carbon content and aggregate stabilities were calculated using Spearman's rank correlation coefficient (Rs). This tests whether the increasing age of fallow is associated with a general increase or decrease in a given property, rather than whether there is a linear association. This technique summarises the strength and direction of a relationship between the rankings of two variables with the result always being on a scale between -1 to –1. The closer to -1 the Rs value is, the less alike the rankings are, whereas the closer to 1, the more alike the rankings are and the more significance is the relationship between the two variables. In addition, all properties were also analysed using ANOVA.

Results

There were no significant differences in BD values, either at 0-5 or 5-10 cm soil depths, between the fallow plots and the forest plots, nor was there any significant trends observed when comparing the age of fallows and change in mean BD values (Table 2). These results are also reflected in the total porosity and air-filled porosity determinations, which show no significant correlations with fallow age or any difference in mean values of either property (Table 2).

At the 5-10 cm soil depth, the volume of pores estimated at the wetter boundary of the available water range (FC) were found to increase significantly with age of fallow, with larger values also being found in the undisturbed forest soil, but there was no corresponding trend in the 0-5 cm soil depth. Similarly, the porosity volume at the drier boundary of the available water range (PWP) in the 0-5 cm layer, increased significantly with a longer fallow period, although a similar trend was not seen in the 5-10 cm soil depth. Despite these differences, the available water, calculated as the difference between the water content held at FC and that at PWP (Table 3), is small for these soils (between 5 and 20%) with no significant correlation with fallow age, or any significant difference between mean values (data not shown).

Using Spearman's rank correlation coefficient, soil organic carbon contents tended to increase in the upper soil layer (Ah horizon, Table 1) with age of fallow through to the undisturbed forest site, though further analysis of differences between the mean values showed only the 10 year fallow to have

significantly greater amounts. The lower 5-10 cm A2 horizon showed no significant differences in soil organic carbon contents with fallow age (Table 2).

Most of the soil aggregates, for all of the fallow ages and the forest soil, remained unchanged when immersed in water. Using the classification system of Emerson (1967), these aggregates were grouped into Class 8, indicating no slaking and no swelling. There were no trends between aggregate stabilities and fallow age and no significant difference between means (data not shown).

Table 2. Dry bulk density, porosity, air capacity and organic carbon contents at 0-5 and 5-10 cm soil depths. Rs is Spearman's Rank Correlation Coefficient showing the relationship between fallow age and the given soil property. For each column, means which have a letter in common do not differ at *P*< 0.05 using the LSD multiple comparison test. Column means without letters do not differ significantly.

Fallow age	Bulk density ($g\ cm^{-3}$) [1]		Porosity ($cm^3\ cm^{-3}$) [1]		Air capacity ($cm^3\ cm^{-3}$) [2]		Organic carbon content (%) [3]	
	0-5 cm	5-10 cm	0-5 cm	5-10 cm	0-5 cm	5-10 cm	0-5 cm	5-10 cm
Forest (undisturbed)	1.12	1.18	0.58	0.56	0.22	0.20	3.22 b	2.02
10 year fallow	1.14	1.25	0.57	0.53	0.21	0.19	4.13 a	2.26
8 year fallow	1.20	1.16	0.56	0.56	0.21	0.22	2.64 b	1.68
6 year fallow	1.30	1.39	0.51	0.48	0.18	0.14	3.17 b	1.95
0 year fallow	1.18	1.15	0.56	0.57	0.21	0.28	3.03 b	1.81
Rs	0.3	-0.7	0.7	-0.15	0.6	-0.3	0.8	0.6
Significance (*P*)	0.2	>0.2	0.2	>0.2	0.2	>0.2	0.1	>0.2

[1,2 and 3] means of 6, 2 and 3 measurements per plot, respectively.

Table 3. Water contents at field capacity (-33kPa) and permanent wilting point (-1500 kPa) (0-5 and 5-10 cm depths). Rs is Spearman's Rank Correlation Coefficient showing the relationship between fallow age and the mean water content at the given matric potential. For each column, means which have a letter in common do not differ at *P*< 0.05 using the LSD multiple comparison test. Column means without letters do not differ significantly.

Fallow age	Field capacity[1] ($cm^3\ cm^{-3}$)		Permanent wilting point[1] ($cm^3\ cm^{-3}$)	
	0-5 cm	5-10 cm	0-5 cm	5-10 cm
Forest (undisturbed)	0.35 a	0.35	0.34 a	0.34
10 year fallow	0.36 a	0.33	0.33 a	0.31
8 year fallow	0.34 b	0.35	0.30 c	0.33
6 year fallow	0.33 c	0.34	0.32 b	0.31
0 year fallow	0.37 a	0.29	0.34 a	0.25
Rs	0.6	1	0.9	0.7
Significance (*P*)	>0.2	0.01	0.05	0.2

[1] means of 2 measurements per plot.

Discussion

The results indicate that soil structure and *soil water characteristics* did not change significantly over the different fallow lengths, as a result of the present management regime, from the soil properties found in the natural state (undisturbed forest soil). However, in discussing these results, it should be borne in mind that the soil chemical and biological properties have not been considered and that the measurements made were limited only to a small portion of the area used for swidden cultivation with other conditions, such as different soil types, not considered. There were also some limitations with the number of plots for some of the fallow ages making differences between ages, and trends related to age difficult to separate from differences between plots which have arisen for some other reason, such as soil heterogeneity.

For all the fallow soils and the forest soils tested, total porosity has been shown to be large, in the range of 0.48 to 0.58 cm^3cm^{-3}, this being reflected in relatively small bulk density values (1.21 ± 0.026 g cm^{-3}). This is generally seen as a positive attribute for plant growth, whether this be for natural vegetation or for cultivated crops. However, it is important to assess the pore size distribution and structural organization of these pores (Greenland 1979).

The available water content for all soils is small, with a range of between 5 and 20%. These values are comparable with those found in similar tropical soils with equivalent soil textures at the same depth (Sanchez 1976). Greenland (1979) reported that despite the fact that Ultisols, Alfisols and Oxisols are frequently referred to as well-structured, actual available water contents in these soil types are often less than 10%. Small available water content indicates small proportions of storage porosity (0.2 to 50 µm diameters, using the system of Greenland, 1977). The remaining porosity will therefore be made up of transmission pores and fissures (>50 µm diameter) and residual pores (<0.2 µm diameter). Air capacity gives an indication of the proportion of transmission pores and fissures; if these pores are continuous, air capacity can give a reasonable estimate of saturated hydraulic conductivity (Townend *et al*. 2001). Development of transmission pores are likely to be the result of the prolonged dry season (November - April) leading to some shrinkage of the clay soils, as evidenced by surface cracks at the time of sampling. Infiltration measurements would have provided useful information about the characteristics of the transmission pores (coarse porosity), but this was not possible due to the large distance between the study site and a water source.

The remaining fraction of the total soil pore space is that of the residual porosity (<0.2 µm), where water is tightly held and is unavailable to plants. This pore fraction is quite considerable, consisting of between 19 and 32% of total porosity for all soils at all depths sampled. This accounts for a large proportion of water that is stored in the soil. Therefore, despite these finer textured soils having a large pore space volume, only a small proportion of this actually holds plant available water making these soils susceptible to drought. This problem might be further exacerbated by any structural degradation resulting from land clearance, raindrop impact and cultivation, but such factors have had minimal effects on the soil physical properties of the study sites tested (Table 2).

All land preparation and cultivation is done by hand (no animal input), with only the top few centimeters of soil being disturbed. Direct physical damage, such as from compaction, should be minimal. In addition, the soil surface is adequately covered and protected from raindrop impact for most of the time. Only for a short period between the burning of surface trash and the emergence and establishment of the crop is the soil surface be left bare. During this time, the intensity of rainfall events in the early part of the rainy season (May-June) are less compared to the rainfall events that would occur later in the wet season (August-September) (Baruah 1973) when the surface soil is protected by the established crop. After harvest, rice crop roots are left in situ and crop residues are returned to the soil surface, without being burned, giving continued soil surface protection from raindrop impact and erosion. The return of crop residues probably accounts for the relatively large organic carbon contents in the zero year fallow compared with other fallow ages and even forest (Table 2). However, the quality of organic matter supplied by the successive fallow ages is likely to be different, with this influencing chemical, biological and physical characteristics (Fischer 1995). Further research to investigate such relationships is necessary.

Despite the aggregate stability test of Emerson (1967) being devised primarily for assessing subsoil stability when wetted, it also has application to surface soils as demonstrated by Greenland et al. (1975), who showed its wide application and how it provides a simple and convenient guide to the physical behaviour of soil. For all soils, most of the soil aggregates were stable when wetted, showing no slaking characteristics and no swelling. This is likely due to the large organic carbon contents, particularly in the surface 5 cm depth, which have been shown by Greenland et al. (1975) to be clearly linked with aggregate stability. Despite this link, there did not appear to be a relationship between the increasing organic carbon contents with associated increasing age of fallow, and aggregate stability, suggesting levels of soil organic carbon were large enough in all plots to maintain structure.

Conclusion

The present swidden cultivation management regime was not shown to have any major impacts on the soil in terms of soil structure, soil water balance and organic carbon content. From the chronosequence analyses, even the intermediate fallow year test sites showed favourable soil properties indicating good soil physical quality, and suggesting that shorter fallow periods may be possible with no detrimental effects. However, such a conclusion does not take into consideration the wider chemical and biological properties, each of which will strongly influence the potential return to a soil similar to that of the natural state soil (Deuchars *et al*. 1999). Further research is needed both to reinforce these preliminary findings, in different conditions, and also to consider the chemical and biological influences on soil property changes resulting from swidden cultivation.

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